# How much recreational exposure to avalanche terrain is there?

## An overview of possible approaches for monitoring winter backcountry use for public avalanche-warning services

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**January 25, 2020**

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## Executive Summary

Winter backcountry mountain sport operators, outdoor mountain recreation industry experts, and researchers in Europe and North America commonly report that participation in winter backcountry recreation in mountainous terrain has increased tremendously in recent decades. While increasing numbers of backcountry skiers, mountain snowmobile riders, snowshoers, ice climbers, and mountaineers venture into the backcountry, these activities are not without risks. The primary hazard faced by winter backcountry recreationists is snow avalanches. Every winter over the last decade, between 125 and 150 backcountry recreationists have died in avalanches in the mountainous regions of central Europe, Scandinavia, and North America.

To be most effective, avalanche-warning services must be based on an in-depth understanding of the size and the characteristics of the winter backcountry recreation community. Meaningful estimates of the size of the community are important for estimating overall and activity-specific accident and fatality rates. An evidence-based understanding of temporal trends of these rates is critical for assessing the effectiveness of existing avalanche awareness initiatives and identifying particularly-at-risk backcountry user segments for new campaigns. Furthermore, an in-depth understanding of recreationists' needs, strengths, and weaknesses in information seeking, decision-making, and risk management is essential for the development of avalanche warning products and services that resonate with recreationists and allow them to make meaningful decisions about backcountry travel.

While there has been considerable growth in human dimensions research in the avalanche safety community, not all the needs listed above have been addressed adequately. Hence, a coordinated effort is required to develop a comprehensive understanding of the winter backcountry user community. However, there is currently no country implementing a comprehensive system to effectively monitor and characterize winter backcountry users as a whole. Fortunately, there are several research fields that have well-established methods for estimating participation rates

and population sizes. These research fields include the management of protected areas and wildlife protection, public health research measuring participation rates in sports and recreation activities, and tourism- and recreation-related economic impact studies. Many of the monitoring methods developed in these fields have the potential to be applicable to winter backcountry recreation contexts and provide useful insights for avalanche-warning services.

**The objectives of this report are to**

a) **explore the applicability of existing visitor monitoring methods and technologies for winter backcountry recreation, and**
b) **propose possible approaches for estimating overall winter backcountry use in a country or region.**

To examine the usefulness of existing visitor monitoring methods for winter backcountry recreation, we conducted an extensive literature review. In total, we **evaluated 22 established monitoring methods** grouped into manual observation methods, automated observation methods, mobile tracking systems, voluntary self-reporting, compulsory registration, surveys, and other methods. While the main body of the report includes concise summaries of the strengths of the 22 methods and their suitability for providing insight into winter backcountry user numbers, the complete evaluations are included in Appendix A2. In these evaluations, the nature of each monitoring method is described in detail and application examples are provided. Our evaluations describe general advantages and disadvantages, list tips for effective use, and discuss additional considerations for winter use if applicable. In addition, we qualitatively characterize the type of personal information collected, the type of spatial and temporal information collected, the reliability of the method, potential impacts on study subjects, the cost of the method, and the method’s technical suitability for winter backcountry monitoring. We conclude each monitoring method’s evaluation with our thoughts on the strengths of the method for collecting meaningful information on winter backcountry recreationists.

While the evaluation of the monitoring methods highlights many possibilities for gathering information about backcountry use, none of the methods alone can offer a spatially comprehensive and temporally continuous overview of backcountry use at the regional and national level. Hence, to be of use to avalanche-warning services, it is necessary to combine several methods with complementary strengths to create a meaningful overall perspective. In this report, we **present five possible approaches for monitoring winter backcountry use comprehensively**:

1. National cross-sectional participation survey
2. Extrapolation from targeted direct counts
3. Extrapolation from indirect counts
4. Extrapolation from citizen science counts
5. Extrapolation from online engagement

For each of these approaches, we outline the steps for implementation and discuss the research required in support of the approach. While the national cross-sectional participation survey is the most direct path to backcountry user numbers, the proposed extrapolations from various other counts might offer useful and potentially more economical alternatives. The feasibility of each described approach depends heavily on the available resources, opportunities for working with national and local stakeholders (e.g., outdoor clubs, national parks), and possibilities for collaborating with partners in related fields (e.g., public health, other outdoor recreation associations).

Due to different circumstances and resources, it might be necessary to implement different monitoring approaches in different regions or countries. However, to ensure comparability, it is important that the international community agrees on some fundamental aspects of the monitoring campaigns, such as preferred backcountry use measure (participation or exposure days) and whether the focus should be on absolute or relative backcountry user numbers. Additional possible considerations are described in the report.

Implementing a comprehensive backcountry monitoring strategy requires a substantial investment of money and time. While this report does not offer a turn-key solution, we hope that it provides the necessary information for having informed conversations and making meaningful first steps.

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Rosemary Langford has a Bachelor of Science in Geography from Simon Fraser University in Vancouver, Canada. Rosemary's research interests centre around mountain hazards, factors contributing to avalanche risk, and the associated socio-environmental complexities of risk management. She is an active member of Dr. Haegeli's avalanche research group.

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## Introduction

Winter backcountry mountain sport operators, outdoor mountain recreation industry experts, and researchers in Europe and North America commonly report that participation in winter backcountry recreation in mountainous terrain has increased tremendously in recent decades (e.g., Etter, Stucki, Zweifel, & Peilmeier, 2008; Rivers & Menlove, 2006; Rupf & Stäuble, 2018; Saly, Hendrikx, Johnson, & Richmond, 2016; Winkler, Fischer, & Techel, 2016). Increasing numbers of backcountry skiers, mountain snowmobile riders, snowshoers, ice climbers, and mountaineers venture into the backcountry to enjoy untracked power snow, serene winter landscapes, or challenging mountain routes. However, these activities are not without risks. The primary hazard faced by winter backcountry recreationists is snow avalanches. Every winter over the last decade, between 125 and 150 backcountry recreationists have died in avalanches in the mountainous regions of central Europe, Scandinavia, and North America. Most of these fatalities are amateur recreationists making their own decisions about when and where to expose themselves to avalanche hazard. In addition to fatalities, every winter an unknown number of individuals are involved in avalanches with the potential for serious consequences.

To enhance the safety of winter backcountry recreationists and reduce the number of avalanche fatalities, public avalanche-warning services have been implemented in most of the highly developed mountainous regions around the world. During the wintertime, these warning services publish daily avalanche bulletins to provide backcountry recreationists with critical information for making informed decisions about when and where to travel in the backcountry. In addition, avalanche awareness courses taught by avalanche professionals and offered through mountaineering schools train recreationists in the skills necessary to use the information included in the bulletins effectively.

To be most effective, avalanche-warning services must be based on an in-depth understanding of the size and the characteristics of the recreational winter backcountry community. Meaningful estimates of the size of the backcountry community are important for justifying the need for avalanche safety programs to funding agencies. In addition, user numbers are a necessary input for estimating overall and activity-specific accident and fatality rates. A meaningful understanding of temporal trends of these rates is critical for assessing the effectiveness of existing avalanche awareness initiatives and identifying particularly-at-risk backcountry user segments for new awareness initiatives. Finally, an in-depth understanding of recreationists' needs, strengths, and weaknesses in information seeking, decision-making, and risk management is essential for the development of avalanche warning products and services that resonate with recreationists and allow them to make meaningful decisions.

While there has been a considerable growth in human dimensions research in the avalanche safety community, not all the needs listed above have been addressed adequately. Most importantly, the total number of recreationists participating in different winter backcountry activities remains unknown (Procter et al., 2013), which prevents the calculation of the statistical risk of death due to avalanches (Winkler et al., 2016). This poses a considerable hurdle for advancing avalanche safety through informative research. Hence, a coordinated effort is required to develop a comprehensive understanding of the winter backcountry user community. However, there is currently no country implementing a comprehensive system to effectively monitor and characterize winter backcountry users as a whole.

There are several research fields that have well-established methods for estimating participation rates and population sizes. These fields include recreation research focused on the management of protected areas and wildlife protection (e.g., Gimblett & Skov-Peterson, 2008; Kajala et al., 2007), public health research measuring participation rates in sports and recreation activity among their citizens (e.g., Lamprecht, Fischer, & Stamm, 2008, 2014; Sport Canada, 1998; TNS Opinion & Social, 2010), and tourism- and recreation-related economic impact studies that combine population size estimates with expenditure profiles to derive the contribution of an activity to the overall economic activity in a region (e.g., Briceno & Schundler, 2015; Kux & Haider, 2014; Wszola et al., 2020). Slightly distant from recreation research, the research field of ecology also has well-established methods for estimating sizes of animal populations (e.g., Sutherland, 2006). Many of the monitoring methods developed in these fields have the potential to be applicable to winter backcountry recreation contexts and provide useful insights for avalanche-warning services. However, since monitoring initiatives are typically quite time-consuming and expensive (Rupf, Wernli, & Filli, 2006), careful evaluation of the available methods is critical to ensure that they are employed effectively and that available resources are used efficiently while meeting the monitoring objectives.

Building on the existing research methods, the objectives of this report are to a) explore the applicability of existing visitor monitoring methods and technologies for winter backcountry recreation and b) propose possible approaches for estimating the overall winter backcountry use in a country or region.

The information presented in this report is organized in the following way. We first provide a comprehensive overview of monitoring methods frequently used in recreation research and discuss their pros and cons for monitoring winter backcountry use. The information presented is supported by an extensive appendix (Appendix A2) that provides more detailed descriptions of each monitoring method. We then introduce five possible approaches for estimating winter backcountry use, each having its own benefits and challenges depending on the local context. Although the approaches presented are not exhaustive, our intent is to provide avalanche-warning services with a meaningful starting point for evaluating options and making informed choices when implementing winter backcountry use monitoring initiatives. While this report is targeted at avalanche-warning services, the information presented might also be of use for other backcountry recreation stakeholders and advocacy groups.

# Overview of monitoring methods and technologies

## Approach

### Literature search

The information on monitoring methods and technologies presented in this report is based on an extensive literature review that was conducted during the summer of 2018 in preparation for a working group meeting in Innsbruck prior to the International Snow Science Workshop in October 2018. An initial, unstructured, general search for literature was conducted using databases such as Google Scholar and the Simon Fraser University Library catalogue. We used the following *keywords* for our initial search: user monitoring, visitor management, protected areas, wildland recreation, visitor use patterns, visitor use management, recreation management, spatial distributions, tourist flow. Terms like 'participation' were not included in the initial search because they were not specific enough. The studies identified in this initial search were classified by monitoring method and were used as a starting point for a second, more in-depth literature search. The second search was more specific and revealed more detailed studies that expanded on and critically applied the identified monitoring methods. Example *keywords* used in this second search include the following: Global Positioning System tracking, visitor survey, video-monitoring visitors, acoustic slab sensors, Strava, Geographic Information Systems (GIS), snowmobile, avalanche warning, backcountry area, off-piste area backcountry skiing.

In total, 157 references were gathered and categorized by monitoring method. The following scientific journals offered extensive literature on existing monitoring methods (alphabetically ordered):

- European Journal of Wildlife Research
- International Journal of Environmental Research & Public Health
- Journal for Nature Conservation
- Journal of Conservation Planning
- Journal of Mountain Research and Development

- Journal of Outdoor Recreation and Tourism
- Journal of Park and Recreation Administration
- Journal of Sustainable Tourism
- Journal of Travel Research
- Landscape and Urban Planning
- Natural Hazards and Earth Systems Science
- Scandinavian Journal of Medicine and Science in Sports
- Tourism Management
- Wilderness & Environmental Medicine

In addition, the proceedings from numerous academic and applied conferences included papers on a broad range of monitoring methods. Some of the most relevant conferences included:

- International Conference on Monitoring and Management of Visitors in Recreational and Protected Areas (MMV)
- International Snow Science Workshop (ISSW)
- Northeastern Recreation Research Symposium

Technical reports on the applications of various monitoring methods were found through government agencies (e.g., U.S. Department of Agriculture Forest Service, New Zealand's Department of Conservation, Parks Canada), international governing bodies such as the World Commission on Protected Areas, and relevant international research collaborations.

While we considered including monitoring methods commonly used in ecological research (e.g., mark-recapture, distance sampling) in our evaluation, our initial explorations revealed that the nature of recreational backcountry use is too different from animal populations for these methods to be of use. Hence, we did not pursue ecological monitoring methods. Readers interested in these methods are referred to Sutherland (2006) for a comprehensive overview.

### Assessment and evaluation of methods

To explore the suitability of the identified monitoring methods for providing meaningful information to avalanche-warning services, we evaluated each of the methods based on the information found in the existing literature and the practical experience of the research team. After describing the nature of a method in detail and discussing relevant application examples, we discuss the strengths and weaknesses of the method, list tips for effective use, and discuss additional considerations for winter use if applicable. Our evaluations pay special attention to the unique characteristics of winter backcountry recreationists and the associated monitoring challenges and considerations (e.g., relatively small number of participants spread over large and potentially remote areas, adverse environmental conditions, safety concern for staff, and significant seasonal variation in participation trends).

To further strengthen the description of the methods, we qualitatively evaluated each method with respect to a variety of characteristics that can be grouped into the following main themes: a) type of personal information collected, b) type of spatial and temporal information collected, c) reliability, d) potential impacts on study subjects, e) cost of the monitoring method, and f) suitability for monitoring winter backcountry recreationists (see Table 1: *Overview of assessed characteristics of monitoring methods*).

For evaluating the **type of personal information collected** we examined whether the monitoring method supports the identification of individuals (*Identity*), regardless of whether the identification is explicit or anonymous. We also evaluated whether the method allows the collection of background information on study subjects (*Individual characteristics*), such as socio-demographics, motivations, and group characteristics. Finally, we evaluated whether the method provides additional information that can offer insight into the behaviour of study subjects, such as their decision-making process or group formation (*Additional insight into behaviour*).

The discussion of the **type of spatial and temporal information collected** focuses on three different aspects, which include the nature of the *Spatial information* collected, the *Spatial extent* or coverage of a monitoring method, and the *Temporal resolution* of the observations.

Table 1: Overview of assessed characteristics of monitoring methods

**a) Type of personal information collected**

| *Characteristic* | *Assessment level* | *Example/Comment* |
|---|---|---|
| Identity<br>Whether individuals are identified | No | No identity information |
| | Yes | Can be explicit or anonymous |
| Individual characteristics<br>Degree to which the method supports the background information on study subjects | None | No information on personal characteristics |
| | Some | E.g., gender, age category |
| | Detailed | Detailed personal background information |
| Additional insight into behavior<br>Degree to which the method can provide addition information that offers further insight into the behaviour of study subjects | None | No additional insight |
| | Some | E.g., categorical information of bulletin use frequency, use of safety equipment |
| | Detailed | E.g., in-depth insight into backcountry travel decisions or group dynamics |

**b) Type of spatial and temporal information collected**

| *Characteristic* | *Assessment level* | *Example/Comment* |
|---|---|---|
| Spatial information<br>Nature of spatial information collected | Position | Single position that indicates presence at the time of recording (e.g., infrared trail counters, aerial photography). |
| | Movement | Two or several positions that indicate presence as well as direction of movement at time of recording (e.g., video monitoring). |
| | Track | Complete record of movement in backcountry (e.g., GNSS tracking). |
| Spatial extent<br>Coverage of monitoring method | Local | E.g., individual trail head, staging area |
| | Regional | E.g., one or several drainages |
| | National | E.g., entire country |
| Temporal resolution<br>Temporal resolution of observations | Low | E.g., annually or less frequently |
| | Medium | E.g., monthly, daily |
| | High | E.g., hourly or higher |

**c) Reliability**

| *Characteristic* | *Assessment level* | *Example/Comment* |
|---|---|---|
| Reliability<br>Relative reliability of collected information | Lower | |
| | Moderate | |
| | Higher | |

Table 1 (cont.): Overview of assessed characteristics of monitoring methods

**d) Potential impacts on study subjects**

| *Characteristic* | *Assessment level* | *Example/Comment* |
|---|---|---|
| Potential for affecting behaviour | Low | No effect |
| | Moderate | |
| | High | May cause study subjects to change their travel plans (e.g., nonparticipant direct monitoring) or provide inaccurate answers (e.g., surveys). |
| Potential for privacy concerns | None | No concerns |
| | Consent | Participants provide explicit consent. |
| | Low | Only limited personal information released into the public domain by study subject on their own terms. |
| | Moderate | Considerable personal information released into public domain by study subjects on their own terms. |
| | High | Using these observations for monitoring backcountry use might require careful consideration of local privacy laws. Even if privacy laws allow use, there is the potential that study subject might raise concerns. |

**e) Cost of monitoring method**

| *Characteristic* | *Assessment level* | *Example/Comment* |
|---|---|---|
| Equipment cost<br>Relative cost including both the initial cost of acquisition and the cost of maintenance | Lower | |
| | Moderate | |
| | Higher | |
| Implementation cost<br>Relative cost for running a single monitoring campaign | Lower | |
| | Moderate | |
| | Higher | |
| Effort and complexity of analysis<br>Relative effort and complexity of analysis | Lower | |
| | Moderate | |
| | Higher | Labour intense or complicated analysis. |

**f) Suitability for monitoring winter backcountry recreationists**

| *Characteristic* | *Assessment level* | *Example/Comment* |
|---|---|---|
| Winter suitability<br>Technical feasibility for monitoring winter backcountry recreationists | Yes | Technically feasible for monitoring. |
| | No | Technically not feasible. |

The **reliability** of the collected information was assessed with a single relative rating with the levels lower, moderate, and higher.

The theme of **potential impacts on study subjects** is divided into two aspects. The *Potential for affecting behaviour* assesses whether the presence of the monitoring method has the potential to affect the choices (i.e., responses) and/or behaviour of the study subjects. The *Potential for privacy concerns* aspect aims to assess whether the information collected might be viewed as invading the privacy of study subjects. Our evaluation of the potential for privacy concerns distinguishes between none, consent, low, moderate, and high.

The **cost of the monitoring method** was examined qualitatively with respect to three different aspects: the *Equipment cost*, which includes both acquisition and maintenance, the *Implementation cost* of a single data collection campaign, and the *Effort and complexity of the analysis* of the collected information. Because the exact costs of a monitoring campaign are context dependent and contingent on many different factors, the various cost aspects were assessed using a relative scale with the levels lower, moderate, and higher.

We also rate the technical **suitability for monitoring winter backcountry recreationists** with a simple yes or no rating. This technical feasibility can refer to information on backcountry recreation numbers, information on the human dimension of avalanche safety, or both.

Each monitoring method's evaluation is concluded with our thoughts on the **strengths of the method for collecting meaningful information on winter backcountry recreationists**.

## Summary of Monitoring Method Assessments

The following sections provide concise summaries of the nature of the monitoring methods evaluated in this report and their suitability for providing meaningful information on winter backcountry recreationists. The structured assessments of the specific characteristics described in the previous section are summarized for all monitoring methods in Table 2: *Overview of monitoring methods characteristics*.

Readers interested in more detailed information about monitoring methods are referred to the various appendices. **Appendix A1** summarizes the content of overview references on visitor monitoring methods commonly referred to in the literature. **Appendix A2** describes the individual methods included in our report in detail. These descriptions include references to relevant literature and elaborate on existing avalanche safety research studies that have employed these methods. **Appendix A3** discusses additional technical considerations for designing effective monitoring campaigns.

## Manual observation methods

Manual observation methods refer to direct, visual observations by human observers that do not require any automated technical means (e.g., counters, cameras).

### *Direct in-situ counting*

Direct in-situ counting includes on-site personnel who use handheld tools, such as counters or tally sheets, to count visitors manually (Cessford & Burns, 2008). Field observers' locations are often fixed, but occasionally observers roam to cover larger study areas (Cessford & Burns, 2008).

Direct in-situ counting is most useful for short and targeted campaigns in areas where traffic volumes are sufficiently high to warrant counting but not so high that they overwhelm the counter. While the method is **not recommended for large-scale monitoring campaigns** due to the high personnel costs, direct in-situ counting **is commonly used to validate other monitoring methods**. For example, direct in-situ counting is the standard method for ground-truthing automated observation methods. The method is also commonly paired with intercept survey campaigns, another method that requires on-site personnel to assess participation rates.

### *Nonparticipant direct monitoring*

Nonparticipant direct monitoring is a social science method where researchers observe a social activity (e.g., backcountry recreation) to directly study the behaviour of study subjects who have consented to being studied within the natural context of the activity of interest. While the researchers in these types of studies are physically present, they do not take an active part in the activity that is being studied. Nonparticipant direct monitoring is used extensively in case study research in the social and behavioural sciences (Laurier, 2010; Liu & Maitlis, 2010).

In the context of avalanche safety research, nonparticipant direct monitoring is most effective for targeted, qualitative, sociology-type studies that investigate risk management practices and group dynamics in avalanche terrain. However, the information collected with this method **does not provide meaningful insight into winter backcountry user numbers**.

#### *Citizen science observation methods*

Citizen science observation methods engage the public in research that requires gathering and analysing large-scale data. This method has been used extensively in natural sciences and is growing in popularity in the scientific community (Follett & Strezov, 2015). For citizen science data to be useful, data collection methods must adhere to scientific standards and care must be taken to continuously validate these methods to ensure the effective long-term continuation of the research project. Additionally, sampling methods must be understandable and practical for participants.

Although volunteers or citizen participants must be trained on how to obtain data, citizen science observation methods have the **potential to be an effective approach for obtaining backcountry user numbers for long-term research projects** due to the reduced personnel costs. Additionally, citizen science observation methods have the potential to be easily integrated into existing avalanche-warning service campaigns. However, since we are not aware of any studies that use a citizen science approach for monitoring recreationists or tourists, we recommend detailed exploratory studies be conducted before committing to the approach on a large scale.

### Automated observation methods

Automated observation methods refer to monitoring approaches that use automated technical means (e.g., counters, cameras) to observe human activity without constant attention by the researcher. The analysis of the collated data may be automated or require manual interpretation.

#### *Pressure-sensitive counters*

Pressure-sensitive counters are buried under paths or trails and respond to micro-variations in pressure when study subjects pass over or step onto them. Pressure-sensitive counters are **not suitable for monitoring winter backcountry users** because the snowpack absorbs the pressure variations that the sensors rely on.

### *Light barriers and infrared counters*

Light barriers are a type of optic sensor that use light beams to connect a transmitter to a receiver and record counts of when this beam is interrupted, such as by a visitor passing. Infrared counters include a pyroelectric sensor that contains a lens, which is sensitive to heat radiation emitted by human bodies. While light barriers are becoming outdated, **infrared counters are the standard method for continuous, long-term monitoring of user numbers on established backcountry routes**. Infrared counters are useful because they are waterproof, function over a wide range of temperatures, can record the direction of visitors' approach, record and store data at 1 hour- or 15 minute-intervals, are easy to maintain, and are cost-effective. However, counts made with infrared counters and light barriers must be periodically validated by direct observation and/or a video recording campaign to ensure the reliability of the collected information. Furthermore, counters must be strategically located to obtain representative results, and it is important to sample both high- and low-use sites if the counters are operating to estimate overall backcountry use in a larger area.

### *Radio frequency identification systems (RFID)*

Radio frequency identification (RFID) is a wireless technology that uses radio-frequency electromagnetic fields to retrieve information from a RFID tag without explicitly coming in contact with the carrier. RFID tags contain unique identifiers that allow the receiver to identify the carrier and application-specific additional information stored on the tag.

In the context of winter backcountry monitoring, RFID systems **are only recommended for small-scale (i.e., local) monitoring campaigns where users are already equipped with RFID tags**. Examples of potentially meaningful applications include the monitoring of out-of-bounds traffic at well-defined exit or re-entry points in the vicinity of ski areas that use RFID for controlling lift access, or the monitoring of access trail use in snowmobile areas with an established trail fee system that uses RFID tags.

### *Photography and video monitoring from fixed locations*

Photography and video monitoring from fixed locations provides photographic recordings that are later viewed and analysed for user data. Photographs are either taken at regular intervals (i.e., time lapse photography) or they are triggered by a motion- or infrared-sensor (i.e., camera trap). While photography and video monitoring in the visual spectrum is most common, infrared cameras allow for monitoring during times when there is no visual light. The recordings are either collected directly from a camera in the field or transmitted to a base from an on-site location.

Photography and video monitoring from fixed locations is **most effective for continuously counting users in small-scale areas with a direct line of sight (e.g., slope-scale or small drainage) and in areas without well-defined routes (e.g., out-of-bounds routes adjacent to ski areas or slopes in close proximity to backcountry huts)**. Compared to methods such as infrared counters, photography and video monitoring is less suitable for continuous monitoring due to higher maintenance requirements and analysis complexity. However, photography and video monitoring from fixed locations can be useful for both ground-truthing infrared counters and for supplementing counts from infrared counters with additional insight on user characteristics. Similarly, photography and video monitoring can provide some insight on risk management practices and group dynamics, though in-depth analysis of observations can be challenging and time consuming.

### *Radar detection from fixed locations*

Building on the fast-developing remote sensing technology for avalanche activity, new approaches for monitoring the movement of people have emerged. An example of such a new technology is the detection and monitoring of backcountry recreationists using radar technology developed by Geopraevent (Saurer, Jackson, & Nalli, 2016). The advantage of radar over camera-based monitoring systems is that radar works reliably day and night, as well as in bad weather conditions (e.g., fog, snowfall, rain).

Radar detection from fixed locations is **suitable to be used in combination with conventional and infrared cameras to offer a reliable system for monitoring backcountry use in relatively small areas** (approximately 1 $km^2$), and it is possible to achieve larger coverage by combining multiple radar systems. However, the cost of the equipment prohibits the use of the technology for large-scale monitoring campaigns.

