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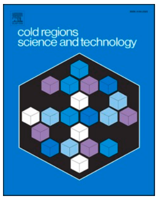

Who skis where, when? – A method to enumerate backcountry usage

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ABSTRACT

Backcountry skiers, travelling in avalanche terrain, account for a large proportion of avalanche fatalities worldwide. Despite this, the exact count of the number of recreationists exposed to avalanches (also known as the background information), is poorly documented in most countries. Without detailed background information on temporal and spatial backcountry usage, making well-reasoned decisions from fatality statistics is impossible. This study developed a methodology to enumerate a large proportion of backcountry usage from a 2589 km^2 study area in Tromsø, Northern Norway. We use an extensive network of specially adapted beacon checkers – small, waterproof devices that detect and count signals from avalanche transceivers. Over two seasons, from December to May from 2021 to 2023, we recorded 56,760 individual trips. Our findings indicate that most (60.0 %) backcountry trips begin between 07:00 and 12:00, with noticeable activity in the afternoon as well. Saturdays and Sundays see the highest daily activity rates, comprising 40.1 % of total weekly traffic, while weekdays, though less busy per day, account for the remaining 59.9 %. The peak season for winter backcountry skiing is during March and April (when counts from the period December to May are considered), accounting for 56.3 % of all traffic. This monthly usage aligns with avalanche incident data, where 55.8 % of incidents occur during the same two months. Our study demonstrates the use of our methodology and advances the understanding of temporal trends from winter backcountry skiing, quantifying the movement characteristics of backcountry skiers in Tromsø, Norway.

1. Introduction/background

Snow avalanches pose a significant hazard in mountainous regions, resulting in an average of 250 fatalities annually worldwide (Schweizer et al., 2021). Over the past decade in Norway, there have been an average of 6.5 yearly fatalities due to avalanches. The annual count has varied, ranging from 2 in the winter of 2016–2017 to 13 in the winter of 2018–2019 (Toft et al., 2023). In the Norwegian subset of fatality data, 90 % of the incidents occur due to recreational activities in avalanche terrain (Varsom, 2023). Furthermore, there has been a noticeable increase in fatalities over the last two decades, especially in Northern Norway. This is believed to be related to the increase in popularity of winter backcountry recreation(e.g. Birkeland et al., 2017). Birkeland et al. (2017) argue that the avalanche **fatality rate** (the number of deaths per unit of usage) is likely decreasing in North America. This decline is attributed to the growing number of recreationalists, often referred to as backcountry skiers,[1] who are often exposed to avalanches. Evidence for this increase in backcountry skiing can be seen in the rising use of avalanche bulletins between 1995 and 2017. According to Langford et al. (2020) no reliable method of directly or indirectly counting the number of backcountry skiers at different times and locations at regional to national scales is available today. To our knowledge, it is only the Swiss national cross-sectional study that has been able to quantify backcountry usage at regional to national scale (Bürgi et al., 2021; Lamprecht et al., 2014; Lamprecht et al., 2008; Lamprecht and Stamm, 2000). Despite the noteworthy work by established avalanche warning services (AWS) and significant focus on avalanche education (Greene et al., 2022), the trend of the fatality rate remains unclear due to

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[1] We use this term to also includes snowboarders. Snowmobilers are not relevant in our study as they are illegal in most backcountry terrain in Norway.

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poorly documented numbers of backcountry usage in most countries, Switzerland being the exception.

The main objective of this paper is to introduce a method that can enumerate backcountry usage within a set area, throughout the entire winter season. This is important, because without an accurate understanding of the number of skiers in an area (i.e. the background information), it is impossible to estimate an accurate fatality rate. The absence of a background information when interpreting fatality count data provides an incomplete understanding of the population level risk, and any changes in the fatality rate over time. The nature of backcountry skiing, dispersed across mountainous terrain without predefined “trails”, makes it challenging to quantify the entire population within an area. In many cases, there is no single point where everybody skis through. And even if starting points can be identified skiing patterns in the terrain might change throughout the season depending on snow conditions, and skier traffic. Conventional attempts often used to count bikers or cross-country skiers, such as thermal counters or induction loops where skiers would have to be led towards a single point or follow the same trail, may therefore fall short in a changing environment. We therefore seek to introduce a method where the skiers have a motivation to seek out the counting stations themselves.

In this paper, we build on previous attempts to enumerate backcountry usage and present a method to quantify backcountry usage by making a large network of modified, counting, beacon checkers in Northern Norway. Although technology has been previously documented by Waller et al. (2012) and further explored in Waller (2014), no results by use of this method have been published to date.

2. Background

In many sports such as climbing, biking, skydiving, and alpine skiing, we understand the background information (Feletti, 2017). However, when it comes to travel in avalanche terrain, the understanding of the background information (e.g. how many are out there) is limited. This is particularly challenging when studying backcountry skiers because of the interaction between avalanches as a natural phenomenon, with limited feedback to those who interact with it, combined with human decision-making. Ideally, the background information, and corresponding fatality data which could aid decision-makers should include information related to demographic insights, details about the total backcountry usage, or statistics on backcountry usage broken down by days, weeks, months, or even hourly patterns. Ultimately, this would allow for an improved understanding of the drivers of changes in avalanche fatality rates, and thereby allow for more targeted solutions.