### *Aerial photography*

Aerial photography uses an aerial platform (fixed-wing aircrafts, drones, or tethered balloons) to obtain photographs of intermediate- to large-scale areas. This method is often repeatedly used to produce photographs at regular temporal intervals for longitudinal studies.

Aerial photography **can provide a valuable snapshot perspective on user numbers and spatial distribution of use at local and regional scales**. However, the analysis of observations made using aerial photography can be challenging and time consuming. Aerial photography is only suitable for monitoring in open areas and under good weather conditions and is not suitable for continuous, long-term observations. Aerial photography has the potential to negatively affect the recreational experience of users due to low-flying altitude requirements. The low-flying altitude requirement is furthermore potentially disruptive and harmful to wildlife in parks and protected areas. However, modern drones, which are increasingly used in ecology and biodiversity research, might allow researchers to avoid some of these challenges.

### *Satellite imagery*

Images taken by satellites orbiting the Earth are a potential approach for examining the presence and distribution of winter backcountry recreation use over large areas. However, **the method is not recommended for routine backcountry user monitoring** due to the high cost, limit control over monitoring interval, and insufficient resolution for identifying individual backcountry users. Satellite images might be suitable for providing single snapshots of backcountry use patterns (e.g., patterns of snowmobile tracks). Recent developments in remote sensing of avalanche activity using satellite imagery might create new opportunities for remote backcountry use monitoring in the future.

## Mobile tracking systems

Mobile tracking systems include mobile devices carried by individual backcountry users to track their movements over time. In the academic literature on tourist movement tracking, this monitoring approach has been divided into satellite-based systems (i.e., Global Navigation

Satellite System, GNSS)[1], where the mobile devices interpolate their position based on signals received from geostationary satellites, and land-based systems, which determine the location of transmitters based on a local network of antennas. The most common form of land-based mobile tracking is cellphone tracking. In addition to the distinction between satellite- and land-based tracking systems, our discussion of this monitoring technology also considers how the tracks are shared with the research team as this can greatly affect the data quality and how it can be used for research.

### *Targeted GNSS tracking*

Targeted GNSS tracking refers to studies where GNSS tracks are specifically collected for the research question at hand. Study participants are explicitly recruited to either upload GNSS tracks that they recorded with a personal device or to record GNSS tracks using tracking units provided by the research team.

Targeted GNSS tracking is the most effective method for obtaining high-resolution data on revealed terrain preferences and is, thus, most suitable for conducting focused research on decision-making and risk management practices with relatively small samples of users who are committed to the research. Tracking with customized GNSS devices is preferred over the collection of tracks recorded with smartphone apps or GNSS devices of participants due to better control over device settings. Targeted GNSS tracking studies are most insightful when paired with other methods such as surveys or interviews.

Due to the targeted nature of these types of GNSS tracking studies, the information collected **cannot provide meaningful insight into backcountry user numbers**.

### *GNSS web-sharing services*

The popularity of web services that allow recreationists to store and share personal GNSS tracks and fitness activities has increased tremendously over the last decade. Examples of these services include Strava, ENDOMONDO, GarminConnect™, the MapMyFitness suite by Under Armour®, wikiloc.com, and GPSies.com, but there are many more. Strava, likely the most

[1] Global Navigation Satellite System (GNSS) is a generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage. Examples of GNSS include GPS, GLONASS, BeiDou, Galileo, and others.

popular GNSS web-sharing service, gains approximately a million new members every 45 days and approximately 8 million activities are uploaded each week (Good, 2017).

The accessibility of available data for research purposes differs among these services. Strava provides free access to aggregated tracks via Strava Global Heatmap (https://www.strava.com/heatmap) and more detailed information can be accessed via the new **Strava Metro for web** service (https://metro.strava.com/strava-metro-web/) that was launched in November 2019. While it might be possible to get detailed use information including demographics for popular backcountry areas through this service, we were not able to confirm this directly with Strava. The cost for accessing the anonymized and aggregated tracks is approximately US$2,500 per year. While we found evidence of studies that used individual GNSS tracks from Strava, we could not find any detailed information on how to purchase GNSS tracks from Strava for research. Other GNSS web-sharing services, such as GPSies.com, wikiloc.com, and MapMyFitness, allow researchers to explicitly search for individual tracks and download them in a variety of formats.

GNSS web-sharing services are **most suitable for obtaining a large-scale overview of relative popularity of backcountry areas**. However, GNSS web-sharing services only reflect use patterns of very specific user groups. These services are not equally popular across all backcountry activities and available GNSS tracks are thus highly skewed toward a small number of committed contributors (i.e., participant inequality). For these reasons, the use of data from GNSS web-sharing service is **not suitable for obtaining absolute user numbers nor is it suitable for long-term monitoring** as data access and privacy policies of service providers are subject to change without notice. To make meaningful extrapolations from GNSS data from web-sharing services, more information is required regarding the use of these services within the recreational backcountry community.

### *Mobile phone tracking*

Due to the prolific use of mobile phones, mobile phone tracking has the potential for large-scale and continuous monitoring of backcountry use without affecting users' behaviour and avoiding the participant inequality challenge of GNSS tracking. The location of a mobile phone can be determined through triangulation of radio signals between multiple network towers and the mobile phone. To locate the phone this way, the phone must emit at least the roaming signal but does not require an active call. Higher density of mobile phone towers allows for higher triangulation accuracy. Due to the limited cellphone coverage in many backcountry areas, we **do not regard mobile phone tracking as an effective monitoring method for winter backcountry users**. In addition, there are considerable privacy concerns associated with the use of mobile phone data, and data access and privacy rules/legislation differ among service providers and among different countries. Changes in these rules and legislation must be anticipated.

## Voluntary self-reporting

Voluntary self-reporting refers to monitoring methods that rely on public-domain platforms where members of the public voluntarily post information about their whereabouts and intentions for reasons other than participating in a research study.

### *Summit registries and hut guestbooks*

Summit registries can be found on many popular peaks and guestbooks are common in mountain huts. These types of voluntary registries are typically maintained by clubs or hut custodians and allow recreationists to leave an 'I was here' message. However, due to the voluntary nature and low reliability, summit registries and hut guestbooks are **not recommended as a user monitoring method**.

### *Self-registration boards*

Self-registration boards are commonly placed at trailheads to allow recreationists to 'check-in' at the beginning of their trip and 'check-out' after their return. Self-registration boards are a valuable method for collecting basic information on backcountry users at targeted locations and provide a lower-budget alternative to intercept surveys, particularly when maintained in collaboration with local clubs. Self-registration boards can be used to augment counts from trail counters, but methods must be in place (e.g., through direct in-situ counting) to account for non-registration rates and characteristics of non-registrants. Because of these limitations, self-registration boards are **not directly suitable for obtaining user counts**.

### *Online backcountry community platforms*

Online community platforms are public websites that serve as trip planning resources. Examples of such community platforms include Gipfelbuch.ch for hiking, mountaineering, and backcountry skiing in Switzerland, Hikr.org for hiking in central Europe, CampToCamp.org for all mountain sports in central Europe, Snowest.com for snowmobiling in North America, Trailforks.com for mountain biking worldwide, and Mountainproject.com for climbing in the United States.

Online community platforms are **most suitable for obtaining a large-scale overview of backcountry activity**. Quantitative analyses of post content have the potential to offer meaningful insight into general trends in backcountry recreation activities (e.g., popularity of destinations). Similar to the data submitted to GNSS web-sharing services, however, postings on online community platforms reflect backcountry activities and motivations of very specific user groups. Online community platforms are not equally popular across all backcountry activities, available posts are highly skewed toward a small number of highly committed contributors (i.e., participation inequality), and these platforms are more niche- than location-based. Online community platforms are therefore not directly suitable for obtaining user counts.

### *General location-based social media platforms*

General location-based social media platforms, such as Instagram, Flickr, Twitter, and Facebook are **not directly suitable for obtaining user counts but have potential for providing a large-scale overview of backcountry activities**. Quantitative analyses of post content might offer meaningful insight into general trends in backcountry recreational activities and user motivations, attitudes, and expectations. However, since these platforms are not equally popular across all backcountry activities, available posts are highly skewed toward a small number of highly committed contributors (i.e., participation inequality). In order to make meaningful extrapolations for the purpose of user monitoring, a **better understanding of social media use within recreational backcountry communities is required**.

There are also serious privacy concerns associated with using data obtained from location-based social media platforms. As a result, this method is not suitable for long-term monitoring as data access and privacy policies of service providers change continuously and without notice.

## Compulsory registration

### *Trip permits and registrations*

Trip permits and registrations are mandatory in certain wilderness areas where the user volume is controlled for natural resources and/or ecological management purposes. In locations where this information is already gathered, obtaining user counts can be an additional component of existing monitoring procedures. Examples of such permit or registration systems are Rogers Pass in Glacier National Park, British Columbia, where the purpose is to protect backcountry users from the dangers of avalanche control along the highway corridor, or the backpacking and mountaineering permits in Denali National Park, Alaska.

The use of trip permits and registrations for user monitoring can be a simple approach for obtaining high quality, management objective, specific-use numbers with complementary information at point locations. Counts are typically most accurate for more remote locations where non-compliance is lowest because access is difficult without going through the official channels. However, **estimating general backcountry use trends from trip permit and registration counts is generally challenging, as the counts do not represent typical backcountry locations**. Furthermore, many locations with mandatory permit systems cap the number of issued permits, which artificially limits backcountry use. Hence, this method is not suitable for large-scale estimates of backcountry use.

## Surveys

Surveys refer to questionnaires or short, structured interviews that can be used to produce datasets that describe backcountry users and their recreational habits. The information collected in surveys can be much richer than just backcountry use numbers and offer valuable insights into attitudes and motivations of recreationists. In this report, we distinguish between intercept surveys, targeted research surveys, and cross-sectional participation surveys.

### *Intercept surveys*

Intercept surveys are a standard research method for collecting detailed information in-situ at locations of interest, such as trailheads or staging areas, to better understand the characteristics and habits of visitors. This method has been used in avalanche safety research for characterizing backcountry user groups and providing insight into their risk management practices.

In the context of backcountry use information, intercept surveys are a **valuable tool for augmenting counting data from trail counters with backcountry information on the local backcountry users**. In addition, intercept surveys can be an effective recruitment method for more in-depth research studies (see next section) and can supplement short-term targeted GNSS tracking studies with useful information. One of the advantages of intercept surveys over targeted research surveys (see next section) is that the research team has access to the true population and the self-selection bias is not as much of a problem. Nevertheless, upscaling the results from intercept surveys to the recreational backcountry population requires taking into account non-participation rates, and the characteristics of non-participants must be explicitly examined. As a result, intercept surveys are not directly suitable for obtaining user counts, although the method can substantially enhance the information collected by other methods.

### *Targeted research surveys*

Targeted research surveys are a standard research method for collecting in-depth information on a specific target population. This type of survey is typically conducted over the Internet, by phone, or by mail. Targeted research surveys are broadly used in recreation research and have been used in numerous avalanche safety research studies to provide insight into backcountry users' motivations, attitudes, preferences, backcountry use patterns, and risk-management practices. Although modern survey tools make the design of Internet surveys easier and more accessible, one of the main challenges of targeted research surveys is the recruitment of meaningful survey samples. While convenience samples are the most commonly used approach for recruiting survey participants, this approach tends to disproportionally attract high-end backcountry users with advanced levels of avalanche awareness and community engagement.

Targeted research surveys are **not directly suitable for obtaining user counts** unless they are specifically designed for it and proper sampling procedures are in place to produce a representative population sample (see next section). Instead, targeted research surveys are **an important research method for examining backcountry users' motivations, attitudes, preferences, and practices**. However, it is important to note that surveys are most effective when focused on a well-defined research question and the survey questions are grounded in established frameworks and theories. Qualitative interviews are much more effective for exploring new topics where research questions are less clear, and theories are not yet established.

A new survey approach that might provide an interesting avenue for gathering information on backcountry use preferences is explicitly **map-based surveys** (e.g., maptionnaire software), which allows survey participants to identify locations and provide relevant spatial information.

### *Cross-sectional participation surveys*

Cross-sectional surveys aim to collect information from a representative sample to explicitly draw conclusions about the characteristics, preferences, and behaviours of an entire population. Some government agencies regularly conduct cross-sectional surveys (often referred to as census) to better understand the engagement in sports and outdoor recreation among their citizens.

In our opinion, cross-sectional participation surveys are the **most direct approach for obtaining conclusive insight into overall participation in winter backcountry outdoor recreation**. However, there are several challenges that need to be considered. First, conducting proper cross-sectional participation surveys is relatively expensive. Although potential exists for working with government agencies that already conduct these types of surveys or collaborating with other recreation stakeholders that might share common interests, sharing a survey with other stakeholders might limit the number of winter backcountry recreation related questions that can be included. Another challenge is that due to the relatively low rates of participation in winter backcountry activities by the general population (typically <5%) substantial population samples are required for producing meaningful characterizations of backcountry user groups.

Regularly repeated cross-sectional participation surveys can provide accurate estimates of temporal trends in winter backcountry recreation participation. Pairing cross-sectional participation surveys with continuous local backcountry user counting campaigns allows results to be regionalized and intermediate trends between surveys to be monitored.

### Other methods

#### ***Use estimates by local experts***

This method uses the knowledge and experience of local recreation professionals (e.g., guides, tour operators, tourism association representatives) to establish estimates of recreational use. Since use estimates by local experts are associated with considerable uncertainty and tend to be biased toward higher values, this approach is most suitable for identifying the relative popularity of winter backcountry destinations within a region. Consequently, use estimates by local experts are **most useful for planning more in-depth monitoring campaigns**.

### Indirect evidence

In addition to direct counting methods, various information sources exist that might be able to provide complementary, indirect evidence on volume and trends in winter backcountry use. Examples include hotel and hut bookings, transportation bookings/tickets, vehicle counts at staging areas/parking lots, ski area boundary gates, snowmobile licences, rescue calls, submissions to avalanche safety observation platforms, equipment sales and rentals, and club memberships. Interested readers are referred to Appendix A2 for detailed descriptions of these information sources.

Table 2: Overview of monitoring methods characteristics

| Monitoring method | Identity | Indiv. character. | Additional insight | Spatial information | Spatial extent | Temporal resol. | Reliability | Affecting behaviour | Privacy concerns | Equipment cost | Implement. cost | Effort of analysis | Winter suitability |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***a) Manual observation methods*** | | | | | | | | | | | | | |
| Direct in-situ counting | Yes | Some | None | Move | Local | High | Higher | Low | None | Lower | Higher | Lower | Yes |
| Nonparticipant direct monitoring | Yes | Some | Some | Move | Local | High | Mod | Low | Low | Lower | Higher | Mod | Yes |
| Citizen science observation methods | No | Some | None | Position | National | Med | Lower | Low | Low | n/a | Higher | Higher | Yes |
| ***b) Automated observation methods*** | | | | | | | | | | | | | |
| Pressure-sensitive counters | No | None | None | Pos | Local | High | Lower | Low | None | Lower | Lower | Lower | No |
| Light barriers and infrared counters | No | None | None | Pos | Local | High | Mod | Low | None | Higher | Lower | Lower | Yes |
| Radio frequency identification systems | Yes | None | None | Pos | Local | High | Higher | Low | Consent | Higher | Lower | Lower | Yes |
| Photography from fixed locations | Yes | Some | Some | Pos Move | Local | High | Mod | Low | High | Mod | Mod | Higher | Yes |
| Video monitoring from fixed locations | Yes | Some | Detail | Move | Local | High | Mod | Low | High | Higher | Mod | Higher | Yes |

| Monitoring method | Identity | Indiv. character. | Additional insight | Spatial information | Spatial extent | Temporal resol. | Reliability | Affecting behaviour | Privacy concerns | Equipment cost | Implement. cost | Effort of analysis | Winter suitability |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Radar detection from fixed locations | No | None | None | Pos Move | Local | High | Higher | Low | Low | Higher | Mod | Higher | Yes |
| Aerial photography | No | None | None | Pos | Regio | Med | Mod | Low | Low | Higher | Higher | Higher | Yes |
| Satellite imagery | No | None | None | Pos | Regio | Med | Lower | n/a | None | n/a | Higher | Mod | Yes |
| ***c) Mobile tracking systems*** | | | | | | | | | | | | | |
| Targeted GNSS tracking | Yes | Detail | Some | Track | Local | High | Higher | High | Consent | Higher | Mod | Mod | Yes |
| GNSS web-sharing services | Yes | Some | Some | Pos Track | Nation | High Low | Mod | n/a | Mod | n/a | Mod | Mod | Yes |
| Mobile phone tracking – individual records | Yes | None | Some | Track | Nation | High | Mod | n/a | High | n/a | Mod | Mod | Yes |
| Mobile phone tracking – aggregate data | No | None | None | Pos | Nation | High | Mod | n/a | Mod | n/a | Mod | Lower | Yes |
| ***d) Voluntary self-reporting*** | | | | | | | | | | | | | |
| Summit registries and hut guestbooks | Yes | None | None | Pos | Local | Med | Lower | n/a | Low | n/a | Lower | Lower | Yes |
| Self-registration boards | Yes | Some | None | Pos | Local | Med | Lower | Low | Low | Mod | Lower | Lower | Yes |
| Online backcountry community platforms | Yes | Some | None | Pos Move | Nation | Med | Lower | n/a | Mod | n/a | Lower | Higher | Yes |

| Monitoring method | Identity | Indiv. character. | Additional insight | Spatial information | Spatial extent | Temporal resol. | Reliability | Affecting behaviour | Privacy concerns | Equipment cost | Implement. cost | Effort of analysis | Winter suitability |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| General location-based social media platforms | Yes | Some | Some Detail | Pos Move | Nation | Med High | Lower | n/a | Mod High | n/a | Lower | Higher | Yes |
| ***e) Compulsory registration*** | | | | | | | | | | | | | |
| Trip permits and registrations | Yes | Some | None | Pos/ Move | Local | Med | Higher | Low | Low | n/a | Lower | Lower | Yes |
| ***f) Surveys*** | | | | | | | | | | | | | |
| Intercept surveys | Yes | Detail | Detail | Pos/ Move | Local | High | Higher | Mod | Consent | Lower | Higher | Mod | Yes |
| Targeted research surveys | Yes | Detail | Detail | n/a | Nation | Low | Mod | Mod | Consent | Lower | Mod | Higher | Yes |
| Cross-sectional participation surveys | No | Some | None | n/a | Nation | Low | Higher | Mod | Consent | n/a | Higher | Lower | Yes |
| ***g) Other methods*** | | | | | | | | | | | | | |
| Use estimates by local experts | No | None | None | Pos/ Move | Local | Med | Mod | n/a | None | n/a | Mod | Mod | Yes |

## Approaches for estimating winter backcountry use

While the overview of the monitoring methods highlights many possibilities for gathering information about backcountry use, none of the methods alone can offer a spatially comprehensive and temporally continuous overview of backcountry use at the regional and national level. It is therefore necessary to combine several methods so that their combined strengths create a meaningful perspective that is useful to avalanche-warning services. This section introduces five possible approaches for monitoring winter backcountry use comprehensively.

The approaches are presented in no particular order and their descriptions are primarily intended as starting points for the design of specific monitoring campaigns in a region or country. The feasibility of the described approaches depends heavily on the available resources, opportunities for working with national and local stakeholders (e.g., outdoor clubs, national parks), and possibilities for collaborating with partners in related fields (e.g., public health, other outdoor recreation associations).

### Backcountry use measure considerations

An important consideration for monitoring backcountry use is whether to focus on participation in winter backcountry activities (i.e., number of people) or estimate actual exposure to avalanche hazard (i.e., number of backcountry days). While both measures offer insight into the magnitude of and trends in backcountry activities, they result in different rate estimates. Hibbs (2012), who studied snowmobile fatality rates in the Midwest of the United States using registrations as the denominator, is an example of rates derived from participation, whereas Walcher, Haegeli, and Fuchs (2019), who calculated mortality rates in commercial mechanized skiing in Canada based on guest skier days, is an example of rates based on actual exposure. While exposure in outdoor activities and adventure sports has been measured in a variety of units (e.g., Farahmand, Hållmarker, Brobert, and Ahlbom (2007): activity hours of cross-country skiing; Schöffl, Hoffmann, and Küpper (2013): activity hours of climbing; Canbek et al. (2015): jumps in paragliding; Soreide, Ellingsen, and Knutson (2007): jumps in BASE jumping; Walcher et al. (2019): skier days in mechanized skiing; Windsor, Firth, Grocott, Rodway, and Montgomery (2009): exposure days of mountaineers in mountaineering), exposure days seems to be the most appropriate measure for winter backcountry recreation as most of the involved activities require substantial time commitment and cannot be pursued for just a few hours. Although exposure measures offer a more accurate perspective on overall time spent in avalanche terrain than participation, obtaining meaningful estimates is more difficult than for participation.

Another important consideration regarding the backcountry use measure is whether the goal is to produce an accurate estimate of absolute backcountry use in the region of interest or a relative estimate that can be used to monitor long-term trends. While all the approaches discussed in this report can be used to estimate both relative and absolute backcountry use measures, providing reliable absolute estimates requires more care and additional scaling factors to properly extrapolate the use observations to the entire population.

## Approach 1: National cross-sectional participation survey

The most direct approach for obtaining a representative overview of participation in winter backcountry activities is to conduct a national cross-sectional participation survey. In many countries, these types of surveys are regularly conducted by or on behalf of government agencies (e.g., Sport Schweiz, Sport New Zealand), interest groups (e.g., Physical Activity Council of United States), or industry associations (e.g., Outdoor Industry Association). These census-type surveys draw conclusions that represent the characteristics of entire populations due to the relatively large samples and/or the use of established representative survey panels. Many of these surveys are conducted at regular intervals to provide insight about long-term trends. The method for census-type surveys is well established, and many commercial marketing research companies conduct these types of studies on a regular basis.

There are several potential challenges for estimating winter backcountry use with a census-type survey. First, due to the broad mandate of government-run census-type surveys, the information collected about recreational activities is often limited to a few participation questions. For the same reason, it might be difficult to include additional questions about exposure (days of engagement per winter) and other important context variables (e.g., avalanche safety training) into these types of surveys even though this information is critical for providing meaningful insight into winter backcountry use. Hence, census-type surveys might be best suited for estimating participation. However, efficient design of these surveys (e.g., nested questions) can address some of these challenges. Second, because participation in winter backcountry recreation is relatively small in most countries, even large samples will include only small numbers of winter backcountry users, which poses a challenge for data reliability. This particularly applies to the results from questions beyond simply participation. Low participation rates in winter backcountry activities might also mean that avalanche-warning services might not have the necessary influence to be included in a government census-type survey.[2]

We see the following opportunities for overcoming these challenges. Instead of participating in a government-run census study, it might be more promising to collaborate with other outdoor recreation stakeholders who are interested in similar type of data regarding their activity. Sharing the cost will make a large-scale census-type survey affordable and having an outdoor focus will allow for more detailed questions. An example of such a focused census study is the 2019 Special Report on Paddlesports and Safety (Outdoor Industry Association, 2019), which was a collaboration between the Outdoor Foundation, the American Canoe Association, the National Association of State Boating Law Administrators (NASBLA), and the U.S. Coast Guard. Similar collaborations should be possible for winter backcountry recreation and/or snow sports.

If detailed questions about exposure, background, and training cannot be included in the census-type survey, the participation results from the survey could be augmented with a targeted intercept survey campaign that focuses on the additional information. Special attention must be given to ensure that the intercept survey sample is

[2] According to unconfirmed information, we believe that the Swiss Alpine Club was able include some questions about mountain recreation in the upcoming iteration of the Sport Schweiz survey.

representative of the entire winter backcountry recreation community. In contrast to some of the other approaches proposed in this report, where the focus is on obtaining a sample that covers the full range of destinations (i.e., highly popular to rarely visited), the primary aim here is to gather a representative sample of backcountry recreationists (i.e., type of activity, winter backcountry use frequency). Hence, primarily targeting more popular backcountry destinations for each of the backcountry activities of interest might be appropriate if resources are limited. However, repeated samples at a range of locations (e.g., high and low use) will lead to more reliable survey results. Online surveys might be used to further complement the sample, but it is almost impossible to avoid sample bias in these types of studies due to the channels used for their promotion (e.g., avalanche bulletin website, club social media channels) and the voluntary nature of participation.

National cross-sectional participation surveys primarily provide nation-wide overviews, and since these surveys are relatively expensive, they are typically only conducted every 5-10 years. Backcountry user counts using a variety of methods conducted at select backcountry locations in the same years as the nation-wide survey could be used to translate the census participation results to localized backcountry use numbers. Furthermore, systematically conducting the same user counts annually would allow avalanche-warning services to monitor short-term trends between the less frequent census survey campaigns.

Implementing a winter backcountry use monitoring campaign based on national cross-sectional participation surveys requires the following steps:

1. Establish relationships with government agency responsible for national census and/or other interested outdoor recreation stakeholders.
2. Design concise but informative questions for census survey.
3. If required, design complementary intercept survey campaign with more detailed questions.

4. Identify meaningful locations for intercept survey and establish local partnerships for conducting intercept survey. The focus should be on capturing the widest range and the greatest number of backcountry users as possible.
5. If required, identify meaningful locations for user counts (possible synergies with intercept survey locations), establish local partnerships, and decide on most suitable monitoring technique.
6. Conduct census survey at regular intervals (approx. 5-year intervals).
7. Run intercept survey campaign in parallel to census survey.
8. Conduct user counts in parallel to census survey and possibly more frequently.

Because the effective wording of survey questions will depend heavily on context (e.g., partner organizations, other questions), we did not include any suggestions in this report. However, to ensure international comparability, we strongly recommend the working group to collaboratively design these survey questions if the approach of national cross-sectional participation surveys were to be pursued.

### Approach 2: Extrapolation from targeted direct counts

An alternative approach for obtaining backcountry use numbers is direct counts. In comparison to the census approach, which is most suited to gathering information on participation, counting campaigns can provide insight on overall exposure. While many of the counting methods presented in this report are suitable for this approach (e.g., manual and automated observation methods), the main challenge is to select an array of representative monitoring locations and/or times that can offer a comprehensive perspective on winter backcountry use in a region of interest. To address this challenge, we suggest classifying known winter backcountry destinations into three or four categories based on estimated frequency of use or popularity. This classification can be based on evidence from indirect tracking methods (e.g., mobile phone tracking, GNSS web-sharing services) or local expert knowledge. Once the known backcountry destinations have been classified, a manageable number of representative locations can be chosen from each destination class and suitable counting approaches can be implemented. Since growth in backcountry use is not expected to be homogeneous across all backcountry destinations, is important to include locations of all popularity levels to capture temporal changes in backcountry use (incl. spatial displacement) in a meaningful way. While both automated and manual counting methods can be suitable for this approach, finding reliable monitoring sites for automated counting can be challenging for winter backcountry use due to the fluidity of the used trails. Manual counting campaigns are labour intensive and the timing of their monitoring must be chosen carefully. We recommend focusing the monitoring mainly on busy times, but also including quiet times to ensure the variability in local backcountry use activity and potential changes (e.g., temporal displacement) are captured adequately. Following established best practices in visitor monitoring, we strongly recommend that automated monitoring sites be initially validated with manual counts. Once counts from individual destinations have been collected, the data are analysed within each class to calculate representative seasonal summary counts. These counts are then multiplied with the number of destinations in each class to derive an annual estimate for overall backcountry use in the region of interest.

To ensure comparability between winter seasons, it is important that monitoring periods are consistent from year to year. We recommend that particularly busy periods (e.g., Christmas holidays, Easter holidays) be consistently monitored at all locations each winter. To get a complete picture of winter backcountry use, it is important to implement the described approach for each popular winter backcountry activity in the region. New destinations might need to be added to the monitoring network over time if substantial displacement of recreational activities is occurring and/or new backcountry activities are emerging. Posts on social media platforms might offer valuable hints about these types of new trends.

If additional background information about backcountry users is desired, pairing the counting campaigns with brief intercept surveys at select monitoring locations is recommended. Encouraging avalanche safety researchers to conduct their research surveys at established monitoring locations has the potential to result in significant benefits for both parties. Avalanche-warning services will learn more about the backcountry users they monitor, and researchers will be able to take advantage of the rich context information available at these locations.

The main disadvantage of estimating backcountry user numbers by using direct counts is that the approach is expensive as the logistics are complicated, and the approach requires continuous field personnel to count and/or maintain the monitoring network.

Implementing a winter backcountry use monitoring campaign based on direct counts requires the following steps:

1. Create inventory of backcountry destinations and group them into main classes according to expected backcountry activity and estimated frequency of use/popularity.
2. Select a manageable number of representative locations from each class.
3. Implement counting approach at each of the selected locations (incl. validation).
4. If desired, conduct complementary intercept survey campaign to learn more about the characteristics of backcountry users at select monitoring locations.
5. Analyse count data at the locations within destination classes.
6. Extrapolate count data across entire region of interest.
7. Repeat counting campaign annually.

## Approach 3: Extrapolation from indirect counts

Instead of using direct counts for estimating backcountry use as described in the previous section, the approach described in this section uses indirect counts from cellphone tracking or GNSS web-sharing services. Companies like Strava continuously advance their products to provide aggregated user data to interested clients. The **Strava Metro for web** platform (https://metro.strava.com/strava-metro-web/), which was launched in November 2019, provides the most sophisticated application to date for exploring number and locations of tracked activities. While it might be possible to get detailed use information including demographics for popular backcountry areas through this platform, we were not able to confirm this directly with Strava. The cost for accessing the anonymized and aggregated tracks is approximately US$2,500 per year.

While the representativeness of Strava data has been examined in urban locations e.g., Whitfield, Ussery, B., and Wendel (2016) according to our understanding there are no scientific studies that have examined the penetration of Strava use in the winter backcountry community. We suspect that use of GNSS tracking varies dramatically both within backcountry user groups and between them. This is a substantial hurdle for reliably estimating overall winter backcountry use from shared GNSS tracks. We see two possible approaches for overcoming this challenge. First, conducting direct count campaigns at select locations will provide insight into the necessary conversion factors for upscaling the GNSS track numbers to a more useful exposure measure (i.e., backcountry trips and eventually exposure days). Second, we recommend conducting an intercept survey study examining the penetration of GNSS web-sharing services among different types of backcountry users at a wide range of winter backcountry destinations. Because the popularity and use of these GNSS web-sharing services seem to be changing quickly over time, these types of background studies need to be conducted at regular intervals. Furthermore, since the use of these web-sharing services might vary considerably between participating countries, we suggest conducting parallel studies to ensure the comparability of backcountry use estimates.

While this approach is relatively convenient and does not require extensive personnel as does Approach 2, one of its main disadvantages is that it relies on data collected by a third party, commercial company. Data aggregation processes and data access policies can change without notice at any time, which makes long-term planning and comparability of results over time difficult.

Implementing a winter backcountry use monitoring campaign based on indirect counts requires the following steps:

1. Explore data access, available spatial coverage, and data elements with popular GNSS web-sharing services.

2. Identify suitable locations for conducting validation study with direct counts.
3. If useful, conduct intercept survey study on use of GNSS web-sharing services among winter backcountry users.
4. Extrapolate trip numbers from GNSS web-sharing services to overall population using scale factors derived from validation and intercept survey studies.
5. Repeat data extraction and analysis from GNSS web-sharing services annually.
6. Conduct validation studies with direct counts and intercept surveys at regular intervals (approx. 5-year intervals).

### Approach 4: Extrapolation from citizen science counts

Another approach for obtaining information on backcountry use is to start a community engagement campaign and request that backcountry recreationists report the number of people seen on a backcountry trip or cars parked at a trailhead or staging area to the local avalanche-warning service. This approach follows the recent citizen science movement in the natural sciences where researchers have engaged the public in large-scale data collection and monitoring studies. An example of such a study in snow hydrology is the Community Snow Observations initiative (http://communitysnowobs.org/), which is a collaboration of the University of Alaska Fairbanks, the University of Washington, Oregon State University, the state of Alaska, and Mountain Hub, with funding from NASA's Earth Science Program. The snow depth measurements gathered by this initiative are used to calibrate satellite and airborne measurements and improve water runoff models (Arendt, 2019).

An advantage of collecting backcountry use data using backcountry recreationists is that it is much more cost effective and requires fewer personnel, particularly for long-term research projects. Furthermore, many avalanche-warning services have established social media channels (e.g., Facebook groups, Instagram), observation sharing platforms (e.g., Avalanche Canada's Mountain Information Network) and/or trip planning sites (e.g., Swiss White Risk) that have the necessary infrastructure for supporting such a campaign. There might be considerable synergies with existing avalanche awareness campaigns, and a citizen science initiative might further enhance the community engagement of avalanche-warning services. However, the quality of the count data will be much more variable, and the sporadic nature of reports will require more sophisticated statistical methods for deriving comprehensive backcountry use numbers from the observations. An additional consideration is that there will likely be an underreporting of backcountry use in less travelled backcountry areas as recreationalists with local knowledge might not be willing to publicly share their secret locations.

To better understand the capabilities of a citizen science campaign for collecting backcountry use data, we recommend conducting a pilot study in a popular backcountry destination with a variety of trip options. Developing a simple, but reliable and informative reporting form will be critical for implementing a citizen science campaign successfully. Furthermore, correlating citizen science backcountry user reports with direct user counts in a well-controlled study area would provide valuable insight into the reliability of submitted observations and allow the calculation of scale factors for deriving overall backcountry use counts. Complementary intercept survey studies could be used to collect additional context information for converting observations to actual backcountry use counts (e.g., number of backcountry users per car).

While having reports throughout the season is useful, the approach might be most informative if avalanche-warning services explicitly promoted the initiative during key monitoring dates (e.g., Christmas holidays, Easter holidays). To increase comparability of observations, these dates should be consistent from year to year and across regions. Having attractive, backcountry activity-specific draw prizes might further increase participation in the initiative.

Implementing a winter backcountry use monitoring campaign based on a citizen science approach requires the following steps:

1. Develop and field-test reporting infrastructure (e.g., mobile app, database).
2. Develop statistical approach for converting reported numbers into backcountry trip counts.

3. Conduct pilot study to validate approach by correlating user reports with direct count observations.
4. If required, run complementary intercept survey studies to gather additional background information for converting user reports to backcountry trip numbers.
5. Launch large-scale community engagement initiative to collect backcountry use reports across entire area of interest.
6. Synthesize reports to overall estimate of backcountry use.
7. Monitor continuously, but extensively promote initiative at the beginning of each season and prior to key monitoring dates (e.g., Christmas holidays, Easter holidays).
8. Continuously validate and improve statistical model to ensure accuracy of estimations.

### Approach 5: Extrapolation from online engagement

Web analytics of avalanche bulletin websites provide another source of indirect observations that can be indicative of winter backcountry use. However, while measures such as page views, visits, and unique visitors of an avalanche bulletin website can easily be retrieved from web analytics packages and offer some insight into the traffic on the avalanche bulletin website, they are neither a true measure of the number of people using the avalanche bulletin nor of backcountry use in general. Web analytics take advantage of "cookies," which are small pieces of code that are stored on a computer when a website is rendered in a browser. When the same website is visited again, the analytics package checks the information stored in the cookie to determine whether the visit is by a repeat or new user. However, this approach to identify unique visitors does not take into account different people using the same computer to check the avalanche bulletins, visits from the same computer but different browsers (cookies are managed by each browser separately), users blocking cookies or deleting them, and recreationists visiting the bulletin from multiple devices. Hence, unique visitor counts only offer a rough estimate of bulletin user numbers.

To extrapolate backcountry use numbers from website analytics, it is critical to have an in-depth understanding of the avalanche bulletin use behaviour of the backcountry community. A representative intercept survey examining online avalanche bulletin use can provide the necessary information for more reliably inferring backcountry use numbers from web analytics. Critical questions to answer include how often recreationists check the bulletin per backcountry trip and how many devices they use to access the information. This information is the foundation for linking page views of unique visitors to backcountry trips. Furthermore, it is important to have a clear understanding of the proportion of different types of avalanche bulletin users (incl. non-users) within the winter backcountry community to derive overall backcountry use numbers from web analytics. Since the online world is rather dynamic and user behaviour tends to change quickly, this type of user study would have to be conducted at regular intervals to ensure long-term trends can be estimated in a meaningful way. However, such intercept survey campaigns can likely be paired with other backcountry user studies to maximize value and reduce costs.

A possible approach for getting a more accurate estimate of avalanche bulletin user characteristics is to implement user accounts on avalanche bulletin websites. This would provide a more explicit identifier of unique users. In addition, brief online surveys could be used to gather valuable background information on avalanche bulletin users that facilitate the estimation of backcountry use numbers (e.g., number of trips per year, number of backcountry users in household). However, such an approach would require the implementation of meaningful personalized bulletin products to incentivize bulletin users to sign up for personal accounts. Furthermore, it is important to note that an intercept survey campaign would still be required to understand the penetration of bulletin website user accounts among backcountry users and to explore the backcountry use habits of the recreationists without a bulletin website user account. It is important to note that this approach is of limited value for measuring backcountry use in areas that are not serviced regular avalanche bulletins.

In addition to avalanche bulletin websites, there are many online forums (e.g., social media groups, observation exchange platforms like Avalanche Canada's Mountain Information Network, trip planning tools like the Swiss White Risk) where backcountry users congregate and exchange information. In comparison to avalanche bulletin websites where the identification of unique users is challenging, most of these platforms have user accounts, which make the recognition of individuals easier. However, an in-depth understanding of the extent of use of the particular online forum within the backcountry community, the characteristics of the recreationists partaking in these online forums, and how they differ from non-users is critical for extrapolating overall backcountry use from online forum participation in a meaningful way. Hence, using participation on online forums for estimating backcountry use numbers also requires a comprehensive intercept survey study. Additional challenges for using online forums as the foundation for backcountry use estimates include the fact that backcountry social media platforms typically have a strong local focus (i.e., do not cover the entire region of interest), and that they can potentially be short-lived, which makes them unsuitable for long-term monitoring.

Implementing a winter backcountry use monitoring campaign based on online engagement counts requires the following steps:

1. Understand the available website analytics for the avalanche bulletin website.
2. Explore the social media and online forum landscape in the area of interest.
3. Design a comprehensive intercept survey campaign examining the online habits of winter backcountry users.
4. Combine understanding of online habits with avalanche bulletin website analytics to estimate overall backcountry use.
5. If required, complement estimates based on avalanche bulletin website analytics with similar estimates from other online forums.

## Conclusions

Having a solid understanding of the size and characteristics of the winter backcountry recreation community is of critical importance for evaluating existing avalanche safety programs and making informed decisions about the development of new products. However, to our knowledge, there are no established systems in place to effectively monitor and characterize winter backcountry users.

To address this knowledge gap, this report provides a **comprehensive overview of participation/user monitoring methods commonly used in outdoor recreation management** and assesses their suitability for monitoring winter backcountry use in avalanche terrain. In total, we examined 22 different approaches for backcountry use monitoring ranging from direct in-situ counting to aerial photography, mobile phone tracking, voluntary self-registration, and use estimates by local experts.

While each of the assessed methods has its unique strengths and weaknesses, no method on its own can offer a spatially comprehensive and temporally continuous overview of backcountry use at the regional and national level. In order to produce a comprehensive overview of winter backcountry use, it is necessary to combine several methods that offer complementary perspectives by taking advantage of their individual strengths. To provide avalanche-warning services with a meaningful starting point for developing a comprehensive monitoring strategy, we present **five possible approaches for estimating winter backcountry use**. While the national cross-sectional participation survey is the most direct path to backcountry use numbers, the proposed extrapolations from various other counts might offer useful and potentially more economical alternatives.

Due to different circumstances and resources, it might be necessary to implement different monitoring approaches in different regions or countries. However, to ensure comparability, it is important that the international community agrees on some fundamental aspects of the monitoring campaigns, which include the preferred backcountry use measure (participation or exposure days) and whether the focus should be on absolute or relative backcountry use numbers. In addition, standardizing survey questions and key monitoring dates will further enhance international comparability of backcountry use numbers and create new opportunities for comparative studies.

While this report is focused on winter backcountry recreation and avalanche safety, we believe that the information presented has the potential to also be valuable for monitoring other non-commercial backcountry recreation activities that are practised over large areas and are only loosely organized. Example activities could include hiking, mountain biking, and ocean kayaking. Since all these communities are relatively small and typically only have limited resources, developing activity-specific monitoring approaches might be prohibitive. However, joining forces might highlight synergies for developing effective monitoring systems that cover the needs of multiple communities most effectively.

Regardless of the chosen approach, implementing a comprehensive backcountry monitoring strategy requires a substantial investment of money and time. While this report does not offer a turn-key solution, we hope that it provides the necessary information for having informed conversations and making meaningful first steps.

# Appendices

## A1. Overview references for visitor monitoring methods

In addition to studies related to individual monitoring methods, the literature indicates numerous existing overview references that provide more comprehensive perspectives. We distinguish between guidelines and manuals, reviews summarizing monitoring methods in a general monitoring context, and reviews of monitoring methods in the context of winter backcountry recreation. Each type of study is summarized in the following sections.

### Guidelines and manuals on visitor monitoring

In 1996, the World Commission on Protected Areas established a task force to deal with strategic objectives of tourism and protected areas. The task force identified that the lack of global data on visitor use in the world's protected areas was a major policy issue and substantial hurdle for making informed management decisions. In response, the task force developed definitions, approaches, and standards on public use measurement and reporting for protected areas. The guidelines were subsequently published in **Hornback and Eagles (1999)**, which includes definitions of terms and concepts, guidance on program development, information on counting systems, guidance on different types of visitor studies, information on data collection and analysis, and a special chapter on measuring public use in marine protected areas.

The manual of **Watson, Cole, Turner, and Reynolds (2000)** is designed as a convenient resource for wilderness managers within the National Wilderness Preservation System of the United States (e.g., national park, national forests) who have the responsibility of monitoring and describing visitor use. It is a comprehensive, recipe-style manual on estimation techniques and procedures that are essential for accurately measuring visitor use-related characteristics and conditions in wilderness areas.

More recently, **Kajala et al. (2007)** provide a comprehensive manual for collecting visitor information in nature areas based on the existing research and management experience in Nordic and Baltic countries. This resource was produced by a working group of Nordic and Baltic researchers whose goal was to create a framework for obtaining more comparable and reliable visitor information across different nature areas in northern countries of Europe. The manual focuses primarily on practical matters, such as how to carry out visitor counting and visitor surveys, how to report the results, and how to make use of the information obtained. Included are guidelines, recommendations, and examples about on-site visitor monitoring methodologies applicable to nature areas in the Nordic and Baltic countries.

### General overviews of monitoring methods

We found several reports that summarize, analyse, and contrast visitor monitoring methods with respect to specific monitoring and managing objectives. The most recent and comprehensive overview papers are Cessford and Burns (2008) and Xia and Arrowsmith (2008), but Rupf (2016), Cessford and Muhar (2003), Muhar, Arnberger, and Bradenburg (2002) and Hollenhorst, Whisman, and Ewert (1992) also offer valuable overview perspectives.

**Cessford and Burns (2008)** present a literature review and summary as a key reference resource for making use of visitor monitoring and counting systems. The authors identify the number of visitors and their spatiotemporal distribution as key information for the effective protection of natural, historic, and cultural heritage values when maintaining areas for tourism and recreation. In addition to summarizing the advantages and disadvantages of various monitoring methods, the authors use key literature references to examine the following characteristics of each monitoring method: precision, accuracy, cost, error potential, coverage, data handling, maintenance requirements, detectability, and practicality. These analyses are followed with a discussion of factors to consider when selecting a method, and details on the development of monitoring tools.

The resource includes reviews of the following monitoring methods:

- Field observations
- Camera recordings
- Remote sensing
- Mechanical counters
- Pressure counters
- Active optical counters
- Magnetic sensing
- Microwave sensing
- Visitor registries and hut books
- Permits
- Bookings
- Fees
- Indicator counts
- Interview/survey counts

**Xia and Arrowsmith (2008)** summarize the techniques for counting and tracking the spatial and temporal movements of visitors in protected areas with a focus on the needs of simulation modellers for developing and validating their models. After describing various counting and tracking methods in detail, the authors evaluate the different approaches with respect to the data the approaches can provide, the associated costs, levels of intrusion, and reliability. They then discuss which counting and tracking methods are best suited for specific research applications.

The review of Xia and Arrowsmith (2008) includes the following monitoring methods:

*Methods for counting:*

- Direct observation
- Pressure pads
- Camera-based

- Infrared counters
- Magnetic detectors
- Induction loops
- Microwave detectors

*Methods for tracking:*

- Direct observation
- Observations and interviews
- Questionnaires
- GPS
- Timing systems
- Personal digital assistant tracking
- Mobile phone tracking
- Closed circuit television

### Winter-specific overviews of monitoring methods

We found only three references that explicitly examined the suitability of different visitor monitoring methods for winter backcountry users.

In the densely populated European Alps, the substantial increase in winter backcountry recreation puts significant pressure on the local wildlife populations (Rupf, Haegeli, Karlen, & Wyttenbach, 2019). Hence, an in-depth understanding of the number and movement of backcountry recreationists is critical for wildlife management. Using the Kärpf wildlife sanctuary in Switzerland as a test site, **Rupf and Stäuble (2018)** are currently evaluating the suitability of different methods for monitoring backcountry users. Their study includes the following methods:

- Aerial photography
- Automatic infrared cameras
- Backcountry sports community websites
- Cellphone usage data

- Estimates of local experts
- Passive infrared counters
- Summit registries

**Watson, Warshek, and Hall (2008)** examined different remote sensing methods for monitoring snowmobiling activity over large areas on federal lands in the United States. Their study includes the following monitoring methods:

- Aerial photography
- Satellite imagery

GPS monitoring and VHF radio tracking are also discussed as alternative monitoring methods, but their effectiveness was not explicitly assessed.

**Zweifel, Raez, and Stucki (2006)** tested different monitoring methods in their pilot study on avalanche risk for recreationists in backcountry and off-piste areas. Based on their test results, the authors concluded that light barriers and voluntary registration boards were particularly useful for their research objective. They found that the data generated by these two methods was sufficiently precise to meet the single day resolution required to match the temporal resolution of their snow conditions and avalanche activity datasets. The data provided by these monitoring methods were then used as the foundation for their research on the volume of backcountry and off-piste recreationists. Additionally, the authors used the data to derive avalanche accident risk estimates for their study area. Their review explicitly tested the following monitoring methods:

- Light barriers
- Voluntary registration boards
- Counting by ski patrollers

In addition, the authors shared their perspectives on the use of photographs, aerial photography, satellite imagery, questionnaires, and tourism statistics.

## A2. Monitoring methods and technologies

Monitoring methods have been categorized in the existing literature in different ways. While Hollenhorst et al. (1992) describe three main data collection methods (self-counting, direct-counting, and indirect-counting), Cessford and Burns (2008) distinguish four main categories (direct observations, on-site counters, visit registration, and infrared counts), and Xia and Arrowsmith (2008) simply differentiate between counting and tracking methods.

To assess the usefulness of monitoring approaches and technologies for human dimensions research in avalanche safety, we group them into the following main categories:

- Manual observation methods
- Automated observation methods
- Mobile tracking systems
- Voluntary self-reporting
- Compulsory registration
- Surveys
- Other methods

Each of these categories includes several different monitoring methods, which are discussed in detail in the following sections. At the end of Appendix 2, we also briefly discuss potential sources of indirect evidence on backcountry use numbers.

### Manual observation methods

Manual observation methods refer to direct, visual observations by human observers that do not require any automated technical means (e.g., counters, cameras). We include the following monitoring methods in this section:

- Direct in-situ counting
- Nonparticipant direct monitoring
- Citizen science observation methods

### *Direct in-situ counting*

Direct in-situ counting includes on-site personnel who use handheld tools, such as counters or tally sheets, to count visitors manually (Cessford & Burns, 2008). Field observers' locations are often fixed, but occasionally observers roam to cover larger study areas (Cessford & Burns, 2008).

Direct in-situ counting is commonly used in short monitoring campaigns to evaluate the accuracy of count data from other observation approaches. An example of such a study is Arnberger and Hinterberger (2003), who conducted field counts on specific days at a select number of observation points in a national park. Observers in this study documented the number of visitors, the activities of those visitors, the group size, and their basic route. These observations were used to better understand visitor behaviour within the protected area.

Zweifel et al. (2006) is one of the few studies that explicitly apply this monitoring approach in the context of winter backcountry use. In this study, ski patrollers who often loosely monitor off-piste and backcountry recreationists near ski areas explicitly counted recreationists and their tracks. The use numbers were simply recorded on a tally sheet (Winkler et al., 2016).

#### General advantages and disadvantages

The reviewed literature on direct in-situ counting highlights the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
|---|---|
| • Method is flexible and mobile (Xia & Arrowsmith, 2008). Monitoring location can vary with seasonal changes.<br>• Data is accurate and can include descriptive data on visitor characteristics, behaviour, and mode of travel (Cessford & Burns, 2008). | • The use of on-site trained personnel can result in high costs (Arnberger, Haider, & Bradenburg, 2005; Cessford & Burns, 2008).<br>• If staff resources are limited, counting duties might compete with other staff responsibilities (Cessford & Burns, 2008). |

| | |
|---|---|
| • Estimated data error can be very low (Zweifel et al., 2006).<br>• Communication with visitors is possible (Xia & Arrowsmith, 2008). Data recorded can be very detailed and descriptive. | • Direct in-situ monitoring can accrue a higher error as visitor frequency increases (Wolf, Hagenloh, & Croft, 2012).<br>• Costly in personnel hours (Wolf et al., 2012; Xia & Arrowsmith, 2008).<br>• Data quality and count accuracy depends highly on diligence the observer.<br>• Data quality and count accuracy can vary due to environmental conditions (e.g., visibility).<br>• Count accuracy decreases once visitor volume overwhelms capacity of human counter (Arnberger et al., 2005).<br>• Can negatively affect user (Xia & Arrowsmith, 2008).<br>• Can only be conducted in constrained temporal and spatial domains (i.e., selected locations at limited periods of time). |

## Tips for effective use

Our literature review further revealed the following tips for effective use of direct in-situ counting:

- To collect reliable data, the number of field observers should be set and adjusted flexibly to meet the demand of high-use times or high-use locations (Arnberger et al., 2005).
- Data collection protocols should minimize the number of variables collected by an observer to ensure reliable counts and consistent and relevant user data (Pettebone, Newman, & Lawson, 2010).
- Data recording systems must be highly structured to avoid subjectivity of the observer (Cessford & Burns, 2008).

- Arnberger et al. (2005) found that relevant data such as route choice was difficult to record if observers were situated in a location where visitors are still deciding which route to follow. It is imperative that observation locations allow the research staff to make and record observations that properly align with the research objective.

### Additional considerations for winter use

- The presence, density, and distribution of tracks as well as a visual account of use levels offers a unique opportunity for monitoring the volume of backcountry use in the wintertime. However, the accuracy of this approach depends on weather and snow conditions. While good visibility and fresh snow result in obvious tracks that are easy to count, poor visibility, hard surface snow, extended periods without new snow, and/or high use make poor conditions for this observation approach (Zweifel et al., 2006).
- Clear observation procedures are required to avoid accidental miscounting.
- Due to the possible remoteness of observation locations and adverse winter conditions, special considerations must be given to the comfort and safety of the field observers.

### Assessment and recommendations

- **Type of personal information collected**
    - **Identity**: Yes
    - **Individual characteristics**: Some
    - **Additional insight into behaviour**: None
- **Type of spatial and temporal information collected**
    - **Spatial information**: Movement
    - **Spatial extent**: Local
    - **Temporal resolution**: High
- **Reliability**: Higher
- **Potential impacts on study subjects**
    - **Potential for affecting behaviour**: Low

    - **Potential for privacy concerns**: None
- **Cost of monitoring method**
    - **Equipment cost:** Lower
    - **Implementation cost:** Higher
    - **Effort and complexity of analysis:** Lower
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of direct in-situ counting for addressing the human dimensions needs of avalanche safety programs:

- Not recommended for large-scale backcountry use monitoring campaigns.
- Most useful for short and targeted campaigns in areas with medium traffic volumes.
- Standard method for ground-truthing automated monitoring methods.
- Can be paired effectively with intercept survey campaigns for triangulation with data from other (automatic) methods.

### ***Nonparticipant direct monitoring***

Nonparticipant direct monitoring is a method of direct observation without involvement or participation in the activity by the researcher. Nonparticipant direct monitoring is used extensively in case study research in the social and behavioural sciences (Laurier, 2010; Liu & Maitlis, 2010). The objective is to collect high-quality data on events, activities, and interactions to provide detailed insight into the dynamics of a phenomenon in its natural context. In comparison to participant direct monitoring where trained observers are actively engaged in the social groups and activities being studied, nonparticipant observers have a more distant role. Nonparticipant monitoring may be overt, where participants understand that the observer is there for research purposes, or covert, where participants have no knowledge that they are being studied and observers have no contact with the researched at all.

There are many examples of studies that employ nonparticipant observations. The method is frequently combined with other methods such as interviews, document analyses, and surveys to provide a rich perspective on the study subject. Examples in the area of outdoor recreation include Tzoulas and James (2010), who examined people's use of and concerns about urban green space networks or Stephen Lyng's studies on the sociology of voluntary risk-taking (e.g., Lyng, 1990, 2005).

We recall a study by the German Alpine Club (DAV), where researchers followed groups of backcountry skiers at a distance to study their decision-making process and terrain preferences. These observations were followed up with qualitative interviews to gather additional insight on the observed behaviour. We believe that the study was conducted about 15 years ago (approx. 2004) and published in the magazine *BergUndSteigen*. However, we were unable to locate any related article and could not provide a proper reference.

#### General advantages and disadvantages

The reviewed literature on nonparticipant direct monitoring highlights the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
|---|---|
| • Provides an extremely rich perspective, especially when combined with other qualitative research methods.<br>• Captures the dynamics of participants' interactions with each other and with their environment (Liu & Maitlis, 2010). | • As an exploratory method, not necessarily designed to provide results that can be generalized beyond the event and group studied (Laurier, 2010).<br>• The observations made might not provide a representative sample of the events, activities, and interactions of interest for the study. (Liu & Maitlis, 2010).<br>• Considerable risk that the presence of an observer is causing those under study to change their behaviour (Liu & Maitlis, 2010).<br>• There can be concerns about the observer's ability to remain objective and not get involved in the in the group and/or activity (Liu & Maitlis, 2010).<br>• Requires researcher with proper training, personal research experience, and/or substantial research support to be performed properly. |

## Tips for effective use

- A critical first step in nonparticipant research where participants are aware of the presence of researchers is building trust and developing empathy with participants (Liu & Maitlis, 2010). However, care has to be taken to ensure that researchers do not over-identify with their study subjects.
- Taking detailed field notes is key for conducting successful nonparticipant research. The use of audio and video recorders or cameras to document

activities in a way that augments the field notes is becoming more common (Liu & Maitlis, 2010).

### Considerations for winter use

- Given the inherent risk of backcountry travel in the wintertime, special care must be taken to ensure the safety of the researcher at all times.
- Situations might arise where the researcher (with proper credentials) might feel the need to provide avalanche safety advice to the study participants due to imminent danger from avalanche hazard. It is suggested that proper procedures for this situation are planned in advance and discussed with the risk management team of the research institution.

### Assessment and recommendations

- **Type of personal information collected**
    - **Identity**: Yes
    - **Individual characteristics**: Some
    - **Additional insight into behaviour**: Some
- **Type of spatial and temporal information collected**
    - **Spatial information**: Movement
    - **Spatial extent**: Local
    - **Temporal resolution**: High
- **Reliability**: Moderate
- **Potential impacts on study subjects**
    - **Potential for affecting behaviour**: Low
    - **Potential for privacy concerns**: Low
- **Cost of monitoring method**
    - **Equipment cost:** Lower
    - **Implementation cost:** Higher
    - **Effort and complexity of analysis:** Moderate
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of nonparticipant direct monitoring for addressing the human dimensions needs of avalanche safety programs:

- Not suitable for obtaining backcountry user numbers.
- Most effective for targeted, qualitative, sociology-type studies exploring risk management practices and group dynamics in avalanche terrain.

### *Citizen science observation methods*

In the scientific community, citizen science has grown in popularity and acceptance as a research approach (Follett & Strezov, 2015). Citizen science observation methods engage the public in research that requires gathering and analysing large-scale data. The review paper by Follett and Strezov (2015) states that this method has been used in the fields of wildfire and environmental monitoring extensively. In their assessment of citizen science based research, the authors identify three different classifications of citizen science projects: a) contributory, where participants contribute to data collection; b) collaborative, where citizens also design the study, analyse data and draw conclusions; and c) co-created, where citizens participate in all stages of the project including research design.

In their study, Gouraguine et al. (2019) emphasize the usefulness of citizen science as a research method particularly when sustained funding for long-term research projects is not guaranteed. They argue that data collected through citizen science can be critical in generating global datasets and thus provides data where it otherwise would not be available.

Plieninger et al. (2018) used participatory mapping in conjunction with narrative analysis to detect both landscape values and urban development preferences. This approach combined quantitative Public Participation Geographic Information Systems (PPGIS) with qualitative narratives to inform public policy in the remote Faroe Islands.

Citizen science has been applied in a winter context in the Community Snow Observations (CSO) initiative, which is a project aimed at achieving an improved understanding of snow depth variability over large areas ("Community Snow Observations, Citizen Science", 2017). This initiative uses a citizen science method to obtain snow depth observations in mountainous regions in order to support the interpretation of satellite and airborne snow measurements collected by NASA and similar agencies, to create water runoff models, and to better understand runoff effects on snow avalanches, water resources, ecology, tourism, and climate change. Community Snow Observations (CSO) uses a smartphone application called “Mountain Hub” where observers can submit snow-depth measurements taken with an avalanche probe. Additionally, the project's website provides clear instructions to viewers on how to obtain accurate measurements in addition to more formal tutorials on the process. In addition to promoting continuous observations made by individuals, this project has also completed intensive observations where scientists and leaders conduct daylong measurement efforts with groups of individuals.

### General advantages and disadvantages

The reviewed literature on citizen science observation methods highlights the following advantages and disadvantages.

| Advantages | Disadvantages |
|---|---|
| • Has the potential to make good use of volunteers thereby reducing the number of paid personnel and, thus, associated cost (Gouraguine et al., 2019).<br>• PPGIS can provide information of value and preference for certain locations (Verbrugge et al., 2019). This has the potential to communicate otherwise intangible information (Verbrugge et al., 2019).<br>• PPGIS is useful in the identification of hotspots (Verbrugge et al., 2019).<br>• The detailed spatial maps resulting from PPGIS are useful and effective for communication in multi-stakeholder situations (Verbrugge et al., 2019).<br>• Enables long-term continuous observations ("Community Snow Observations, Citizen Science", 2017). | • Volunteers or citizen participants must be trained on how to accurately obtain data (Gouraguine et al., 2019).<br>• Additional data treatment procedures may be required to reduce observer-related variability (Gouraguine et al., 2019).<br>• Methods involving PPGIS are subject to geographic discounting, where value can be placed based on distance from an individual (Plieninger et al., 2018).<br>• Technical issues may present barriers to people wishing to complete a PPGIS survey (e.g., lack of Internet connection, no computer, inability to understand the survey format) (Plieninger et al., 2018). |

| | |
|---|---|
| • Methods for observation submission such as smartphone apps make it easy for users to contribute to citizen science initiatives. | |

## Tips for effective use

Our literature review further revealed the following tips for effective use of citizen science observation methods:

- For citizen science data to be useful, data collection methods need to adhere to scientific standards and need to be made available to those responsible for the long-term continuation of the research project (Gouraguine et al., 2019).
- Because consistent data sampling is key for an accurate dataset, care should be taken to ensure that sampling methods are understandable and practical for participants.

## Considerations for winter use

We did not find any references discussing special considerations regarding the use of citizen science observation methods in a winter backcountry environment.

## Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: No
  - **Individual characteristics**: Some
  - **Additional insight into behaviour**: None
- **Type of spatial and temporal information collected**
  - **Spatial information**: Position
  - **Spatial extent**: National
  - **Temporal resolution**: Medium
- **Reliability**: Lower (need to be determined experimentally)
- **Potential impacts on study subjects**
  - **Potential for affecting behaviour**: Low

    - **Potential for privacy concerns**: Low
- **Cost of monitoring method**
    - **Equipment cost:** n/a
    - **Implementation cost**: Higher (initial development or reporting system and promotion) – Moderate (if tied to existing reporting systems and/or social media channels)
    - **Effort and complexity of analysis**: Higher (development of initial statistical analysis approach) – Lower (long-term routine calculations)
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of citizen science observation methods for addressing the human dimensions needs of avalanche safety programs:

- Has potential to provide a cost-effective approach for collecting backcountry user counts over large areas.
- Existing avalanche safety observation platforms (e.g., Avalanche Canada's Mountain Information Network) and social media channels might provide valuable starting points for developing an engaged community of reporters and a reporting system.
- Proper and continuous promotion is critical for the success of a citizen science-based monitoring approach.
- Since we are not aware of any existing studies that used a citizen science approach for user monitoring in a winter backcountry environment, we recommend conducting exploratory studies before committing to the approach on a large scale.
- We also suggest that the statistical methods required for deriving comprehensive backcountry user numbers be explored before pursuing the approach for collecting backcountry user data.

## Automated observation methods

Automated observation methods refer to monitoring approaches that use technical means (e.g., counters, cameras) to observe human activity without constant attention by the researcher. The analysis of the collated data may be automated or require manual interpretation. We included the following monitoring methods in this section:

- Pressure-sensitive counters
- Light barriers and infrared counters
- Radio frequency identification systems (RFID)
- Photography and video monitoring from fixed locations
- Radar detection from fixed locations
- Aerial photography
- Satellite imagery

### *Pressure-sensitive counters*

Pressure-sensitive counters such as acoustic slab sensors and pressure sensors are buried underground. **Acoustic slab sensors** are sensitive to micro-variations in pressure and record these variations as a count (Eco-Counter, 2018). **Pressure sensors** are pressure-sensitive mats, which are buried in the trail and connected to a counter unit (Watson et al., 2000). These mats rely on users stepping on them where the resulting deformation triggers a sensor count (Cessford & Burns, 2008).

Examples of studies that have used pressure-sensitive counters include Rupf et al. (2006), where visitor use and distribution were studied in the Swiss National Park for wilderness management purposes. Acoustic slab sensors were installed in four different locations and then calibrated with counts from on-site field observers. In 2007, the research team conducted a more extensive calibration study to further improve the precision and confidence in the collected counts (Rupf, Wernli & Haller, 2008).

We did not find any literature describing the application of pressure-sensitive counters for monitoring winter backcountry recreation.

#### General advantages and disadvantages

The reviewed literature on pressure-sensitive counters highlights the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
|---|---|
| • Data can show short-term trends over time with data and time information (Rupf et al., 2006).<br>• Automated data transmission is possible with limited power requirements (Rupf, 2015).<br>• Using multiple mats, visitor numbers and direction of travel can be recorded (Rupf et al., 2008). | • Miscounts are possible due to variables including user weight, users travelling in groups, and step lengths (Rupf et al., 2006).<br>• Counts may be overestimated due to ground vibrations that are not related to visitor traffic (Watson et al., 2000).<br>• Accuracy of data is compromised if the power supply is low, or if installation and |

| | |
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| • Lower power requirements and long battery lives make them highly autonomous counting devices with low maintenance requirements (Cessford & Burns, 2008; Eco-Counter, 2018; Rupf, 2015; Xia & Arrowsmith, 2008).<br>• Can be connected to other monitoring devices, such as cameras, where a count triggers a camera recording.<br>• Pressure pads are available in a variety of sizes to meet different monitoring objectives (Xia & Arrowsmith, 2008).<br>• Sensitivity and interval can be adjusted to account for false counts.<br>• Pressure sensors are placed underground making them less vulnerable to vandalism (Rupf, 2015; Watson et al., 2000).<br>• Pressure-sensitive counters are minimally invasive toward users (Xia & Arrowsmith, 2008). | calibration have not been properly executed.<br>• High operational maintenance needs required to ensure that power supply is adequate (Watson et al., 2000).<br>• Pressure-sensitive devices do not account for different user types or trends over time.<br>• Pressure counters do not work in snow (Rupf, 2015).<br>• Poor weather conditions and cold temperatures can affect the performance (Xia & Arrowsmith, 2008).<br>• Ease of installation is affected by ground conditions (Xia & Arrowsmith, 2008). Installation may require substantial resources.<br>• High initial operation costs (Rupf, 2015).<br>• Directional data provides counts of path use in a particular direction, but not an estimate of visitor numbers (Rupf et al., 2008). |

## Tips for effective use

Our literature review further revealed the following tips for effective use of pressure-sensitive counters:

- If cameras are used to calibrate the acoustic slab sensors, they should be set in places where traffic will be visible for long distances to account for the time lag between the sensor detection and the camera's trigger (Watson et al., 2000).
- On-site observing is an appropriate form of calibration of acoustic slab sensors.

- Acoustic slab sensor sensitivity should be adjusted so as to eliminate or account for false counts, such as vegetation movement or snowfall (Cessford & Burns, 2008).
- To avoid multiple counts, the acoustic slab sensor must be adjusted for both sensitivity and length of delay between readings.
- The sensitivity of the pressure-sensitive devices should be adjusted carefully so as to eliminate or account for false counts (such as vegetation movement or snowfall) (Cessford & Burns, 2008).
- Accuracy of the pressure-sensitive counters is highly dependent on the correct installation, sensitivity calibration, and quality of electronics and programming (Cessford & Burns, 2008).
- Pressure-sensitive counters should be installed on a descent route. This ensures that the barriers are not located where users may stop potentially triggering multiple counts from one person.
- To avoid miscounts, pressure-sensitive counters should be installed where users are likely travelling single file and cannot detour around the counter (Peters & Dawson, 2004; Rupf et al., 2008; Watson et al., 2000).
- Rupf et al. (2008) outline the following recommendations for selecting a site suitable for pressure sensors: path width should be very narrow; the view at the sensor site should not tempt visitors to stop; proximity to obstacles should be avoided; placing the sensors near path crossings and rest areas should be avoided; stairs provide good locations as they regulate user steps; path erosion should be considered; steep sites are not recommended; and drainage of sites should be considered.

### Considerations for winter use

- When using acoustic slab sensors, frozen ground can result in undercounts (Ross, 2005).
- Pressure sensors can be sensitive to temperature, which would be difficult to control for during winter conditions (Cessford & Burns, 2008).

- Pressure-sensitive counters require ongoing calibration to account for changes in the overlying surface, such as snow or ice build-up (Cessford & Burns, 2008).
- Most studies on the use of pressure-sensitive counters for monitoring use have analysed and discussed the device with respect to footsteps. Because the pressure signal of winter backcountry users on skis, snowshoes, or snowmobiles is substantially different from summer users on foot, and because the pressure signal diminishes with depth as the pressure is absorbed by the internal deformation of the snowpack (see, e.g., Thumlert, Exner, Jamieson, & Bellaire, 2013), this monitoring method is not suitable for reliably counting winter backcountry users.

### Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: No
  - **Individual characteristics**: None
  - **Additional insight into behaviour**: None
- **Type of spatial and temporal information collected**
  - **Spatial information**: Position
  - **Spatial extent**: Local
  - **Temporal resolution**: High
- **Reliability**: Lower
- **Potential impacts on study subjects**
  - **Potential for affecting behaviour**: Low
  - **Potential for privacy concerns**: None
- **Cost of monitoring method**
  - **Equipment cost**: Lower
  - **Implementation cost**: Lower
  - **Effort and complexity of analysis**: Lower
- **Winter suitability**: No

Based on the available information, we draw the following conclusions about the value of pressure-sensitive counters for addressing the human dimensions needs of avalanche safety programs:

- Not recommended for monitoring winter backcountry users because the snowpack absorbs the pressure variations that the sensors rely on.

### *Light barriers and infrared counters*

**Light barriers** are a type of optic sensor that uses light beams to connect a transmitter to a receiver and record counts of when this beam is interrupted, such as by a visitor passing. **Infrared counters** consist of a pyroelectric sensor containing a lens that is sensitive to heat radiation emitted by human bodies. These types of counters are useful because they are waterproof, function over a wide range of temperatures, can record the direction of visitors' approach, record and store data at 1 hour- or 15 minute-intervals, are easy to maintain, and are cost-effective. Andersen, Gundersen, Wold, and Stange (2014) recently evaluated the accuracy of these types of counters for monitoring visitors in winter alpine environments in Norway.

Both light barriers and infrared counters have been popular in outdoor recreation and conservation management research, and there are many examples of studies of their use in the literature. However, light barriers are now considered out-dated technology. Andersen et al.(2014) state that infrared sensors are in broad use in the United Kingdom and Scandinavia to monitor the number of pedestrians, bikers, cross-country skiers, and visitors in mountainous areas. Infrared counters are also used by Parks Canada to monitor visitor traffic. Rettie (2014) used infrared counters at select sites in Canada's mountain national parks to determine the level of backcountry winter use to address management knowledge gaps on conservation, visitor experience, and education. The resulting insight was subsequently used for resource allocation decisions for track setting, safety, trail expansions, off-piste access, and user conflicts.

An example of the use of light barriers in an avalanche safety related study is Zweifel et al. (2006), who used a counting device specifically developed for alpine ski sports to monitor skiing activities outside of a ski area in Switzerland. The purpose of this study was to investigate the behaviour of recreationists in winter activities and explore their response to avalanche danger and quality of snow conditions. Rubin and Camp (2012) describe a wireless sensor system called SkinTrack and its use at the Loveland ski area in Colorado to monitor the traffic at boundary gates that lead to out-of-bounds areas. The system also combined a light barrier with an avalanche transceiver checker to collect information on whether skiers were wearing avalanche transceivers.

### General advantages and disadvantages

The reviewed literature on infrared counters and light barriers highlights the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
|---|---|
| • Infrared counters are small in size and weight, making installation easier (Cessford & Burns, 2008).<br>• Infrared counters are highly accurate (Cessford & Burns, 2008).<br>• Data can show trends in use over time with date and time data (Cessford & Burns, 2008; Watson et al., 2000).<br>• Sensitivity, interval, and placement can all be adjusted to exclude some false counts (Cessford & Burns, 2008).<br>• Data generated by a wireless sensor system, such as SkinTrack, can be transmitted for monitoring in near real-time (Rubin & Camp, 2012).<br>• Automated data transmission is possible with limited power requirements (Rupf, 2015).<br>• Mechanical access gate counters have the potential to provide other meaningful data when integrated into existing backcountry access technologies (such as beacon checkers) (Rubin & Camp, 2012). | • Reliable high-quality infrared counters are relatively expensive (approx. US$3000) (Rupf, 2015).<br>• Accuracy depends on air temperature, distance to the counter, type of clothing, and visitor volume. False counts can easily be triggered by wildlife, vegetation movement, and/or snow drift (Andersen et al., 2014 Campbell, 2006; Cessford & Burns, 2008; Rupf, 2015; Zweifel, Procter, Techel, Strapazzon, & Boutellier, 2016). In one study, there was an 80% error rate due to moving vegetation (Rettie, 2012).<br>• Infrared counters do not account for different user types or trends over time.<br>• Infrared counters require careful alignment during installation and alignment is highly sensitive to disturbance (Cessford & Burns, 2008).<br>• Infrared counters require frequent maintenance to download data and ensure that units are functioning properly. |

| | |
|---|---|
| • Long battery life reduces maintenance requirements (Rupf, 2015).<br>• Infrared counters are suitable for long-term monitoring objectives (Rupf & Stäuble, 2018).<br>• Infrared counters are minimally invasive toward the users and are easily integrated into the surroundings (Pettebone et al., 2010; Rupf, 2015; Xia & Arrowsmith, 2008). | • Adjustments must be made to account for snow accumulation (Rupf & Stäuble, 2018).<br>• Infrared counters require long calibration periods (Rettie, 2012).<br>• Due to their installation needs, infrared counters are hard to conceal. As a result, infrared counters can be subject to vandalism (Cessford & Burns, 2008; Watson et al., 2000).<br>• Infrared counters have high power requirements. Meeting this may be challenging as infrared counters require either separate batteries for the transmitter and receiver or a power cable that runs between the two units (Cessford & Burns, 2008; Kajala et al., 2007).<br>• Infrared counters are susceptible to weather conditions, and are affected by heavy rain or snow (Rupf, 2015; Rupf & Stäuble, 2018; Xia & Arrowsmith, 2008). |

### Tips for effective use

Our literature review further revealed the following tips for effective use of light barriers and infrared counters:

- Infrared counters and light barriers should be installed on a tree where there is large enough diameter to avoid most false counts attributed to vegetation movement (Peters & Dawson, 2004).
- Infrared counters and light barriers should be installed where users are likely travelling single file and cannot detour around the counter (Peters & Dawson,

2004; Watson et al., 2000). To reduce miscounts, it is advantageous for light barriers to be situated on descent routes, where users are less likely to stop or repeatedly pass through the light barrier (Zweifel et al., 2006).

- Infrared counters should be attached to a vertical surface so that the sensor and reflector are opposite each other at no more than 100 feet (30.48 metres) apart. The vertical surface should be large enough to prevent swaying (Watson et al., 2000).
- Due to high potential for miscounts, infrared counters can be paired with an additional monitoring tool (e.g., camera) to support valid counts.
- Selected sites can be based on popularity and avalanche hazard (Rettie, 2012).

### Considerations for winter use

- A unique advantage of infrared counters specific to its application as a winter monitoring method is that accuracy is expected to increase with decreasing air temperatures due to a great contrast between the ambient air temperature and the body temperature of a user (Andersen et al., 2014).
- Miscounts and overcounts can occur from periods of snowdrift. These counts can be filtered and are easily identified as periods of extremely high counts. Although this filtering is beneficial, it is not possible to accurately count people during these times because their signals are superposed by the snowdrift counts (Zweifel et al., 2006).
- There are numerous winter-specific challenges with infrared counters and light barriers, including reduced battery performance, malfunction due to moisture in the unit and cold temperatures, and burial of sensors by snow (Rettie, 2014).
- Rettie (2014) suggests that infrared counter malfunction during winter conditions can be avoided with use of lithium batteries, proper calibration of counters, and consistent maintenance (including repositioning scopes after heavy snowfalls).

- Light barriers should be installed on a descent route. This ensures that the barriers are not located where users may stop, potentially triggering multiple counts from one person (Zweifel et al., 2006).
- Due to seasonal changes in temperature, infrared counter sensitivity should be refined accordingly to reflect this change in temperature and the resulting change in user attire (Andersen, Gundersen, Wold, & Stange, 2012).

### Assessment and recommendations

- **Type of personal information collected**
    - **Identity**: No
    - **Individual characteristics**: None
    - **Additional insight into behaviour**: None
- **Type of spatial and temporal information collected**
    - **Spatial information**: Position
    - **Spatial extent**: Local
    - **Temporal resolution**: High
- **Reliability**: Moderate
- **Potential impacts on study subject**
    - **Potential for affecting behaviour**: Low
    - **Potential for privacy concerns**: None
- **Cost of monitoring method**
    - **Equipment cost:** Higher
    - **Implementation cost:** Lower
    - **Effort and complexity of analysis:** Lower
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of light barriers and infrared counters for addressing the human dimensions needs of avalanche safety programs:

- Standard method for continuous, long-term monitoring of user numbers on established routes.
- Counts need to be periodically validated by direct observation and/or video recording campaigns.
- To provide insightful information on user numbers, counters should be installed in both high- and low-use areas.
- Upscaling to entire recreational backcountry community possible if embedded in larger-scale monitoring framework.

### *Radio frequency identification systems (RFID)*

Radio frequency identification (RFID) is a wireless technology that uses radio-frequency electromagnetic fields to retrieve information from a RFID tag without explicitly coming in contact with the carrier. RFID tags contain unique identifiers that allow the receiver to identify the carrier and application-specific additional information stored on the tag. RFID technology is used widely for wireless identification and tracking. Examples include the tracking of goods, machine-readable travel documents, and electronic keys and fobs. In sports, RFID technology is widely used for timing races, and ski areas have adopted RFID tags to allow skiers to pass through ski lift access gates without having to take their passes out.

O'Connor, Zerger, and Itami (2005) used running race time equipment (ALGE-timing system) to monitor visitor movements along a small network of paths in Twelve Apostles National Park, Australia. Seven ALGE receivers recorded the precise location of 900 individuals wearing ankle transmitters over three days. While RFID technology has potential for tracking winter backcountry recreationists, we did not find any research study using the technology or evaluating its suitability.

#### General advantages and disadvantages

Based on our understanding of the RFID technology, we see the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
|---|---|
| • Allows the tracking and counting of individuals in a hidden way that does not have the potential to affect their behaviour. | • Tracked individuals need to have an RFID tag. |

#### Tips for effective use

We did not find any scientific studies that offered insight about the effective use of the RFID technology for tracking individuals in relevant outdoor recreation activities.

### Considerations for winter use

We are not aware of any special considerations required for the effective use of RFID technology in wintertime.

### Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: Yes
  - **Individual characteristics**: None
  - **Additional insight into behaviour**: None
- **Type of spatial and temporal information collected**
  - **Spatial information**: Position
  - **Spatial extent**: Local
  - **Temporal resolution**: High
- **Reliability**: Higher
- **Potential impacts on study subjects**
  - **Potential for affecting behaviour**: Low
  - **Potential for privacy concerns**: Consent
- **Cost of monitoring method**
  - **Equipment cost:** Higher
  - **Implementation cost:** Lower
  - **Effort and complexity of analysis:** Lower
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of radio frequency identification systems for addressing the human dimensions needs of avalanche safety programs:

- Only suitable for small-scale monitoring campaigns where users are already equipped with RFID tags (e.g., vicinity of a ski area to track out-of-bounds traffic at well-defined exit or re-entry points, snowmobile area access trails with trail fee system).

### ***Photography and video monitoring from fixed locations***

Photography and video monitoring from fixed locations provides photographic recordings that are later viewed and analysed for user data. While photography and video monitoring in the visual spectrum is most common, infrared cameras allow for monitoring during times when there is no visual light. The recordings are either collected directly from a camera in the field or transmitted to a base from an on-site location (Cessford & Burns, 2008). Photographs are either taken at regular intervals (i.e., time lapse photography) or they are triggered by a motion- or infrared-sensor (i.e., camera trap).

Examples of research studies that used primarily photography from fixed locations for counting users include Czachs & Brandenburg (2014) and Arnberger et al. (2005). Both studies used camera-recording technology to evaluate visitor management and regulation compliance at the wilderness-recreation interface.

Saly et al. (2016) and Saly, Hendrikx, Birkeland, Challender, and Johnson (2018) applied photography from fixed locations in winter-specific conditions with the purpose of understanding how off-piste users were involved in assisting a winter search and rescue effort that occurred on a ski slope known for complex avalanche danger. Researchers found that such camera recordings have the potential to improve our understanding of how to most effectively initiate search and rescue efforts in the case of avalanche involvements. Zweifel et al. (2006) who tested numerous monitoring approaches within a winter backcountry context, briefly mentioned photography as a potential method for capturing user frequency in off-piste terrain by photographing ski tracks.

Saurer et al. (2016) used infrared radiation thermography (i.e., thermal imagery) using a handheld *Helios 640 HD Thermal Imaging Bi-Ocular* to scan for the heat signature of backcountry skiers on slopes above the road in Little Cottonwood Canyon, Utah, prior to avalanche control missions. Based on a winter of testing, the authors conclude that thermal imaging offers a valuable tool for detecting backcountry skiers in control areas.

Campbell (2006) used photography from fixed locations to overcome the shortcomings of infrared sensors for visitor monitoring. This monitoring project was initiated by an impact monitoring study in response to increased use of trails and campsites in a national park and the associated ecological effects.

### General advantages and disadvantages

The reviewed literature on photography and video monitoring from fixed locations highlights the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
| --- | --- |
| • This method can be flexible and mobile to account for seasonal changes (Cessford & Burns, 2008).<br>• Camera recordings are reliable for capturing counts at heavily used intersections with mixed-user types (Arnberger et al., 2005).<br>• High detail of recordings allows for the identification of user groups, group sizes, temporal use patterns, and inter-activity comparisons (Arnberger & Eder, 2007; Arnberger et al., 2005; Arnberger & Hinterberger, 2003; Rupf & Stäuble, 2018).<br>• Camera recordings provide highly detailed data (Xia & Arrowsmith, 2008).<br>• Cameras only require a short calibration phase (Muhar et al., 2002).<br>• Cameras can operate in time-lapse for long-term monitoring, permanently for short-time observations, or be triggered by a counter or motion detector | • Equipment is vulnerable to damage and vandalism (Rupf & Stäuble, 2018).<br>• Repairs can be costly (Cessford & Burns, 2008).<br>• Power requirements restrict locations for installation and limit this method as an option for long-term monitoring at unattended sites (Arnberger et al., 2005; Cessford & Burns, 2008; Cessford & Muhar, 2003; Janowsky & Becker, 2003).<br>• Limited reliability in low visibility conditions or at night (Wahlen, Meier, Wyssen, & Arnold, 2018).<br>• Determining an appropriate location for installation is challenging and time-consuming (Campbell, 2006).<br>• Devices set to take high-resolution images/video require more frequent service.<br>• Accuracy is challenged when recording fast-moving activities (Arnberger et al., 2005). |

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| (Arnberger et al., 2005; Cessford & Burns, 2008).<br>• Digital cameras in weatherproof housing are relatively low cost and have low maintenance requirements (Saly et al., 2016).<br>• Camera recordings require lower costs than methods of similar accuracy such as on-site observers (Cessford & Muhar, 2003). | • Accuracy of counts may be challenged if users are passing in groups.<br>• Quality of count data highly reliant on analysts' accuracy (Arnberger et al., 2005).<br>• Manual interpretation of camera recordings is time-consuming and costly (Kajala et al., 2007; Rettie, 2012; Rupf & Stäuble, 2018).<br>• Subject to privacy and ethical issues (Rupf & Stäuble, 2018).<br>• Can affect the behaviour of study subjects if equipment is noticed (Rupf & Stäuble, 2018).<br>• The resolution settings (to observe distinguishing user characteristics) is limited by the necessity of maintaining user privacy (Arnberger & Hinterberger, 2003). |

### Tips for effective use

Our literature review further revealed the following tips for effective use of photography and video monitoring from fixed locations:

- Recording intervals of the camera between 10 and 20 seconds optimize monitoring accuracy for fast-moving activities (Czachs & Brandenburg, 2014).
- To avoid damage and vandalism, cameras can be hidden in nesting boxes. Furthermore, cables should be concealed and recording units should be placed in buildings inaccessible to park visitors (Arnberger et al., 2005).
- Time-lapse video recorders with lower power requirements decrease maintenance frequency (Muhar et al., 2002).

- To maintain user privacy, camera resolution should be set such that visitors should not be recognizable.
- Campbell (2006) set cameras to the lowest resolution possible to minimize maintenance requirements, speed up the refresh rate of the cameras on standby, and maintain user privacy.

### Considerations for winter use

- Quality of data gained from recordings is highly dependent on weather and lighting conditions, which are often uncertain and variable during the winter season (Czachs & Brandenburg, 2014).
- Fogging and freezing of the camera lenses and/or housing is possible and can cause loss of data.
- Cameras should be located to capture up-track movement to avoid the challenge of capturing fast moving activities such as skiing and snowboarding.

### Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: Yes
  - **Individual characteristics**: Some
  - **Additional insight into behaviour**: Some (photo) – Detailed (video)
- **Type of spatial and temporal information collected**
  - **Spatial information**: Position - Movement
  - **Spatial extent**: Local
  - **Temporal resolution**: High
- **Reliability**: Moderate
- **Potential impacts on study subjects**
  - **Potential for affecting behaviour**: Low
  - **Potential for privacy concerns**: High
- **Cost of monitoring method**
  - **Equipment cost:** Moderate (photo.) – Higher (video)

  - **Implementation cost:** Moderate
  - **Effort and complexity of analysis:** Higher
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of photography and video monitoring for addressing the human dimensions needs of avalanche safety programs:

- Effective for continuously counting users within direct line of sight in small-scale areas (i.e., slope-scale, small drainage) without well-defined routes (e.g., out-of-bounds route adjacent to ski areas, slopes close of backcountry hut).
- Less suited for continuous monitoring than infrared counters due to higher maintenance requirements.
- Useful for ground-truthing infrared counters.
- Can complement counts from infrared counters by offering valuable additional insight on user characteristics.
- Can offer some insight on risk management practices and group dynamics.
- Analysis of observations can be challenging and time consuming.

### *Radar detection from fixed locations*

Building on the fast-developing remote sensing technology for avalanche activity, new approaches for monitoring people have emerged. An example of such a new technology is the detection and monitoring of backcountry recreationists using radar technology developed by Geopraevent (Saurer et al., 2016). The advantage of radar over camera-based monitoring systems is that radar works reliably day and night, as well as in bad weather conditions (e.g., fog, snowfall, rain). The area that can be covered by a system such as Geopraevent is of the order of 1 $km^2$, but it is possible to achieve larger coverage by combining multiple radar systems (see https://www.geopraevent.ch/technologies/radar-people-detection/?lang=en). While the system was initially developed to monitor people in avalanche control areas (Saurer et al., 2016), it seems well suited for other small-scale monitoring applications, even in remote locations. However, these advantages require that the user is in a clear line of sight and, thus, can be limited.

#### General advantages and disadvantages

The reviewed literature on radar detection from fixed locations highlights the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
|---|---|
| • Radar detection works during night and in bad weather conditions (Saurer et al., 2016). | • Relatively new technology.<br>• Requires clear line of sight between the equipment and persons of interest. |

#### Tips for effective use

Our literature review further revealed the following tips for effective use of radar detection from fixed locations:

- Combining radar with conventional and infrared cameras can overcome some of the detection challenges (Saurer et al., 2016).

### Considerations for winter use

- There are no concerns regarding winter use.

### Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: No
  - **Individual characteristics**: None
  - **Additional insight into behaviour**: None
- **Type of spatial and temporal information collected**
  - **Spatial information**: Position, movement
  - **Spatial extent**: Local
  - **Temporal resolution**: High
- **Reliability**: Higher
- **Potential impacts on study subjects**
  - **Potential for affecting behaviour**: Low
  - **Potential for privacy concerns**: Low
- **Cost of monitoring method**
  - **Equipment cost:** Higher
  - **Implementation cost:** Moderate
  - **Effort and complexity of analysis:** Higher
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of radar detection for addressing the human dimensions needs of avalanche safety programs:

- The combination of radar, conventional, and infrared cameras can offer a reliable system for monitoring backcountry use in relatively small areas (approx. 1 $km^2$).
- Cost of equipment prohibits the use of the technology for large-scale monitoring campaigns.

### *Aerial photography*

Aerial photography uses an aerial platform (fixed-wing aircrafts, drones, or tethered balloons) to obtain photographs of intermediate- to large-scale areas (Watson et al., 2008). Often, the method is repeatedly used to produce photographs at regular intervals for longitudinal studies (Watson et al., 2008). These photographs provide quantifiable densities of use when analysed with digitized layering (Harris, Nielson, Rinaldi, & Lohuis, 2013).

Watson et al. (2008) describe the use of aerial photography for winter user monitoring to identify areas accessed by recreational users. These descriptions helped indicate potential use areas in other locations and guide ground photoreconnaissance of the identified potential areas (Watson et al., 2008). Harris et al. (2013) also used aerial photography in their study on the impacts of winter recreation on wildlife. In this study, aerial photographs of a snowmobile recreation area were taken during times with peak snowmobile activity and optimal lighting conditions. Rupf and Stäuble (2018) evaluate the use of oblique aerial photography for monitoring winter backcountry use in a wildlife protection area in Switzerland.

Another approach in aerial photography is the use of remotely piloted aircraft (RPA), otherwise known as drones. Technologies such as drones are increasingly being used in the field of ecology to both improve data collection processes as well as to capture novel data (Hodgson et al., 2018). The Threatened Species Recovery Hub (Beniston, 1997) has used drones for research in biodiversity monitoring. Their research found that new technologies such as drones have the potential to provide accurate data by monitoring study subjects from a distance without affecting their behaviour and at the same time reduce costs (Beniston, 1997). Hodgson et al. (2018) describe the use of drones for conducting transect counts, nesting locations, and detailed physical attributes of certain animal species.

#### General advantages and disadvantages

The reviewed literature on aerial photography highlights the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
|---|---|
| • Aerial photographs are very useful in covering large areas (Rupf & Stäuble, 2018; Watson et al., 2008).<br>• Images are in high-resolution (Watson et al., 2008).<br>• Images reveal both number and distribution of users (Cessford & Burns, 2008).<br>• Aerial photographs can be repeated regularly and consistently (Cessford & Burns, 2008; Watson et al., 2008).<br>• Aerial photography can be applied for other natural resource purposes, such as wildlife monitoring or for industry purposes, such as logging (Cessford & Muhar, 2003).<br>• No concerns about affecting behaviour of study subjects (Rupf & Stäuble, 2018).<br>• Drones can carry remote sensing instruments. They can obtain data at a finer spatial and temporal resolution than instruments mounted to aircraft (Hodgson et al., 2018).<br>• Counting of observed individuals using drone imagery can be highly accurate at the 30-to-60 m resolution (Hodgson et al., 2018).<br>• Drone-derived data can be more accurate and precise than traditional data collection methods, such as ground counting methods, enabling an increase in statistical | • The accuracy of aerial photography is dependent on factors such as snow conditions, weather conditions, and daylight (Harris et al., 2013; Rupf & Stäuble, 2018).<br>• Permits may be required for flights in protected or park lands resulting in additional costs and/or time.<br>• If used to determine number of tracks, accuracy is dependent on photographs taken after last snowfall or before windblown snow covers tracks (Rupf & Stäuble, 2018).<br>• It is difficult to ensure temporal continuity while maintaining cost effectiveness (Zweifel et al., 2006).<br>• Analysis is time-consuming and can be costly in personnel hours (Rupf & Stäuble, 2018).<br>• High cost (Cessford & Burns, 2008; Cessford & Muhar, 2003; Watson et al., 2000).<br>• Images only provide single snapshots in time (Cessford & Burns, 2008; Cessford & Muhar, 2003).<br>• Low altitude flights can be disruptive to wildlife in natural areas (Watson et al., 2000).<br>• High visitor burden due to noise (Watson et al., 2000). |

| | |
|---|---|
| power to detect population trends (Hodgson et al., 2018). | |

## Tips for effective use

Our literature review further revealed the following tips for effective use of aerial photography:

- If remote sensing is employed, aerial photographs have better resolution than satellite imagery and allow more accurate counts of ski tracks (Zweifel et al., 2006).
- An estimated maximum of 1,000-foot (304.8-metre) altitude flights is required for adequate imagery (Watson et al., 2000).
- Aerial photographs should be taken at a time of year when lighting conditions are optimized. Harris et al. (2013) indicated that March would provide lighting conditions that minimized shadows that would challenge photography interpretation.
- Rupf and Stäuble (2018) suggest that costs of this method can be reduced with the use of oblique photographs (photographs taken at an angle).
- Because manual counts of aerial imagery may be required, a systematic counting method should be employed with the use of scientific image processing computer programs, such as ImageJ (Hodgson et al., 2018).

## Considerations for winter use

- Aerial photography campaigns require fair weather conditions, which can be limited or unpredictable in winter months (Cessford & Burns, 2008).

## Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: No
  - **Individual characteristics**: None
  - **Additional insight into behaviour**: None

- **Type of spatial and temporal information collected**
  - **Spatial information**: Position
  - **Spatial extent**: Regional
  - **Temporal resolution**: Medium
- **Reliability**: Moderate
- **Potential impacts on study subject**
  - **Potential for affecting behaviour**: Low
  - **Potential for privacy concerns**: Low
- **Cost of monitoring method**
  - **Equipment cost:** Higher
  - **Implementation cost:** Higher
  - **Effort and complexity of analysis:** Higher
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of aerial photography for addressing the human dimensions needs of avalanche safety programs:

- Can provide valuable snapshot perspective on user numbers and spatial distribution of use at intermediate spatial scales (larger drainages).
- Only suitable for monitoring in open areas under good weather conditions.
- Not suitable for continuous, long-term observations.
- Potential to negatively affect the recreational experience of users due to low-flying altitude requirement.
- Not suitable in protected areas where wildlife might be affected.
- Analysis of observations can be challenging and time consuming.

### *Satellite imagery*

Satellite imagery refers to digitally transmitted images taken by satellites orbiting the Earth (Watson et al., 2008). This imagery shows the presence and distribution of users' tracks at different times without relying on direct observations (Cessford & Burns, 2008; Watson et al., 2008).

An example of a study using satellite imagery for winter visitor monitoring is Watson et al. (2008), who used the approach to study the impact of snowmobiling on wildlife populations, threatened and endangered species, and other resources affected when backcountry users trespass restricted and protected areas. The purpose of this research was to determine recreation activity over large areas using existing technologies.

The use of satellite imagery for detecting and mapping avalanche activity is currently an active area of research (eg., Eckerstorfer, Bühler, Frauenfelder, & Malnes, 2016). Developments in this area might open new opportunities for monitoring backcountry use remotely with satellite imagery in the future.

#### General advantages and disadvantages

The reviewed literature on satellite imagery highlights the following advantages and disadvantages of this method.

| Advantages | Disadvantages |
|---|---|
| • Satellite imagery can cover large areas (Cessford & Burns, 2008; Cessford & Muhar, 2003; Watson et al., 2008).<br>• Images reveal both number and distribution of users (Cessford & Burns, 2008).<br>• Satellite imagery can easily be applied for other natural resource purposes, such as wildlife monitoring or for industry | • High cost of equipment use (Cessford & Burns, 2008; Cessford & Muhar, 2003; Eckerstorfer et al., 2016; Watson et al., 2000; Zweifel et al., 2006).<br>• Ensuring temporal continuity and spatial resolution is costly (Eckerstorfer et al., 2016; Zweifel et al., 2006).<br>• Images only provide single snapshots in time (Cessford & Burns, 2008; Cessford & Muhar, 2003). It is thus difficult to ensure |

| | |
|---|---|
| purposes, such as logging (Cessford & Muhar, 2003).<br>• Satellite imagery can be repeated regularly and consistently (Cessford & Burns, 2008; Watson et al., 2008).<br>• Generally safe data acquisition (Eckerstorfer et al., 2016). | temporal continuity due to method requirements.<br>• Images are lower resolution than, for example, aerial photography (Watson et al., 2008).<br>• Certain satellite images with 1 m resolution can show individual tracks, however this is dependent on optimal visibility conditions (Zweifel et al., 2006).<br>• Challenging trade-off between high spatial resolution and small widths and/or small ranges (Eckerstorfer et al., 2016). |

## Tips for effective use

Our literature review further revealed the following tips for effective use of satellite imagery:

- Satellite imagery as a monitoring method is most useful in locations with low tree density (Cessford & Burns, 2008). As a result, many recreational areas that are forested would not yield representative counts.
- Zweifel et al. (2006) state that they were able to identify ski tracks on satellite images with a spatial resolution of 1 m under ideal conditions (i.e., clear spring day after fresh snowfall).

## Considerations for winter use

We did not find any references discussing special considerations regarding the use of satellite imagery for monitoring backcountry use in winter.

## Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: No
  - **Individual characteristics**: None

  - **Additional insight into behaviour**: None
- **Type of spatial and temporal information collected**
  - **Spatial information**: Position
  - **Spatial extent**: Regional
  - **Temporal resolution**: Medium
- **Reliability**: Lower
- **Potential impacts on study subjects**
  - **Potential for affecting behaviour**: n/a
  - **Potential for privacy concerns**: None
- **Cost of monitoring method**
  - **Equipment cost:** n/a
  - **Implementation cost:** Higher
  - **Effort and complexity of analysis:** Moderate
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of satellite imagery for addressing the human dimensions needs of avalanche safety programs:

- Not recommended for backcountry use monitoring due to the high cost, limit control over monitoring interval, and insufficient resolution for identifying individual backcountry users.
- Might be suitable for providing single snapshots of backcountry use patterns (e.g., patterns of snowmobile tracks).
- Recent developments in remote sensing of avalanche activity using satellite imagery might create new opportunities for remote backcountry use monitoring.

## Mobile tracking systems

In the last decade, there have been tremendous advances in the development of mobile technology that can be used for tracking. In the academic literature on tourist movement tracking, mobile tracking systems have been divided into satellite-based and land-based systems (Shoval & Isaacson, 2010).

The **satellite-based** systems relate to Global Navigation Satellite Systems (GNSS)[3], which consist of a series of satellites that broadcast signals picked up by mobile receivers (i.e., GNSS trackers) (Hallo et al., 2012; Shoval & Isaacson, 2007). This form of tracking has become well established and produces GNSS tracks that can offer insight on high-resolution information on route characteristics as well as track densities in a given area (Taczanowska, Bielański, Gonzalez, Garcia-Masso, & Toca-Herrera, 2017). Over the last decade, specialized GNSS devices and smartphones with GNSS capabilities have become common navigation aids among backcountry travellers. Since these devices are becoming progressively smaller and increasingly sophisticated, they have tremendous potential to be useful and applicable to both tourists and the industries monitoring and managing recreational areas (Shoval & Isaacson, 2007). In this methodological overview, we distinguish between **targeted GNSS tracking**, where recreationists are specifically approached for participating in a research project, and **GNSS web-sharing services**, where the retrieved GNSS data were collected for other purposes.

**Land-based tracking systems** consist of transmitters and local networks of antennas. The tracking is based on the principle that electromagnetic signals travel at a known speed along a known path. Zhao (1997) describes three different technologies for identifying the location of the transmitter: a) time difference of arrival, b) angle of arrival, and c) cell sector identification. While this technology has long been used in the natural science for animal tracking, the proliferation of mobile phone use has opened unprecedented opportunities for the technology to contribute to our understanding of

[3] Global Navigation Satellite System (GNSS) is a generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage. Examples of GNSS include GPS, GLONASS, BeiDou, Galileo, and others.

the density and movement of people in a wide variety of contexts (Deville et al., 2014). While **mobile phone tracking** is the most common type of land-based tracking in tourism research, there are other technologies as well (e.g., Bluetooth, Wi-Fi). Interested readers are referred to Shoval and Isaacson (2010) for a comprehensive overview.

### *Targeted GNSS tracking*

Targeted GNSS tracking refers to studies where GNSS tracks are specifically collected for the research question at hand. Study participants are explicitly recruited to either upload GNSS tracks that they recorded with a personal device or to record GNSS tracks using tracking units provided by the research team. The GNSS tracks can be shared with the research team either after the monitored trips have been completed (i.e., upload of complete tracks) or tracks can be transmitted continuously if connectivity is available (e.g., via cellphone network, satellite connection).

The use of GNSS tracking is now widespread in outdoor recreation research. Examples include Beeco, Hallo, and Brownlee (2014), who combined GNSS visitor tracking with recreation sustainability maps to inform visitor management decisions in a small public forest, and Rupf (2015), who used GNSS tracking to better understand the behaviour and preferences of hikers and mountain bikers in Val Müstair in southeastern Switzerland.

Examples of GNSS tracking studies in winter backcountry recreation include, Olson et al. (2017), who used this approach to better understand the terrain preferences of snowmobile riders, backcountry skiers, and snowmobile assisted backcountry skiers in two study areas in Colorado, USA. The objective of the study was to provide the necessary information for designing recreation policies that would maintain recreation opportunities while reducing conflict and ecological impact to sensitive wildlife. Rettie (2012) conducted a study that used GNSS units to capture information on the levels and types of visitor usage of trails in a national park. The use of GNSS units was part of a multi-year campaign to collect quantitative observations on visitor usage in Canada's mountain national parks (Rettie, 2012). Similarly, Bielański, Adamski, and Witkowski (2014) used GNSS tracking to recognize spatiotemporal distribution of ski tourers within a Polish national park. The resulting digital tracks were compiled to create a density map, indicating both the use values and the overall popularity of different areas within the park. Many more studies in outdoor recreation research have used GNSS tracking (e.g., D'Antonio et al., 2010).

GNSS tracking also been used in various avalanche safety studies. Hendrikx, Johnson, and Southworth (2013) used the mobile app SkiTracks to collect GNSS tracks from backcountry skiers. The purpose of the study was to better describe and quantify decision-making dynamics and the demographic of backcountry users. The research group of Jordy Hendrikx at Montana State University in Bozeman has also tracked snowmobile riders using the same approach (Hendrikx & Johnson, 2016), and professional heli-ski guides with standard handheld GNSS units (Hendrikx, Johnson, & Shelly, 2016). The White Heat Tracks project, a collaboration between researchers at UiT-The Arctic University of Norway in Tromsø, Montana State University in Bozeman, USA, and Umeå University in Umeå, Sweden, is the current continuation of this project. See https://whiteheatproject.com for more details.

Another example of a GNSS tracking study focused on public avalanche safety is (Martensson, Palmgren, Gunnholt, & Wikberg, 2014). In this study, participants used a mobile app on their smartphones that included a GNSS-positioned map that showed the local terrain classified according to the avalanche terrain exposure scale. Users' positions were logged on the mobile app every 60 m and the resulting tracks were analysed to examine how skier behaviour might be affected by the use of smartphones as decision tools.

The research group of Pascal Haegeli at Simon Fraser University in Canada aims to better understand the decision-making process of professional heli-ski guides in avalanche terrain. To-date, this research group has collected GNSS tracks from more than 40,000 ski runs from collaborating operations under a wide variety of conditions (http://www.avalancheresearch.ca/researchareas/terrain-management/). Numerous analyses have been conducted (Haegeli & Atkins, 2016; Sharp, Haegeli, & Welch, 2018; Thumlert & Haegeli, 2018) and are currently underway to better understand the risk involved in mechanized skiing, provide insight on the decision-making process, and develop meaningful decision aids.

## General advantages and disadvantages

The reviewed literature on visitor counts through targeted GNSS tracking highlights the following advantages and disadvantages of the method.

| **Advantages** | **Disadvantages** |
|---|---|
| • GNSS is a global system and is thus available worldwide and at all times (Shoval & Isaacson, 2006).<br>• Current technological advances allow collecting larger samples of spatiotemporal data (Shoval & Isaacson, 2006).<br>• Useful for tracking users spread over large areas (Bielański et al., 2014).<br>• Provides highly precise data (Rupf, 2015; Xia & Arrowsmith, 2008).<br>• High-resolution spatiotemporal data of GNSS monitoring can enhance other monitoring methods (Hendrikx et al., 2013; Taczanowska et al., 2012).<br>• Data is easy to import into a GIS application for further analysis and provides important information regarding management of outdoor activities (Mendes, 2014; Watson et al., 2008).<br>• GNSS tracks provide unbiased data (Hendrikx et al., 2013).<br>• The use of mobile positioning from GNSS for visitor monitoring makes it possible to acquire geographically accurate data over | • GNSS coverage can be limited as it requires a direct line of sight between the receiver's antenna and the satellite (Shoval & Isaacson, 2006). Hence, tracks may be less reliable in areas with dense forests (Shoval & Isaacson, 2006) or in canyons.<br>• High power requirements, making long-term tracking difficult (Rupf, 2015; Shoval & Isaacson, 2006).<br>• If GNSS units are not supplied by the managing agency, data acquisition is dependent on the use of mobile phones, which creates a disproportionate set of data affected by access rates or mobile device coverage (Ahas, 2014).<br>• High cost with high potential for device damage or loss (Wolf et al., 2012; Xia & Arrowsmith, 2008).<br>• High costs limit sample size (Rupf, 2015; Xia & Arrowsmith, 2008).<br>• High potential for affecting behaviour of study subjects (Taczanowska et al., 2017; Xia & Arrowsmith, 2008).<br>• Access is highly influenced by privacy and data protection regulations, as well as the |

| | |
|---|---|
| a long period of time with limited user interference (Ahas, 2014).<br>• GNSS data can be linked to physiological, demographic, psychographic, and behavioural characteristics of recreationists to fully describe trends in use and other important recreational management components (D'Antonio et al., 2010; Shoval & Isaacson, 2006; Skove-Petersen, Rupf, Kochli, & Snizek, 2012; Taczanowska et al., 2012).<br>• GNSS technology is already widely used across industry and public safety organizations as well as among recreationists (Hendrikx et al., 2013).<br>• GNSS tracking technology is mature, and effective application procedures and analysis methods are well established (Xia & Arrowsmith, 2008).<br>• GNSS tracks have to the potential to provide both use values and density values (D'Antonio et al., 2010). | attitude of the public toward this process (Ahas, 2014). |

## Tips for effective use

Our literature review further revealed the following tips for effective use of targeted GNSS tracking:

- Bielański et al. (2014) distributed GNSS devices at four park entry points. These entry points remained flexible and mobile to adapt to changing seasonal snowpack levels and the associated backcountry access/route change (Bielański et al., 2014).

- Wolf et al. (2010) suggests the following when using GNSS tracking devices: choose a GNSS device where utilities are not displayed (to disguise their utility in regards to potential theft); secure the device from tampering; equip the user with the GNSS device in such a way that maximizes the satellite reception; provide an easy, self-regulated drop-off location for GNSS device return; provide a participation statement, indicating the privacy of the data (to address changes in behaviour of the user due to being tracked).
- While using the GNSS capabilities of smartphones is convenient and cheaper, there is extremely limited control over the tracking quality and frequency.

### Considerations for winter use

- Lower temperatures during winter reduce battery life of tracking device.
- There is the potential for these devices to interfere with avalanche transceivers (Meister & Dammert, 2014).

### Assessment and recommendations

- **Type of personal information collected**
    - **Identity**: Yes
    - **Individual characteristics**: Detailed
    - **Additional insight into behaviour**: Some
- **Type of spatial and temporal information collected**
    - **Spatial information**: Track
    - **Spatial extent**: Local
    - **Temporal resolution**: High
- **Reliability**: Higher
- **Potential impacts on study subjects**
    - **Potential for affecting behaviour**: High
    - **Potential for privacy concerns**: Consent
- **Cost of monitoring method**
    - **Equipment cost:** Higher
    - **Implementation cost:** Moderate

  - **Effort and complexity of analysis:** Moderate
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of targeted GNSS tracking for addressing the human dimensions needs of avalanche safety programs:

- Not directly suitable for comprehensive backcountry monitoring and obtaining backcountry user numbers.
- Most effective method for obtaining high-resolution data on revealed terrain preferences.
- Most suitable for conducting research on decision-making and risk management practices with committed user group.
- Most insightful when paired with complementary data from counting stations, surveys, or interviews.

### *GNSS web-sharing services*

The popularity of web services that allow recreationists to store and share personal GNSS tracks and fitness activities has increased tremendously over the last decade. Examples of these services include **Strava**, ENDOMONDO, **GarminConnect**™, the **MapMyFitness** suite by Under Armour®, **wikiloc.com** and **GPSies.com**, but there are many more. After uploading their personal GNSS tracks, users can use the functionalities of these services to assess their performance, keep track of their activities, and share them with friends. Most of these services offer basic accounts free of charge, but the use of more advanced features requires paying a subscription fee. However, regardless of whether the services are free, charge freemiums (i.e., basic service is free of charge but additional features require payment), or a full paid service, they attract large communities of engaged users worldwide.

There is a growing number of scientific studies in outdoor recreation research that use information from these types of services to better understand magnitudes of visitations and visitor movement (Wolf & Mendes, 2018). In the academic research, this type of data loosely falls under the broader themes of *Crowdsourcing* and *Volunteer geographic information* (VGI), which Goodchild (2007) defines as a type of data collection where members of the general public create georeferenced facts about the Earth's surface and contribute them to websites where they are synthesized into databases. Another term that is commonly used in connection to this type of data in the academic literature is *Public Participation Geographic Information Systems* or *Participatory GIS* (PPGIS), which generally refers to public consultation initiatives that are facilitated by geographic information systems. Due to the sheer volume of data collected, research in this area also relates to what is called *Big data research*.

The way the available data can be accessed for research purposes differs among these services. **Strava**, likely the most popular GNSS web-sharing service, was founded in 2009 and is based in the San Francisco area. According to Good (2017), Strava gains approximately a million new members every 45 days and approximately 8 million activities are uploaded each week. Strava Labs offers a few interactive tools to explore personal tracks and an overview of the complete available dataset (https://labs.strava.com/projects/). The most relevant tool for backcountry use monitoring is **Strava Global Heatmap** (https://www.strava.com/heatmap), which is a freely accessible visualization tool that shows two years of anonymized and aggregated tracking data from Strava members to highlight popular trails (Robb, 2017). The information currently shown in the tool was last updated in 2017. In 2014, Strava launched a for-fee data service called **Strava Metro** (https://metro.strava.com/), which aims to help city planners better understand the walking and bicycling traffic and evaluate the effects of infrastructure changes. In comparison to the Global Heatmap, Strava Metro can provide planners with more targeted and more detailed information about the tracked traffic at locations of interest. In November 2019, Strava launched the **Strava Metro for web** service (https://metro.strava.com/strava-metro-web/), which provides planners and researchers with more sophisticated functionality to explore numbers and locations of tracked activities. While it might be possible to get detailed use information including demographics for popular backcountry areas through this service, we were not able to confirm this directly with Strava. The cost for accessing the anonymized and aggregated tracks is around US$2,500 per year. While we found evidence of studies that used **individual tracks from Strava** (see Romanillos, Zaltz Austwick, Ettema, and De Kruijf (2016) for an overview of examples in cycling research), we could not find any detailed information on how to purchase GNSS tracks from Strava for research.

We found several studies examining the usefulness of the tools provided by Strava. Herrero (2016) provides an overview of Strava Heatmap, Strava Clusterer (does not seem to be available anymore), and Strava Metro. The report clearly highlights that these tools are unable to offer insight into total user numbers, but rather show differences in general popularity of trails among Strava users. Citing studies that examined the penetration of Strava among trail users, Herrero (2016) highlights that there is considerable variability in trail popularity with values ranging from 1 to 12%. These values were from 2014 and might be higher now. CDM Research (2018) conducted a study to validate the quality of Strava Metro's relative cycling density estimates (e.g., Route A is 50% busier than Route B) against data from automatic cycling counters. The results of this study show that while Strava Metro data seems to capture the seasonal variability and the day of the week distribution reasonably well, the time-of-day estimates were substantially biased toward earlier morning riders, and the identification of busier and quieter cycling paths did not correlate well with the results from the counters.

Other services, such as GPSies.com (https://www.gpsies.com/trackList.do), wikiloc.com (https://www.wikiloc.com/wikiloc/find.do), and MapMyFitness (https://www.mapmyfitness.com/us/), allow researchers to explicitly search for individual tracks and download them in a variety of formats. Examples of outdoor recreation studies examining GNSS tracks from these types of services include Campelo and Nogueira Mendes (2016) and Norman and Pickering (2017), but there are many more.

We did not find any scientific studies that used data from GNSS web-sharing services for monitoring winter-specific backcountry activities.

### General advantages and disadvantages

The reviewed literature on visitor counts through fitness activity GNSS web-sharing services highlights the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
| --- | --- |
| • Data can provide information on the number of people accessing areas, their spatial distribution and what type of activity they are undertaking (Herrero, 2016).<br>• Distinguishes between different user types (Schallinger & Rüede, 2018). | • Data doesn't show total trail use but rather the relative popularity of trails among app users (Herrero, 2016).<br>• Risk of high user disproportionality (largely male demographic), and skewed data due to special events such as races (Herrero, 2016). |

| | |
|---|---|
| • Services are highly popular among backcountry users who wish to record their movements.<br>• Cost-effective data acquisition (Rupf, 2015). | • Strava data is limited by low spatial granularity and coverage (Sun, Du, Wang, & Zhuang, 2017).<br>• Data acquisition is reliant on the cooperation of web-service provider. Access might change without notice.<br>• Access is also highly influenced by privacy and data protection regulations, as well as the attitude of the public toward this process (Ahas, 2014; Rupf, 2015).<br>• No control over battery life of device and therefore duration of tracking (for live tracking) (Rupf, 2015). |

## Tips for effective use

Our literature review further revealed the following tips for effective use of GNSS web-sharing services:

- Because information from these web-sharing services can only provide relative popularity of use and not actual use numbers, another source of data (such as a trail counter) would be required to gain information on total use.
- Data from these services might be effective for visitor monitoring if used in combination with other counting methods. Lower cost counting devices can be used to complement available records (Herrero, 2016).
- Since GNSS trackers rely on line-of-sight connection to satellites, the quality of the GNSS tracks highly depends on adequate reception. This means that tracks in terrain in high forest density may be of lower quality and that these areas might be underrepresented in aggregate data sets.

## Considerations for winter use

- Lower temperatures during winter reduce battery life of tracking device.

- There is the potential for these devices to interfere with avalanche transceivers.

### Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: Yes
  - **Individual characteristics**: Some
  - **Additional insight into behaviour**: Some
- **Type of spatial and temporal information collected**
  - **Spatial information**: Track – Relative popularity (aggregate data)
  - **Spatial extent**: National
  - **Temporal resolution**: High (Tracks) – Low (Aggregate data)
- **Reliability**: Moderate
- **Potential impacts on study subjects**
  - **Potential for affecting behaviour**: n/a
  - **Potential for privacy concerns**: Moderate
- **Cost of monitoring method**
  - **Equipment cost:** n/a
  - **Implementation cost:** Moderate
  - **Effort and complexity of analysis:** Moderate
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of GNSS web-sharing services for addressing the human dimensions needs of avalanche safety programs:

- Most suitable for obtaining large-scale overview of relative popularity of backcountry areas.
- Only reflects use patterns of very specific user groups. Services not equally popular across all backcountry activities and available tracks highly skewed toward a small number of highly committed contributors (i.e., participation inequality).

- To make meaningful extrapolations, more information is required regarding the use of GNSS web-sharing services within recreational backcountry community.
- Not suitable for obtaining absolute user numbers.
- Not suitable for long-term monitoring as data access and privacy policies of service providers continuously change without notice.

### *Mobile phone tracking*

Cellphone use is widespread across both developed and developing countries of the world. The latest statistics from the International Telecommunications Union indicate that the penetration of cellular telephone subscriptions in the developed world is now at 127.3 subscriptions per 100 inhabitants (International Telecommunications Union, 2018). For western countries with exposure to avalanche hazard, penetration rates range from 170% in Austria, to 140% in Italy, 133% in Switzerland, 125% in Sweden, 122% in the United States, 107% in Norway to 86% in Canada.

The location of a mobile phone can be determined through triangulation of radio signals between multiple network towers and the mobile phone. To locate the phone this way, the phone must emit at least the roaming signal but does not require an active call. Higher densities of mobile phone towers allow for higher triangulation accuracy. Shoval and Isaacson (2010) offer a comprehensive overview of the technology underlying cellphone tracking in the context of tourist tracking.

While Deville et al. (2014) outline the general benefits of using mobile phone data for population mapping, Shoval and Ahas (2016) offer an overview of the use of the technology in tourism research in the last decade. All of the studies cited in this overview paper used passive phone tracking except one and were conducted in Estonia by the research group of Rein Ahas. McKercher and Lau (2009) attempted to evaluate mobile phone tracking for conducting a study of tourist movements in Hong Kong. However, their trial failed, primarily due to a lack of cooperation from tourists who found the technology too invasive. Rupf and Stäuble (2018) provide preliminary insight about the use of mobile phone data for monitoring winter backcountry activities in a small area in Switzerland.

To our knowledge, Francisco et al. (2018) is the only study using mobile phone tracking for monitoring backcountry use in avalanche terrain. The study used call detail records (CDR) from the national telecom company in Andorra to examine terrain choices of backcountry users in the Sorteny Valley between February 1 and 20, 2018. The main objective of the study was to explore the relationship between the magnitude of backcountry activity in avalanche terrain of different severity and the danger rating published in the local avalanche bulletin. The authors conclude that CDR data offers a valuable approach for passively monitoring backcountry use without having to explicitly interact with users and rely on their cooperation. However, they state that the main technical limitation of this monitoring approach is the accuracy of geolocation, which they say is around 150 m in mountainous terrain in Andorra (Francisco et al., 2018).

The reliability of mobile phone tracking in avalanche terrain depends heavily on recreationists leaving their phone turned on. Backcountry travellers are generally encouraged to turn their cellphones to airplane mode to prevent interference with avalanche transceivers. Furthermore, they might turn their cellphones off to save battery power for emergency calls. A recent winter backcountry survey by Ortega, Wollgast, and Latosuo (2018) at Hatcher Pass, Alaska, revealed that that all of the 63 interviewed backcountry recreationists had a smartphone and that roughly half of the interviewees typically leave the phone turned on whereas the rest turn theirs to airplane mode.

While mobile phone tracking has tremendous potential for monitoring the location and movement of people, there are also serious privacy concerns (e.g., https://www.zeit.de/datenschutz/malte-spitz-data-retention). Depending on the privacy legislation of a country, mobile phone companies will only provide mobile phone tracking information in particular formats ranging from call records in Estonia (e.g., Ahas, Aasa, Roose, Mark, & Silm, 2008) and Andorra (e.g., Francisco et al., 2018) to anonymized and aggregated location data (number of mobile phone users within an area over a specific period of time) in Switzerland (Rupf & Stäuble, 2018).

### General advantages and disadvantages

The reviewed literature on mobile phone tracking highlights the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
|---|---|
| • Access to a large sample size (Rupf, 2015).<br>• Long observation period possible (Rupf, 2015; Rupf & Stäuble, 2018).<br>• Can provide detailed user-specific information (Rupf & Stäuble, 2018).<br>• Data is highly accurate (Shoval & Ahas, 2016).<br>• Has the ability to provide high spatial and temporal resolution data (depending on the density of cellphone networks and data access) (Xia & Arrowsmith, 2008; Ahas, 2014; Ahas, Aasa, Mark, Pae, & Kull, 2007)<br>• Cost-effective data acquisition and data units (Ahas et al., 2007; Rupf, 2015)<br>• Limited concerns about the monitoring method affecting the behaviour of study subjects (Xia & Arrowsmith, 2008).<br>• Ability to analyse space-time movement to further understand user distribution and behaviour (Ahas, 2014) and allows the collection of both subjective and objective data (Shoval & Ahas, 2016).<br>• Useful in less frequently visited areas where other methods would not be suitable (for example, questionnaires) (Ahas, 2014).<br>• There is widespread use of smartphones, which have tracking abilities and location transmitting (Shoval & Ahas, 2016). | • Observation limited to short-term due to device battery life (Rupf, 2015).<br>• Data precision relies on network coverage (Rupf, 2015).<br>• Data availability differs spatially (Rupf & Stäuble, 2018).<br>• Possible data protection issues (Rupf, 2015; Xia & Arrowsmith, 2008).<br>• Resolution of data depends on the density of cellphone network and data access.<br>• Barriers to use exist. For example, cost of data or call roaming abroad may discourage tourists from using their mobile phones during travels in foreign countries (Ahas, 2014). |

| | |
|---|---|
| • Reduced burden to users (Shoval & Ahas, 2016). | |

## Tips for effective use

Our literature review did not reveal any particular tips for effective use of mobile phone tracking.

## Considerations for winter use

- Colder temperatures reduce the battery life of mobile phones.
- In Canada and the United States, mobile phone coverage is often limited in backcountry areas.
- Mobile phones can interfere with avalanche safety equipment such as avalanche transceivers.
- Mobile phone users might turn their phone off while travelling in the backcountry to avoid interference with avalanche safety equipment and preserve battery power for emergency calls.

## Assessment and recommendations

- **Type of personal information collected**
    - **Identity**: Yes (individual) – No (aggregated)
    - **Individual characteristics**: None
    - **Additional insight into behaviour**: Some (individual) – None
- **Type of spatial and temporal information collected**
    - **Spatial information**: Track (individual) – Counts at position (aggregate)
    - **Spatial extent**: National
    - **Temporal resolution**: High
- **Reliability**: Moderate
- **Potential impacts on study subjects**
    - **Potential for affecting behaviour**: n/a
    - **Potential for privacy concerns**: High (individual) – Moderate (aggregate)

- **Cost of monitoring method**
    - **Equipment cost:** n/a
    - **Implementation cost:** Moderate
    - **Effort and complexity of analysis:** Moderate (individual) – Lower (aggregate)
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of mobile phone tracking for addressing the human dimensions needs of avalanche safety programs:

- Prolific use of mobile phones makes the approach highly attractive for large-scale and continuous monitoring of backcountry use without affecting the behaviour of recreationists.
- Not suitable in areas without reliable mobile phone coverage (e.g., many backcountry areas in Canada).
- Serious privacy concerns.
- Data access and privacy rules/legislation differ among service providers/countries and future changes in these rules have to be anticipated.

### Voluntary self-reporting

Voluntary self-reporting refers to monitoring methods that rely on public-domain platforms where members of the public voluntarily post information about their whereabouts and intentions for reasons other than participating in a research study. Our overview includes the following voluntary self-reporting platforms:

- Summit registries and hut guestbooks
- Self-registration boards
- Online backcountry community platforms
- General location-based social media platforms

### *Summit registries and hut guestbooks*

Summit registries can be found on many popular peaks and guestbooks are common in mountain huts. These types of voluntary registries are typically maintained by clubs or hut custodians and allow recreationists to leave an 'I was here' message. If non-compliance rates could be determined, this voluntary registration method could have potential to provide population-representative information regarding users at extremely low cost (Hollenhorst et al., 1992). However, the highly informal nature of summit registries and hut guestbooks makes this very unlikely.

We did not find any studies that explicitly used this data source for visitor monitoring.

#### General advantages and disadvantages

The reviewed literature on summit registries and hut guestbooks highlights the following advantages and disadvantages.

| Advantages | Disadvantages |
| --- | --- |
| • Summit registries and hut guestbooks are flexible, low cost, and simple (Cessford & Burns, 2008; Rupf & Stäuble, 2018).<br>• Hut guestbooks and registries have a long history in many regions and are thus useful for long analysis periods and for monitoring changes over time (Cessford & Burns, 2008; Rupf & Stäuble, 2018).<br>• No concerns about affecting behaviour of study subjects (Rupf & Stäuble, 2018). | • Lack of consistent response levels (Hollenhorst et al., 1992; Zweifel et al., 2006). This inconsistency can make it difficult to compile, organize, and standardize data for further interpretation.<br>• Use values are unreliable as participation rates are unknown (Rupf & Stäuble, 2018).<br>• Response rates vary according to site location, presentation, maintenance, advocacy, and cultural tradition (Cessford & Burns, 2008).<br>• The culture of summit registries might only be common among backcountry skiers and ski mountaineers. |

| | |
|---|---|
| | • In general, the higher the number of visitors, the lower the percentage of registration (Muhar et al., 2002).<br>• A summit registry or hut guestbook might be full for a long time before it is replaced. |

## Tips for effective use

Our literature review further revealed the following tips for effective use of summit registries and hut guestbooks:

- To account for non-compliance, visitor registries could be employed in conjunction with mechanical counters (Hollenhorst et al., 1992). Registration rates are accurately and effectively observed with the use of a camera triggered by a photoelectric counter or human observers stationed at high-use entrances (Watson et al., 2000).
- Summit registries and hut guestbooks can be easily integrated into existing huts or summit locations.

## Considerations for winter use

- Summit registries might become even more challenging for monitoring winter backcountry use as if snow covers them up.

## Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: Yes
  - **Individual characteristics**: None
  - **Additional insight into behaviour**: None
- **Type of spatial and temporal information collected**
  - **Spatial information**: Position
  - **Spatial extent**: Local

  - **Temporal resolution**: Medium
- **Reliability**: Lower
- **Potential impacts on study subjects**
  - **Potential for affecting behaviour**: n/a
  - **Potential for privacy concerns**: Low
- **Cost of monitoring method**
  - **Equipment cost:** n/a
  - **Implementation cost:** Lower
  - **Effort of analysis:** Lower
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of summit registries and hut guestbooks for addressing the human dimensions needs of avalanche safety programs:

- Not suitable for monitoring winter backcountry user numbers due to the voluntary nature and low reliability.

### ***Self-registration boards***

Self-registration boards are commonly placed at trailheads (Watson et al., 2000) to allow recreationists to 'check-in' at the beginning of their trip and 'check-out' after their return. The primary motivation for self-registering at these trailhead boards is safety. In case of an emergency, the information given could provide Search and Rescue with valuable information for the rescue mission. Self-registration boards can be staffed or unstaffed.

If non-registration rates can be determined, this voluntary registration method could have potential to provide population-representative information regarding users at extremely low cost (Hollenhorst et al., 1992). Leatherberry and Lime (1981) explicitly evaluated registration compliance for unstaffed registration boards at a small U.S. Forest Service experimental forest in the upper Michigan Peninsula. Their results suggest that time of day (mid-day periods yielding higher registration compliance), length of stay (longer stays yielding higher registration compliance), time of year (summer having higher registration rates than spring and fall), size of group (larger groups yielding higher registration compliance), and recreation pursuit (hunters registering less frequent than hikers) influence user compliance rates of self-issued voluntary and self-issued mandatory registration approaches.

An example of an avalanche safety related visitor-monitoring study that used self-registration boards is Zweifel et al. (2006). In their study, voluntary self-registration boards with survey sheets were installed at two popular backcountry ski access points and visitors recorded the date, their route, and their ascent style. Information was collected from these registration boards for three winters to examine the suitability of voluntary self-registration boards for counting users accessing backcountry areas. This dataset was later used again by Zweifel et al. (2016) to examine the effect of group size on backcountry avalanche risk.

#### General advantages and disadvantages

The reviewed literature on self-registration boards highlights the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
| --- | --- |
| • Inexpensive implementation (Rupf, 2015).<br>• Suitable for long-term monitoring campaigns (Zweifel et al., 2016).<br>• Visitor registries can be easily integrated into the visitor experience as part of daily safety checks or trailhead billboards (Cessford & Burns, 2008). | • Precision of data relies on visitor understanding (for example, of route) (Rupf, 2015).<br>• Response rates vary according to site location, presentation, maintenance, advocacy, and cultural tradition (Cessford & Burns, 2008).<br>• Lack of consistent response levels (Hollenhorst et al., 1992; Zweifel et al., 2006). This inconsistency can make it difficult to compile, organize, and standardize data for further interpretation.<br>• Significant effort may be required to determine non-compliance rates.<br>• Substantial resources and efforts may be required for installation, data collection, and any required maintenance.<br>• No information on the distribution of the visitors within the area is provided.<br>• The success of this technique is unique to different cultures. Experiences and results cannot be compared across countries and regions. |

## Tips for effective use

Our literature review further revealed the following tips for effective use of self-registration boards:

- It must be obvious to the user (e.g., through a sign) that it is worth the user's time to register (Petersen, 1985).
- Registration cards should be designed in such a way that guarantees the most important user information is collected first. Since many visitors only fill out the first few lines on a registration card, it is crucial that the most important information is asked first (Petersen, 1985).
- Research has shown that sign design, trail register maintenance, card design, and the location of the trail register are chief influences on user compliance. The two most important of these influences are sign design and location of registration station. Petersen (1985) described the following criteria for appropriate selection of registration station site: the site should be safe; signs should be visible from a reasonable distance; the site should be located where users are likely to be most available to register (for example, a likely spot for a rest rather than the parking lot) (Zweifel et al., 2006).
- Maintenance should be employed to ensure there is a constant supply of materials necessary to complete registration (Petersen, 1985).
- Signboards may be unnoticed at trailheads. Registration station locations should be strategically placed at a distance from the trailhead (Petersen, 1985). Stations located up the trail from the trailhead are also less prone to vandalism (Watson et al., 2000).
- Assessing data from voluntary registration boards is difficult due to the daily variation in visitor registration numbers. This method would be suitable to be accompanied by another monitoring method, such as automated camera systems (Zweifel et al., 2006).
- Accuracy of use levels depends on the maintenance of the station and the adequacy of non-registration rate estimates. Data will not be accurate if non-registration rates are unknown or only crudely estimated (Watson et al., 2000).
- To account for non-compliance, visitor registries could be employed in conjunction with counters (Hollenhorst et al., 1992).

- Visitor registries can be implemented as part of existing on-hill or off-piste/backcountry safety procedures. For example, lift-access off-piste skiing could use waivers and a backcountry check-out to obtain user data.
- Brief self-registration forms can be used as a recruitment method for more detailed follow-up interviews or questionnaires (Cope, Doxford, & Probert, 2000).
- In their study, Zweifel et al. (2006) found that only one fifth of all recreationists used a voluntary registration board. The researchers have noted that the use of voluntary registration boards as a method for user monitoring must be improved.

### Considerations for winter use

- Self-registration stations have the potential to encourage existing operational safety procedures (such as backcountry sign-outs or waivers that remind users to have the proper avalanche safety equipment). This can further provide an indication of the preparedness of backcountry users for emergency situations.

### Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: Yes
  - **Individual characteristics**: Some
  - **Additional insight into behaviour**: None
- **Type of spatial and temporal information collected**
  - **Spatial information**: Position
  - **Spatial extent**: Local
  - **Temporal resolution**: Medium
- **Reliability**: Lower
- **Potential impacts on study subjects**
  - **Potential for affecting behaviour**: Low
  - **Potential for privacy concerns**: Low

- **Cost of monitoring method**
  - **Equipment cost:** Moderate
  - **Implementation cost:** Lower
  - **Effort and complexity of analysis:** Lower
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of self-registration boards for addressing the human dimensions needs of avalanche safety programs:

- Not directly suitable for obtaining user counts.
- Has potential for collecting basic information on backcountry users at targeted locations as a low-budget version of an intercept survey campaign.
- Most effectively used in combination with trail counters to augment counting data. However, non-registration rate and characteristics of non-registrants need to be explicitly examined (e.g., direct in-situ counting).

### *Online backcountry community platforms*

Online backcountry community platforms are public websites that serve as a resource for trip planning and public observations. In the scientific literature, the data generated from online community platforms is generally referred to as user-generated content (UGC). Online community platforms and the user-generated content they provide are important for the information searches of both travellers and tourists (Plank, 2016). Examples of such community platforms include **Gipfelbuch.ch** for hiking, mountaineering, and backcountry skiing in Switzerland; **Hikr.org** for hiking in central Europe; **CampToCamp.org** for all mountain sports in central Europe; **Snowest.com** for snowmobiling in North America; **Trailforks.com** for mountain biking worldwide; and **Mountainproject.com** for climbing in the United States. These platforms typically maintain catalogues of trips or discussion forums focusing on specific destinations. Users can post trip reports to inform the community about current conditions, directions, or difficulty of certain outings (Plank, 2016). The amount of structured detail submitted in the trip report varies among platforms.

In the academic literature, these types of online platforms fall into the category of *Volunteered Geographic Information* (VGI) or *Public Participation GIS* (PPGIS) and in general, Citizen Science, which also includes GNSS tracks shared on websites and posts on social media platforms. While the analysis of volunteered geographic information is increasingly getting attention from research, we found only one research study that used information from these types of online platforms. Techel, Zweifel, and Winkler (2015) used the number of trip reports posted on two community online platforms—bergportal.ch (now Gipfelbuch.ch) and CampToCamp.org—to estimate backcountry ski touring use levels for a spatiotemporal analysis of the risk of backcountry recreationists to be involved in a severe avalanche accident in Switzerland. To get around the issue of participation inequality—small numbers of users submitting the vast majority of trip reports, while most users only contribute very few or none at all—the platform users were classified into three categories (heavy, frequent, and rare contributors) and stratified samples of the trip reports were taken to give less weight to the heavy contributors and more weight to the rare contributors. Since the submitted trip reports do not provide an absolute measure of backcountry use, the analysis only examined temporal and spatial differences in relative risk.

### General advantages and disadvantages

The reviewed literature on online backcountry community platforms highlights the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
|---|---|
| • Can provide detailed description of routes and current conditions useful for warning services (Rupf & Stäuble, 2018).<br>• Since data is examined after it has been posted, concerns about the monitoring affecting participants' behaviour are not applicable (Rupf & Stäuble, 2018).<br>• Can provide a comprehensive understanding of user behaviour (Rupf, 2015).<br>• Provides valuable base information about user frequency (Rupf & Stäuble, 2018). | • Does not provide visitor numbers. Data primarily indicates relative popularity of an area (Norman & Pickering, 2017; Rupf & Stäuble, 2018).<br>• Bias is generated by participation inequality (Techel et al., 2014).<br>• Subject to privacy and ethical issues (Rossi, Barros, Pickering, Leung, & Walden-Schreiner, 2018).<br>• On some platforms, users may have to register to view or share information. This may be a deterrent to participation (Plank, 2016). |

### Tips for effective use

Our literature review did not reveal any special tips for the effective use of online backcountry community platforms for monitoring backcountry recreation. Incentivizing participation (e.g., prize draws, payment for submission) can increase reporting substantially. However, it also has the potential to bias the sample of reporters in unintended ways and lead to false reporting.

### Considerations for winter use

We did not identify any challenges for using online backcountry community platforms for conducting research on winter backcountry use.

### Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: Yes
  - **Individual characteristics**: Some
  - **Additional insight into behaviour**: None
- **Type of spatial and temporal information collected**
  - **Spatial information**: Position – Movement
  - **Spatial extent**: National
  - **Temporal resolution**: Medium
- **Reliability**: Lower
- **Potential impacts on study subjects**
  - **Potential for affecting behaviour**: n/a
  - **Potential for privacy concerns**: Moderate
- **Cost of monitoring method**
  - **Equipment cost:** n/a
  - **Implementation cost:** Lower
  - **Effort and complexity of analysis:** Higher
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of online backcountry community platforms for addressing the human dimensions needs of avalanche safety programs:

- Most suitable for obtaining large-scale overview of backcountry activity.
- Postings only reflect backcountry activities and posting motivations of very specific user groups Platforms not equally popular across all backcountry

activities and available posts highly skewed toward a small number of highly committed contributors (i.e., participation inequality).

- Used by a highly specific segment of the backcountry user community. Less commonly used than location-based social media platforms.
- Not suitable for obtaining absolute user numbers.
- Qualitative analyses of post content have potential to offer meaningful insight into general trends backcountry recreation activities.

### *General location-based social media platforms*

Like GNSS tracks uploaded to web-sharing services and trip reports submitted to community websites, posts on social media platforms fall under the general category of volunteered geographic information (VGI). With the popularity of smartphones, VGI is seen as an opportunity to engage citizens in planning processes (Guerrero, Møller, Olafsson, & Snizek, 2016). Additionally, social media has been a source of user-generated content for the assessment of international tourism and mobility patterns, to estimate visitation rates, to identify user hot spots, and to refine tourism marketing (Batista e Silva et al., 2018). These types of information sources are increasingly used to study human activity in natural spaces as they are an inexpensive alternative to fieldwork intensive methods (Tenkanen et al., 2017; Wood, Guerry, Silver, & Lacayo, 2013). However, Heikinheimo et al. (2017) highlight that social media data is not purely 'volunteered' due to the passive role of the contributors in the research, and taking advantage of these data in academic research requires special considerations of ethical use.

One type of VGI is **geotagged photographs** (i.e., photographs with geographic location information) posted on social media platforms, such as Flickr (established in 2004) or Instagram (established in 2010). These posts can be used to derive use density maps to highlight areas of high visitor frequency. This type of VGI has been referred to as ambient geospatial information (AGI) and is a strong medium for obtaining a shared connection with users and their distribution as the data comes directly from the users (Guerrero et al., 2016). Visitor Employed Photography (VEP) is a closely related method in which image-taking methods are controlled (Guerrero et al., 2016). Both VEP and VGI use photographs to reveal spatial and temporal user distribution as well as behavioural characteristics of users. Another type of volunteered geographic information is facilitated VGI (or f-VGI) in which planners seek information regarding a predefined topic or area (Guerrero et al., 2016). Here, planners facilitate public participation in VGI through a pre-established design (Guerrero et al., 2016).

The study of Wood et al. (2013) shows that photographs posted on Flickr can be used to approximate visitation rates in national parks around the world. Similarly, the comparison of images posted on Instagram and visitor surveys in Finnish national parks by Heikinheimo et al. (2017) showed that this type of social media platform can provide valuable information about visitor use of national parks. Numerous studies exist that used geotagged photographs to understand flow of visitors and visitor frequencies. Examples include Orsi and Geneletti (2012), Keeler et al. (2015), Heikinheimo et al. (2017), and Guerrero et al. (2016). Many of these studies suggest that gathering information from openly shared Instagram posts has become more difficult due to changes in their Application Programming Interface (API) and privacy policy in June 2016.

**Twitter** (established in 2006) allows users to post short messages called 'tweets' that include up to 280 characters. Tweets can also include a photo. Posts can include hashtags as keywords or references to predefined topics that are being discussed. Posts can also be directed to other users by including the @ sign and their username in the tweet. With the permission of the user, tweets can be geo-tagged using location information obtained from the GNSS of the mobile device at the time the tweet is submitted. Hence, tweets can contain location information both in their content and in the associated geotag. While Steiger, Albuquerque, and Zipf (2015) offer a comprehensive overview of spatiotemporal research of Twitter data, Tenkanen et al. (2017) systematically compare how park popularity and temporal visitor counts derived from geotags of the social media posts on Instagram, Twitter, and Flickr compare against high-precision visitor statistics in 56 national parks in Finland and South Africa. The results of the study show that social media activity is highly correlated with park popularity, and social media-based monthly visitation patterns match relatively well with the official visitor counts. However, there were considerable differences between platforms as Instagram clearly outperformed Twitter and Flickr. In addition, the study shows that social media data tend to perform better in more visited parks and should always be used with caution.

Tenkanen et al. (2017) highlight that **Facebook**, the most popular social media platform, is difficult to use for detailed research objectives as access to data is limited. In early 2020, Facebook rejected an informal inquiry by Pascal Haegeli about programmatically extracting (commonly referred to as scrapping) data from a public winter backcountry focused Facebook group for avalanche safety research purposes. Heikinheimo et al. (2017) conducted on-site interviews with visitors in a Finnish national park to explore social media use and the sharing of national park experiences on social media. Within their sample, Facebook was the most popular platform (36% of survey respondents), followed by Instagram (13%), Twitter (7%), Flickr (1%), and other platforms (7%).

### General advantages & disadvantages

The reviewed literature on visitor counts through general location-based social media platforms highlights the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
|---|---|
| • Data is generated continuously, enabling both long-term and real-time monitoring (Guerrero et al., 2016; Tenkanen et al., 2017).<br>• Publicly available and shared directly by users, therefore generates a large dataset (Guerrero et al., 2016).<br>• The acquisition of data generated by social media requires little time commitment from personnel, thus minimizing costs (Tenkanen et al., 2017). Application Programming Interfaces (APIs) make access and text and spatial analysis readily achievable (Guerrero et al., 2016). | • This method works well on a long-term basis, but making observations on daily visitor patterns would be challenging due to a lack of consistent observations from social media (Tenkanen et al., 2017).<br>• It can be challenging to tease meaningful and useful information regarding user characteristics from big data (Wood et al., 2013).<br>• Geotagged photographs may be published multiple times or at later times by the same user, misrepresenting visitor frequency and usage trends over time.<br>• Resulting density values do not represent actual numbers of users, but rather which locations experience high use or which |

| | |
|---|---|
| • Social media data has broad spatial coverage (Guerrero et al., 2016; Tenkanen et al., 2017).<br>• VGI is effective in identifying main recreational use patterns and spatial tendencies of citizens (Guerrero et al., 2016; Olafsson et al., 2018).<br>• Extensive fieldwork and personnel resources are not required. This method is cost-effective for large areas over long periods of time (Orsi & Geneletti, 2012).<br>• Can outline geographical and temporal trends on backcountry frequency (Rossi et al., 2018; Techel et al., 2015).<br>• Minimal concerns about monitoring studies affecting users' behaviour (Rupf & Stäuble, 2018).<br>• Has the potential to create meaningful visualizations and communication tools of spatial and temporal use patterns (Guerrero et al., 2016).<br>• Data generated through VGI enables hotspot analysis for the identification of user clusters (Guerrero et al., 2016).<br>• Has the ability to identify focal areas for user monitoring and management purposes and to support other monitoring methods.<br>• VGI data can be supported by other established monitoring methods, such as surveys and interviews (Guerrero et al., 2016). | areas see usage in general (Orsi & Geneletti, 2012; Rupf & Stäuble, 2018).<br>• Georeferencing can have low accuracy and photographs may not be geotagged to the actual location of the photograph (Guerrero et al., 2016; Orsi & Geneletti, 2012).<br>• Understanding how well the data represents a population is challenging if no socio-economic data is collected (Guerrero et al., 2016).<br>• Bias is generated by a distinct age and gender difference of social media users (Tenkanen et al., 2017).<br>• Bias toward high-density areas, such as starting points of routes or popular sites along a given route (Orsi & Geneletti, 2012).<br>• Careful measures must be taken to reduce biases introduced by heavy social media contributors (Techel et al., 2015).<br>• Subject to privacy and ethical issues, which can limit access to data (Ahas, 2014; Etter et al., 2008; Guerrero et al., 2016; Pickering, Rossi, Hernando, & Barros, 2018).<br>• The ability to quantitatively assess VGI data relies on innovative and evolving methods (Guerrero et al., 2016).<br>• Barriers to participation in VGI include: insufficient personal capacity and abilities, limited financial capacity, political and |

| | |
|---|---|
| • Are applicable at a broad range of scales (local, regional, international) and dimensions (political, scientific, civic) (Møller et al., 2019). They, thus, have the potential to engage both a large number of citizens as well as random population samples in order to ensure representativeness (Møller et al., 2019).<br>• Social media platforms are available to a diverse user base. | management support, leadership and coordination and legal issues (Møller et al., 2019).<br>• Mobile applications may take longer to become institutionalised as a new form of participation in monitoring methods (Møller et al., 2019).<br>• Training and education of both planners and participants may be required (Møller et al., 2019). |

## Tips for effective use

Our literature review further revealed the following tips for effective use of general location-based social media platforms:

- Certain social media platforms are easier to extract data from. If there is a reliable statistical relationship between image and field-based records, social media is a powerful tool for tracking how people interact with their surroundings (Wood et al., 2013).
- When compared to other social media platforms such as Twitter and Flickr, Instagram is successful in revealing monthly visitor patterns (Tenkanen et al., 2017).
- Because social media data tend to perform better in popular areas, particular care should be taken to be cautious of bias (Tenkanen et al., 2017; Wood et al., 2013).
- Although data acquisition involves little personnel time, categorizing geo-referenced images with automated methods does not produce as strong results as manual categorization of images (Guerrero et al., 2016). Determining image content and validity of geographical referencing can be challenging and time demanding. Careful consideration must be taken to balance the importance of

up-to-date and stimulating mobile applications with approachable levels of technicality to avoid excluding some groups (Etter et al., 2008; Møller et al., 2019).

- For mobile applications to be an effective part of monitoring objectives, it is important that their processes are transparent (Møller et al., 2019).
- Due to the potential for exclusion of certain user groups, care must be taken to be aware of the groups that have limited access to mobile applications and ensure appropriate measures are taken to account for these limitations (Møller et al., 2019).
- While utilizing social media posts for monitoring backcountry activity passively cannot affect backcountry users' behaviour, the fact that the media is being used in this way might have a substantial effect on what users do in the backcountry and what they post.

### Considerations for winter use

- The availability of VGI data is highly influenced by weather conditions (that provide good conditions for photo-taking), location profile (some places attract more users and thus receive more social media coverage), and visitor profile (there are clear age and gender differences in the use of social media) (Tenkanen et al., 2017).
- Photographs will be taken more often on fair weather days or in aesthetic locations. As a result, geotagged photographs may misrepresent popular locations or routes and trends in visits over time.
- Colder temperatures reduce the battery life of mobile phones.
- In Canada and the United States, mobile phone coverage is often limited in backcountry areas.
- Mobile phones can interfere with avalanche safety equipment.
- Mobile phone users might turn their phone off while travelling in the backcountry to avoid interference with avalanche safety equipment and preserve battery power for emergency calls.

### Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: Yes
  - **Individual characteristics**: Some
  - **Additional insight into behaviour**: Some – Detail
- **Type of spatial and temporal information collected**
  - **Spatial information**: Position - Movement
  - **Spatial extent**: National
  - **Temporal resolution**: Medium – High
- **Reliability**: Lower
- **Potential impacts on study subjects**
  - **Potential for affecting behaviour**: n/a[4]
  - **Potential for privacy concerns**: Moderate – High
- **Cost of monitoring method**
  - **Equipment cost:** n/a
  - **Implementation cost:** Lower
  - **Effort and complexity of analysis:** Higher
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of location-based social media platforms for addressing the human dimensions needs of avalanche safety programs:

- Most suitable for obtaining large-scale overview of backcountry activity, but not for obtaining absolute numbers.
- Postings only reflect backcountry activities and social media posting motivations of very specific user groups. Platforms not equally popular across all backcountry

[4] While utilizing social media posts for monitoring backcountry activity passively cannot affect backcountry users' behaviour, the fact that the media is being used in this way might have a substantial effect on what users do in the backcountry and what they post.

activities and available posts highly skewed toward a small number of highly committed contributors (i.e., participation inequality).

- To make meaningful extrapolations, a better understanding of social media use within recreational backcountry community is required.
- Qualitative analyses of post content have potential to offer meaningful insight into general trends in backcountry recreation activities and user motivations, attitudes, and expectations.
- Potential for serious privacy concerns.
- Not suitable for long-term monitoring as data access and privacy policies of service providers continuously change without notice.

## Compulsory registration

### *Trip permits and registrations*

Trip permits and registrations are mandatory in wilderness areas where the amount of use is controlled to keep visitation levels from exceeding carrying capacities. Since this information is already collected by management agencies, Hollenhorst et al. (1992) and Muhar et al. (2002) highlight that it can be used for recording visitor use and collecting population data.

While we did not find any academic studies explicitly using permit, booking, or registration fee data to monitor winter backcountry use, we are aware of at least one permit system that would allow such use: the mandatory winter permit system in Rogers Pass, Glacier National Park in British Columbia (https://www.pc.gc.ca/en/pn-np/bc/glacier/visit/hiver-winter/ski). The purpose of this permit system is to protect backcountry users from the dangers of avalanche control, which detonates explosives along the highway corridor that crosses the national park.

#### General advantages and disadvantages

The reviewed literature on trip permits and registrations highlights the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
|---|---|
| • Using permit, booking, and fee data is simple and accurate (Cessford & Burns, 2008).<br>• Low cost of implementation (Cessford & Burns, 2008).<br>• Data gathered is specific to the management and monitoring objectives and can be easily linked to safety management procedures (Cessford & Burns, 2008). | • The effectiveness of this method is dependent on the type of environment. For example, large areas with uncontrolled access points would not be suitable environments for the use of this method.<br>• Data is only available where bookings, permits, or fees are required. This limits data to a specific set of respondents (Cessford & Burns, 2008). |

| | |
|---|---|
| • Mandatory registration through permits, bookings, and fees reduces non-compliance (Watson et al., 2000). | • Highly reliant on visitor compliance and the cooperation of the private enterprises or park administrations that provide data (Cessford & Burns, 2008; Muhar et al., 2002).<br>• Costly to enforce (Hollenhorst et al., 1992; Watson et al., 2000).<br>• May reduce visitor freedom and spontaneity of user (Hollenhorst et al., 1992).<br>• Visitor experience may be compromised by a sense of regimentation and control implied by issuing permits, which may detract from visitor experience (Hollenhorst et al., 1992; Watson et al., 2000).<br>• Office personnel must be available to issue permits. The need for on-site personnel is often accompanied by high costs (Cessford & Burns, 2008; Watson et al., 2000).<br>• Can affect visitor experience negatively (Hollenhorst et al., 1992).<br>• Visitor numbers on popular trips are capped by allowed capacity and not overall visitor demand. |

## Tips for effective use

Our literature review further revealed the following tips for effective use of trip permits and registrations:

- Managing agencies should consider whether mandatory permits or self-issued permits are more suitable. Mandatory permits may provide the best use numbers, but incur higher costs of administration, whereas self-issued permits are a lower cost option but require enforcement and careful determination of visitor compliance (Hollenhorst et al., 1992).
- Self-issued permits are a lower-cost alternative than agency-issued permits but have higher enforcement requirements and compliance rate monitoring (Hollenhorst et al., 1992).
- Monitoring visitor use numbers can be easily integrated into systems where access to areas is restricted by the purchase of a ticket or permit (Muhar et al., 2002).

### Considerations for winter use

- This method encourages existing operational safety procedures, such as backcountry sign-outs or waivers that remind users to have the proper avalanche safety equipment.

### Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: Yes
  - **Individual characteristics**: Some
  - **Additional insight into behaviour**: None
- **Type of spatial and temporal information collected**
  - **Spatial information**: Position - Movement
  - **Spatial extent**: Local
  - **Temporal resolution**: Medium
- **Reliability**: Higher
- **Potential impacts on study subjects**
  - **Potential for affecting behaviour**: Low
  - **Potential for privacy concerns**: Low

- **Cost of monitoring method**
    - **Equipment cost:** n/a
    - **Implementation cost:** Lower
    - **Effort and complexity of analysis:** Lower
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of trip permits and registrations for addressing the human dimensions needs of avalanche safety programs:

- Valuable approach for obtaining high-quality use numbers with some complementary information at point locations.
- More effective in remote locations as likelihood of non-compliance is lower.
- Not suitable for upscaling observations to entire community.

## Surveys

Surveys are used extensively in the social sciences to better understand the characteristics of a population and provide insight into motivations, preferences, perceptions, etc.

In this overview, we distinguish between the following three types of surveys:

- Intercept surveys
- Targeted research surveys
- Cross-sectional participation surveys

### *Intercept surveys*

Intercept surveys use questionnaires or interview scripts to produce datasets that accurately describe visitors and the characteristics of their visits at a specific site (Kajala et al., 2007). Their reach is distinctly different from larger-scale surveys that are conducted by mail, phone, Internet or other methods (Kajala et al., 2007).

There are many examples of studies in outdoor recreation and tourism that use intercept surveys or interviews to better understand visitors. The method has also been popular among avalanche safety researchers for gaining insight into the characteristics of backcountry user groups and their risk management practices. Examples of recent large-scale applications include Zweifel et al. (2006), Procter et al. (2013), Strong-Cvetich (2014) and Hallandvik, Andresen, and Aadland (2017), but there are many more.

Procter et al. (2013) conducted a large intercept survey study to quantify adherence to basic avalanche safety practices among backcountry skiers and snowshoers in South Tyrol, Italy. Over a one-week period, the research team surveyed almost 2000 groups of recreationists at 22 different backcountry access points. The study of Strong-Cvetich (2014) aimed to better understand the barriers for becoming avalanche trained and to using the public avalanche bulletins among mountain snowmobilers in western Canada. The intercept survey component of this study was conducted at five popular snowmobile destinations on weekends during the winter of 2011/12 and resulted in an overall sample of slightly more than 1,000 participants. The objective of the intercept survey was to recruit participants for a more comprehensive online survey and gather a representative sample of mountain snowmobilers. Hallandvik et al. (2017) surveyed participants at an avalanche awareness seminar about their avalanche risk management practices.

The USDA Forest Service has used visitor use surveys in their National Visitor Use Monitoring Program (Rivers & Menlove, 2006). These surveys were designed to measure the motivation for visits to particular places as well as the amount of participation in different winter activities at that location (Rivers & Menlove, 2006).

## General advantages and disadvantages

The reviewed literature on intercept surveys highlights the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
|---|---|
| • Data provides specific information regarding user type and characteristics (Cessford & Burns, 2008; Hollenhorst et al., 1992; Muhar et al., 2002).<br>• Interview and survey questions can be curtailed to obtain information specific to further monitoring purposes such as user behaviour.<br>• This method is particularly useful to enhance other methods and can be used to obtain contact information for further user characterization (Strong-Cvetich, 2014).<br>• Intercept surveys can be used in combination with a post-visit questionnaire to obtain more detailed information. | • Highly reliant on rigorous sampling and question design (Cessford & Burns, 2008)<br>• Interviews and questionnaires do not estimate total use unless proper sampling procedures are used or the method is accompanied by another counting device (Hollenhorst et al., 1992).<br>• The use of on-site trained personnel can result in high costs (Rupf, 2015).<br>• If staff resources are limited, surveying duties might compete with other staff responsibilities. |

## Tips for effective use

Standard references for survey research include Dillman, Smyth, and Christian (2014) and Vaske (2008), who explicitly focuses on human dimensions research in the context of outdoor recreation in protected areas. Our literature review further revealed the following tips for effective use of intercept surveys:

- The quality of the survey response is directly related to the quality of the questionnaire design. Careful questionnaire design is essential to producing quality answers (Kajala et al., 2007).

- Interviews & surveys should be kept short. Content should be easy to answer, highly structured, and provide factual questions (Watson et al., 2000).
- If the intercept survey approach is used for collecting visitor counts, detailed records of visitors declining participation must be maintained.
- Response bias should be accounted for when intercept surveys are used. Accounting for this bias includes testing both for non-response bias and self-selection bias (Strong-Cvetich, 2014).
- Surveying via questionnaires and interviews is often used in combination with direct observation methods such as on-site observers and camera recordings to either calibrate or complement these methods (Hollenhorst et al., 1992; Kajala et al., 2007).
- Attractive incentives (e.g., draw prizes, handouts, hot chocolate) can increase participation. However, they can also bias the sample in unintended ways.

### Considerations for winter use

- Poor weather conditions can make it difficult to conduct surveys, and on fair weather days, users are eager to get on their route and are reluctant to be surveyed (Ankre, 2014).
- In a study done by Ankre (2014), surveying was most productive at avalanche awareness nights, during onsite promotion events, and at local visitor centers where winter trail users are required to register before entering the backcountry.
- Since backcountry use is low in many locations and at certain times (for example, weekdays), long and repeated surveying periods might be required to collect meaningful datasets.
- Due to the possible remoteness of observation locations and adverse winter conditions, special considerations must be given to the comfort and safety of interviewers.

### Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: Yes
  - **Individual characteristics**: Detailed
  - **Additional insight into behaviour**: Detailed
- **Type of spatial and temporal information collected**
  - **Spatial information**: Position - Movement
  - **Spatial extent**: Local
  - **Temporal resolution**: High
- **Reliability**: Higher
- **Potential impact on study subjects**
  - **Potential for affecting behaviour**: Moderate
  - **Potential for privacy concerns**: Consent
- **Cost of monitoring method**
  - **Equipment cost:** Lower
  - **Implementation cost:** Higher
  - **Effort and complexity of analysis:** Moderate
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of intercept surveys for addressing the human dimensions needs of avalanche safety programs:

- Standard research method for collecting detailed information on backcountry users in-situ at targeted locations.
- Not directly suitable for obtaining user counts.
- Most effectively used in combination with trail counter to augment counting data. However, non-participation rate and characteristics of non-participants need to be explicitly examined (e.g., direct in-situ counting).

- Effective recruitment method for more in-depth research studies (e.g., targeted research surveys, interviews, etc.).
- Can complement short-term targeted GNSS tracking studies with useful background information.
- Upscaling of results to entire recreational backcountry community challenging.

### *Targeted research surveys*

Targeted research surveys refer to surveys that aim to reach larger numbers of participants and are typically conducted over the Internet, by phone, or by mail. These types of surveys are broadly used in recreation research and there are many examples in the academic literature. Some recent examples of targeted research surveys in avalanche safety research include Haegeli, Gunn, and Haider (2012), Winkler and Techel (2014), Wikberg, Palmgren, Maartenson, and Nordlund (2014), Eyland and Thibeault (2016), Johnson, Haegeli, Hendrikx, and Savage (2016), Haegeli and Strong-Cvetich (in press), Wikberg, Palmgren, Hallberg, Maartenson, and Norlund (2018) and Mannberg, Hendrikx, and Johnson (2018), but there are many more.

In addition to thoughtful survey design, recruiting a **meaningful survey sample** is critical for conducting an insightful survey study. Since backcountry users are not well organized or registered in any way, it is extremely difficult for avalanche safety researchers to obtain unbiased survey samples that holistically represent the backcountry community. Instead, researchers typically rely on convenient samples, which are composed of participants who can be accessed with relative ease. Recruitment methods for convenience samples include intercept surveys, posts on social media websites, advertising on avalanche safety websites, or collaborations with community partners (e.g., clubs, retail stores, hotels). Hence, results from convenience sample survey studies do not provide representative insight and therefore need to be interpreted with care.

An example of avalanche risk related targeted research surveys is a study done by Winkler et al. (2016), which determined the type and frequency of sport activities of Swiss residents through three surveys in 1999, 2007, and 2013 with a total of 23,000 participants. These surveys were conducted as a computer-aided telephone interview (CATI) and were followed up with written and online surveys (Winkler et al., 2016).

Several research surveys have examined participants' terrain preferences using hypothetical, but realistic decision scenarios. Examples include the surveys of Haegeli et al. (2012) and Haegeli and Strong-Cvetich (in press) using discrete choice experiments

(Hensher, Rose, & Greene, 2015), or the survey of Mannberg, Hendrikx, Landrø, and Stefan (2018). While these types of studies can offer useful insight, it is important to remember that there might be considerable difference between stated terrain preferences and true terrain preferences in the backcountry (i.e., revealed terrain preferences). To address this issue, Hendrikx, Johnson, and Mannberg (2018) offer a preliminary perspective on the difference between stated and revealed terrain preferences in winter backcountry travel.

A new survey approach that might provide an interesting avenue for gathering information on backcountry use preferences is explicitly **map-based surveys** that allow survey participants to identify locations and provide relevant spatial information. Maptionnaire (https://maptionnaire.com/) is a commercial platform for the development of custom-built map-based surveys.

### General advantages and disadvantages

The reviewed literature on targeted research surveys highlights the following advantages and disadvantages of the method.

| **Advantages** | **Disadvantages** |
| --- | --- |
| • Data provides specific information regarding user type and characteristics (Cessford & Burns, 2008; Hollenhorst et al., 1992; Muhar et al., 2002).<br>• Interview and survey questions can be curtailed to obtain information specific to further monitoring purposes, such as user behaviour.<br>• This method is particularly useful to enhance other methods and can be used to obtain contact information for further user characterization (Strong-Cvetich, 2014). | • Highly reliant on rigorous sampling and question design (Cessford & Burns, 2008).<br>• Participants in avalanche safety surveys are typically skewed toward highly engaged members who are experienced and avalanche aware.<br>• Recreationists with limited avalanche awareness are much more difficult to recruit.<br>• Interviews and questionnaires do not estimate total use unless proper sampling procedures are used or the method is |

| | |
|---|---|
| | accompanied by another counting device (Hollenhorst et al., 1992).<br>• Analysis of questionnaire and survey data can be time-consuming.<br>• When asked about winter backcountry use, participants may provide the number of days they wish to be in the backcountry, rather than their actual frequency (Winkler et al., 2016).<br>• There is difficulty to ensure representativeness when surveys are released to the public (Plieninger et al., 2018). |

## Tips for effective use

Standard references for survey research include Dillman et al. (2014) and Vaske (2008), who explicitly focuses on human dimensions research in the context of outdoor recreation in protected areas. Our literature review further revealed the following tips for effective use of targeted research surveys:

- The quality of the survey response is directly related to the quality of the questionnaire design. Careful questionnaire design is essential to producing quality answers (Kajala et al., 2007).
- Surveys should be kept short. Content should be easy to answer, highly structured, and provide factual questions (Watson et al., 2000).
- Response bias should be accounted for when online surveys are used. Accounting for this bias includes testing both for non-response bias and self-selection bias (Strong-Cvetich, 2014).

- This method is highly dependent on sampling procedures. Statistically sound, unbiased sampling techniques will provide the most accurate information (Watson et al., 2000).
- The possibility of over-reporting should be considered by replacing mean values with median values (Winkler et al., 2016).
- Attractive incentives (e.g., draw prizes) can increase participation. However, they can also bias the sample in unintended ways.

### Considerations for winter use

There are no special considerations for conducting targeted research surveys for winter backcountry recreation.

### Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: Yes
  - **Individual characteristics**: Detailed
  - **Additional insight into behaviour**: Detailed
- **Type of spatial and temporal information collected**
  - **Spatial information**: n/a
  - **Spatial extent**: National
  - **Temporal resolution**: Low
- **Reliability**: Moderate
- **Potential impacts on study subjects**
  - **Potential for affecting behaviour**: Moderate
  - **Potential for privacy concerns**: Consent
- **Cost of monitoring method**
  - **Equipment cost:** Lower
  - **Implementation cost:** Moderate
  - **Effort and complexity of analysis:** Higher
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of targeted research surveys for addressing the human dimensions needs of avalanche safety programs:

- Standard research method for collecting in-depth information on backcountry users' motivations, attitudes, preferences, and risk-management practices.
- Special attention must be given to participant recruitment. Online surveys tend to attract high-end participants with advanced levels of avalanche awareness and community engagement.
- Not directly suitable for obtaining user counts.
- Most effective when survey design is grounded in established frameworks and theories (e.g., risk perception, decision-making, risk communication). Qualitative interviews more effective for exploratory studies aiming to develop new frameworks and theories.
- Upscaling of results to entire recreational backcountry community is challenging. Complementary intercept surveys can offer some, but not conclusive, insight on sample bias.
- Explicitly map-based surveys (e.g., maptionnaire) might offer an interesting avenue for collecting information on backcountry use.

### *Cross-sectional participation surveys*

Cross-sectional surveys aim to collect information from a representative sample to explicitly draw conclusions about the characteristics, preferences, and behaviour of an entire population. Some government agencies regularly conduct cross-sectional surveys (often referred to as census) to better understand the engagement in sports and outdoor recreation among their citizens. Examples include Switzerland (Lamprecht et al., 2008, 2014)[5], the European Union (TNS Opinion & Social, 2010), the United States (Outdoor Industry Association, 2013), New Zealand (Sport New Zealand, 2016, 2018), and Canada (Sport Canada, 1998). While these types of studies have traditionally been conducted as telephone surveys, the use of online surveys is increasingly common. Cross-sectional participation surveys are often conducted at regular intervals to better understand trends in population-wide engagement in sports and outdoor-recreation. An example of a smaller-scale cross-sectional survey study is Kux and Haider (2014) who looked at participation in non-motorized outdoor recreation in British Columbia, Canada, and its economic impact.

While some of these studies include statistics on winter backcountry recreation (e.g., Kux & Haider, 2014; Lamprecht et al., 2008, 2014), we are not aware of any cross-sectional survey studies that have explicitly focused on winter backcountry recreation activities.

#### General advantages and disadvantages

The reviewed literature on cross-sectional participation surveys highlights the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
|---|---|
| • Working with marketing companies that have established participant panels allows | • The relatively low population-wide participation rate in winter backcountry recreation requires large survey samples |

[5] According to unconfirmed information, we believe that the Swiss Alpine Club was able integrate some questions about mountain recreation in the latest iteration of the Sport Schweiz survey.

| | |
|---|---|
| for efficient creation of representative population samples.<br>• Studies repeated at regular intervals provide information regarding trends over time.<br>• It might be possible to team up with other outdoor recreation stakeholders to conduct a large-scale participation study together. | to derive participation rates with sufficient confidence.<br>• High cost in personnel hours (Kajala et al., 2007; Sport Canada, 1998).<br>• Depending on the method of surveying (e.g., telephone surveys, online survey), certain demographics may be excluded (Sport Canada, 1998). |

## Tips for effective use

Our literature review further revealed the following tips for effective use of cross-sectional participation surveys:

- The quality of the survey response is directly related to the quality of the questionnaire design. Careful questionnaire design is essential to producing quality answers (Kajala et al., 2007).
- Interviews and surveys should be kept short. Content should be easy to answer, highly structured, and provide factual questions (Watson et al., 2000).
- The large sample required for insightful results makes this type of survey very expensive. Partnerships with government agencies and other interest groups are critical for sharing the cost and making the approach affordable.

## Considerations for winter use

- Because only a small percentage of the population is pursuing winter backcountry sports in avalanche terrain, substantial population samples are required to achieve meaningful sociodemographic profiles for backcountry recreationists. For example, the 10,000 Swiss residents surveyed by Lamprecht et al. (2014) included 1.4% backcountry skiers (approx. 140 individuals) and 2.7% snowshoers (approx. 270 individuals).

### Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: No
  - **Individual characteristics**: Some
  - **Additional insight into behaviour**: None
- **Type of spatial and temporal information collected**
  - **Spatial information**: n/a
  - **Spatial extent**: National
  - **Temporal resolution**: Low
- **Reliability**: Higher
- **Potential impacts on study subjects**
  - **Potential for affecting behaviour**: Moderate
  - **Potential for privacy concerns**: Consent
- **Cost of monitoring method**
  - **Equipment cost:** n/a
  - **Implementation cost:** Higher
  - **Effort and complexity of analysis:** Lower
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of cross-sectional participation surveys for addressing the human dimensions needs of avalanche safety programs:

- Large-scale, nation-wide participation surveys are the most direct approach for gaining conclusive insight into overall participation in winter backcountry outdoor recreation.
- The relatively low population participation rates in winter backcountry activities (typically < 5%) require large population sample sizes for obtaining meaningful characterizations of backcountry user groups.

- While the cost of a large-scale participation survey is high, considerable potential exists for collaborating with government and other outdoor recreation stakeholders.
- Participation surveys repeated at regular intervals will provide accurate estimates of trends in winter backcountry recreation participation.
- Pairing with continuous, local backcountry user counting campaigns will allow results to be regionalized and intermediate trends between surveys to be monitored.

## Other methods

### ***Use estimates by local experts***

This method takes advantage of the knowledge and experience of local recreation professionals (e.g., guides, tour operators, tourism association representatives) to establish estimates of recreational use from subjective estimates (Rupf & Stäuble, 2018). For example, ski patrollers are continuously observing a ski area and may provide a reliable or useful overview of user numbers (Zweifel et al., 2006).

An example of a winter-specific application of this approach is Haegeli (2005) who used the opinions of industry experts to estimate trends in backcountry use in British Columbia. A more recent example of the approach is Rupf & Stäuble (2018), who surveyed local experts backcountry winter sport and wildlife management experts about backcountry use in a wildlife disturbance monitoring context. In this study, the expert estimates were validated against trail counters.

#### General advantages and disadvantages

The reviewed literature on use estimates by local experts highlights the following advantages and disadvantages of the method.

| Advantages | Disadvantages |
|---|---|
| • No concerns about affecting the behaviour of study subjects (Rupf & Stäuble, 2018). | • Uncertainty of results with a potential for bias toward a perceived higher participation (Rupf & Stäuble, 2018).<br>• Difficulty to calibrate estimates or generate uniform descriptions of use values.<br>• Relying on local expert estimations can be accurate for good visibility and fresh tracks, however variable winter conditions may render inaccurate estimates (Zweifel et al., 2006). |

## Tips for effective use

Our literature review further revealed the following tips for designing effective surveys to gather use estimates from local experts:

- In-depth understanding of the backcountry activity is critical for the design of a meaningful survey. Hence, collaboration with local experts during the design phase of the survey is critical.
- A carefully thought-out and well-designed survey (e.g., meaningful categories) is critical for obtaining meaningful use estimates.
- Clear instructions will ensure that study participants complete survey as intended.

## Considerations for winter use

There are no special considerations for the application of use estimates by local experts for winter backcountry recreation.

## Assessment and recommendations

- **Type of personal information collected**
  - **Identity**: No
  - **Individual characteristics**: None
  - **Additional insight into behaviour**: None
- **Type of spatial and temporal information collected**
  - **Spatial information**: Position - Movement
  - **Spatial extent**: Local
  - **Temporal resolution**: Medium
- **Reliability**: Moderate
- **Potential impacts on study subjects**
  - **Potential for affecting behaviour**: n/a
  - **Potential for privacy concerns**: None
- **Cost of monitoring method**
  - **Equipment cost:** n/a

  - **Implementation cost:** Moderate
  - **Effort and complexity of analysis:** Moderate
- **Winter suitability**: Yes

Based on the available information, we draw the following conclusions about the value of use estimates by local experts for addressing the human dimensions needs of avalanche safety programs:

- Most suitable for providing general overview of backcountry use in region.
- Useful for planning more in-depth monitoring campaign.

### Indirect evidence

The backcountry use monitoring methods described in this section refer to existing information sources that might provide complementary, indirect evidence on volume and trends in winter backcountry use.

#### ***Hotel and hut bookings***

Zweifel et al. (2006) indicated that lodging statistics of alpine club mountain huts and local hotels could offer insight about trends in backcountry recreation. This particularly applies to more remote areas where huts are the only access option. The researchers identified the challenge of obtaining a high questionnaire return rate as well as the difficulty in identifying appropriate lodging accommodations (Zweifel et al., 2006). Furthermore, while hotel and hut bookings can offer a useful perspective on the local numbers of backcountry users, it is not possible to extrapolate the observed trends to the broader backcountry community. Many popular huts use lottery systems to manage reservations as demand often exceeds capacity. Hence, user numbers are capped by hut capacity.

Batista e Silva et al. (2018) used data from both official European statistical bodies and online booking services to achieve an improvement in the existing knowledge base of spatiotemporal distribution of tourism in the European Union. This study's research objectives included increasing geographical detail of existing spatial distribution statistics, developing regional temporal profiles of tourism demand, generating tourist density maps, and using the data to assess dimensions of tourism such as intensity, seasonality, and vulnerability. In combination with other emerging, big data sources, Batista e Silva et al. (2018) produced a dataset that described local and regional spatiotemporal patterns and characteristics of tourism in Europe.

In their study, Etter et al. (2008) also used trends in hotel overnights during winter as a foundation from which to compare the amount of avalanche-warning service information made accessible to the public, trends in avalanche science education, and trends in the development of number of people who are skiing/freeriding in out-of-bounds terrain. This information helped support the effectiveness of avalanche warning products and avalanche education.

#### *Transportation bookings/tickets*

Like hotel and hut bookings, transportation bookings to remote backcountry destinations might offer insight about backcountry recreation trends. However, the bookings are often limited by the capacity of the accommodation options at the destination or by a permit system. Hence, the resulting user estimates suffer from the same limitations as hotel and hut bookings.

#### *Vehicle counts at staging areas/parking lots*

Counting vehicles at staging areas (manually or automatically) can provide meaningful estimates of backcountry user volumes at a specific destination. Regularly counting vehicles at predefined times might be an efficient and cost-effective alternative to more in-depth monitoring efforts. However, to enhance the value of the information collected, vehicle counts should initially be validated with a more formal counting method (e.g., infrared counters on access roads or trails accessing recreation area).

#### *Ski area boundary gates*

Ski resorts in North America commonly use gates to mark exit points from the secured ski area and manage access to the adjacent, uncontrolled backcountry area. Some of these gates are equipped with avalanche transceiver checkers (e.g., https://www.backcountryaccess.com/product/bca-beacon-checker/) and some have barriers that need to be opened to pass through. Adding counters to boundary gates could provide some insight about trends in the volume of backcountry use adjacent to a ski area. This is one of the applications where radio frequency identifier (RFID) might be useful. However, the approach is unable to provide absolute user numbers, as many backcountry users will exit the ski area boundary away from the monitored gates.

#### *Snowmobile licences*

In jurisdictions where snowmobiles must be registered, licence counts offer annual information about the absolute size of the snowmobiling community. However, the percentage of snowmobiles used for mountain snowmobiling is generally unknown even though information on model type might provide some indication. Furthermore, licence counts do not provide any information about the frequency of use in terrain that is exposed to avalanche hazard.

#### *Rescue calls*

Number of rescue calls might also offer insight into the volume of backcountry activity in an area. However, conditions (both weather and avalanche conditions) are important contributing factors that determine the volume of rescue calls. This makes it difficult to properly isolate the relationship between rescue calls and backcountry use. Furthermore, the level of rescue services' and recreationists' attitudes toward when to call for help vary among different areas and countries, which makes cross-jurisdictional comparisons difficult.

#### *Submissions to avalanche safety observation platforms*

Numerous avalanche-warning services are operating online platforms that allow recreationists to share condition reports and avalanche safety observations within the community and submit them to the forecaster team. While the number and location of submissions offer some insight about backcountry activity, these types of platforms suffer from the same participation inequity issue as social media and GNSS web-sharing platforms. The majority of submissions are typically provided by a relatively small number of committed contributors, while the majority of recreationists submit rarely or not at all. Since the motivation for submission on these platforms is narrower than on other social media websites (i.e., contributing observations to improve avalanche warnings is more specialized than posting photographs for friends or uploading GNSS tracks for personal recordkeeping), the issue of participation inequality might even be exacerbated.

#### *Equipment sales and rentals*

Winter backcountry travel necessitates specialized equipment (e.g., skis, snowmobiles, snowshoes) as well as safety equipment (i.e., avalanche transceiver, shovel, and probe). Hence, equipment sales statistics have the potential to provide indirect evidence on how many people are accessing backcountry areas and in what capacity (Mitsui, 2013; Zweifel et al., 2006). This information further provides a possibility for understanding the temporal trends of winter sport (Zweifel et al., 2006).

However, we see numerous challenges with the use of these types of statistics for estimating backcountry use. Like snowmobile licences, equipment purchases are not linked to frequency of use in avalanche terrain. Furthermore, equipment purchases are heavily driven by the introduction of new technology and fashion trends, as well as economic conditions. Hence, equipment sales statistics primarily represent trends in outdoor activity markets rather than backcountry use.

Equipment rental statistics might suffer less from the shortcomings mentioned above, but rental equipment is primarily used by entry-level users and rental statistics can therefore only offer insight on a very specific segment of the backcountry recreation population. However, rental programs might be valuable recruitment partners for an otherwise more difficult-to-reach target audience for avalanche safety messages and research.

We did not find any scientific studies that explicitly used equipment sales or rental statistics as proxy measures for backcountry use.

### *Club memberships*

Memberships in specialized clubs (e.g., alpine clubs, snowmobiling clubs) might offer indirect evidence of backcountry use levels. In recent years, however, club membership has been declining as more modern ways of connecting (e.g., social media platforms) have become popular.

## A3. Additional technical considerations for designing effective monitoring campaigns

In addition to considering effectiveness when choosing an appropriate monitoring method for fulfilling management goals for avalanche-warning services, there are many technical considerations that need to be examined. Primary considerations include the location of installation, the calibration requirements associated with each method, the ability of monitoring methods to be used in conjunction with other methods, and the availability of resources to meet monitoring objectives.

### Location

Choosing an appropriate location for each monitoring method involves considering the efficacy of a location for the given monitoring method. Some monitoring methods, such as pressure-sensitive devices, require narrow paths where users will pass over the sensor. Other methods, such as camera recordings, would be most effective for monitoring if they can capture slower, up-track movement.

Furthermore, critical consideration must be given to the safety of those who are installing, monitoring, maintaining, and enacting the monitoring method. Avalanche hazard presents a unique challenge when working in a winter wilderness setting and safety protocols should be developed and employed specific to each monitoring method.

Winter conditions have potential to damage certain devices installed for visitor monitoring. Strategic locations should be determined that minimize exposure of counting devices to conditions that may hamper their function. For example, video cameras should be placed in a waterproof housing to ensure that the equipment does not fail due to water damage. A further example includes a pressure-sensitive device buried underground. The device may not be suited to below tree-line areas as snow falling from the trees may add enough pressure to trigger a count, whereas sensitivity can be adjusted to account for more gradual changes such as light daily snowfall.

Another important condition to consider regarding installation location is the vulnerability of the location. For example, infrared counters require both a sending and receiving component above ground, which limits suitable installation locations if there is concern over vandalism or theft. In contrast, video cameras can be easily concealed in vegetation and can blend in with their local environment.

### Calibration & Complementary Methods

An important consideration for all counters is calibration. Calibration is required to assess the reliability of the counting device by comparing its output to an alternative method of known accuracy (Watson et al., 2000). Some monitoring methods require frequent or continued calibration. Cessford, Cockburn, & Douglas (2002) outline three factors that determine what combination of techniques should be used when considering the application of a monitoring method in relation to the costs and available resources. These factors are visitor use patterns, physical settings, and availability of resources (Cessford et al.,2002).

Throughout the reviewed papers, it has been suggested that some combination of methods would be most useful not only in meeting monitoring objectives but also for cost effectiveness and for providing more reliable data (Kajala et al., 2007). In addition, many of these complementary methods are important in their ability to calibrate one another. Particularly, passive on-site counters are often complemented by direct observation methods that not only provide additional relevant data, but also serve to calibrate the counter. As Cessford and Burns (2008) discuss, direct observations are reliable, provide a high level of detail, and preclude the need for calibration, but have limited application for long-term use due to costs. Conversely, counting devices can be used for long-term monitoring but do not provide such a high level of detail and are subject to miscounting issues. Examples of complementary methods include the following:

- Both Watson et al. (2000) and Campbell (2006) discuss the use of infrared counters in conjunction with camera records.

- User photography is suitable to be accompanied by a post-trip questionnaire or survey.
- Brief visitor interviews, surveys, or registries can gather contact information that can be followed up by a more detailed telephone survey.
- Data provided by visitor registration boards must include nonresponse rates in its consideration. Video monitoring can provide indications of these rates.

### Resource Availability

When choosing a monitoring method, resource availability is at the forefront of considerations. Throughout the literature, advantages and disadvantages are often discussed in these terms and include staffing requirements, scope of method application, and ongoing costs for long-term monitoring. Primary sources of demand on resources include the following:

- **Staffing—**Methods that do not require on-site staff, in general, are the most cost-efficient. With passive counters, once installation, implementation, and calibration of the method have taken place, few staff hours are required until data analysis is performed. Exceptions to this are passive on-site counters that require continued calibration. Pressure-sensitive counters, for example, require consistent maintenance and calibration during the winter season to account for build-up of snow or ice. Indirect observation through, for example, visitor registration boards, can also be costly if many hours are needed for visitor register installation, monitoring, data collection, maintenance, and compliance efforts (Hollenhorst et al., 1992).
- **Scope of relevance**—In this report, monitoring methods were assessed in relation to meeting management goals for avalanche-warning services. However, many methods have been researched for their applicability to other management objectives, such as wildlife management, ecosystem carrying capacity assessment, and human impact assessment. If a method's scope of relevance is large, there is potential to spread the costs of the method across

other managing agencies. Examples of monitoring methods with a broad scope of relevance include the following:

- GNSS monitoring. This method is applicable to other industries such as emergency management, firefighting, search and rescue, and administrative risk settings (Hendrikx et al., 2013).
- Camera recordings. This method has further valid uses including assisting first responders in avalanche emergencies in determining involvement, studying terrain use, understanding user decision-making, studying avalanche cycles in remote terrain, and monitoring start zones and commonly failing slopes to determine potential trigger points.
- Satellite imagery. This method can easily be applied for other natural resource-related purposes such as wildlife monitoring or for industry purposes such as logging (Cessford & Muhar, 2003).

### Extrapolation to entire backcountry user population

Each of the monitoring approaches will only be able to observe a sample of backcountry users and/or destinations. Hence, it will be necessary to extrapolate the observations to make meaningful conclusions about the entire backcountry user population. Since each of the monitoring methods has unique sample characteristics, different statistical methods are required for the various methods. It is beyond the scope of this report to describe the suitable statistical methods in detail, but we recommend experienced statisticians be consulted when implementing any backcountry user monitoring campaign.

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