Similar to backcountry skiing, road traffic statistics has many related patterns. Just like with avalanches fatalities, there are daily and seasonal fluctuations influenced by travel behaviors or natural factors such as snow, ice, and rain (Malin et al., 2019). Demographic data also plays a crucial role here; for instance, men are statistically more prone to traffic accidents than women, and this observation is supported by extensive research (Cullen et al., 2021). To gain a similar understanding and making informed decisions in the avalanche community, a more in-depth investigation of the background information is needed compared to what is available today.

Analyzing temporal distributions, whether in terms of days of the week, months, or annual patterns, can shed light on behavioral trends and associated risks. Past studies have tried to quantify the yearly terrain usage, although often resorting to educated estimations (Jamieson et al., 2009; Münter, 2003; Valla, 1984). Zweifel et al. (2006) was the first to enumerate backcountry skiers within a limited area by directly counting. Using an experimental setup of light barriers, observations from ski patrol and voluntarily registration boards they were able to estimate a total of 2922 off-piste runs from the Rinerhorn ski resort in Switzerland.

In Canada, Sole (2008) estimated the number of recreational skiers, using a survey ($n = 447$) to find the percentage of people with a recreational avalanche safety course through Canadian Avalanche Association (CAA) between 2005 and 2007. The courses were taught by independent avalanche course providers, but the CAA developed the curriculum. Using the total number of students (provided by CAA), he was (simply put) able to estimate a backcountry population of 34,485. A similar study was conducted by Procter et al. (2014) in Italy, where they surveyed 5576 individuals over a 1-week period to learn more about the demographics of backcountry skiers. Furthermore, Techel et al. (2015) used social media platforms to extract 15,586 tours from Switzerland. Using the information available, they estimated the background information as a function of weather, snowpack, avalanche danger and day of week.

One of the most comprehensive studies on the backcountry population is the Swiss cross-sectional national survey, conducted in 2000, 2008, 2014 and 2020 (Bürgi et al., 2021; Lamprecht et al., 2014; Lamprecht et al., 2008; Lamprecht and Stamm, 2000). The results indicate a rapid growth in the backcountry skiing population over the last decade, from approximately 1.4 % of the population from 2000 to 2014 to 3.4 % in 2020 (Table 1). Although, the median number of hours spent in avalanche terrain decreased from 56 h in 2014 to 20 h in 2020, meaning that the total number of hours spent by the entire population did not change substantially. This data suggests that the growth in the backcountry skiing population may be due to less experienced individuals taking up the sport, who typically spend fewer hours per year on avalanche terrain. The cross-sectional study from Switzerland is, to our knowledge, the only study that has been able to reliably estimate backcountry usage at a national scale.

When Winkler et al. (2016) compared the survey results with avalanche fatalities, the data revealed a minuscule decrease in the fatal accident rate from 9.4 to 8.7 micromorts (i.e. 9.4 to 8.7 $\times 10^{-6}$) from 1999 to 2013, where one micromort is equivalent to a one-in-a-million chance of death in a given year (Howard, 1984). For comparison, a skydiving jump in the US has a probability of 5.1 micromorts (United States Parachute Association, 2022). The study by Winkler et al. (2016) is a compelling example of the importance of considering background information when assessing outcomes. If we only consider the fatality data alone, there appears to be a concerning 20 % increase in skier deaths in Switzerland between the periods 1993/94 to 2003/04 and 2004/05 to 2014/15.

Using another approach, in work in Montana, USA, at Saddle Peak near Bridger Bowl ski area, Saly et al. (2020) used remote time-lapse photography monitoring from a fixed distance to record terrain metrics of all skiers in avalanche terrain. Saly et al. (2020) counted 525 skiers over a period of 13 days and identified 7499 skier point locations (the timelapse camera took photos every 10 s resulting in multiple locations for each skier). This method captures all skiers but is limited by visibility. In the same season, Sykes et al. (2020) counted and tracked 136 participants over 19 field days using intercept surveys and GPS tracking, but this method is limited by the high personnel costs, and location conducive to capturing participants on their route. Both methods are limited to counting skiers at slope scale and are difficult to apply at scale for a region or entire country.

In Northern Norway, Toft et al. (2023) attempted to quantify backcountry skiers using signaling data from mobile network operators.

Table 1
Results from the Swiss cross-sectional survey between 2000 and 2020 (Bürgi et al., 2021; Lamprecht et al., 2014; Lamprecht et al., 2008; Lamprecht and Stamm, 2000).

Year	Proportion of the population [%]	Touring days per year [median]	Average No. of hours per year [median]	Total No. of hours per year [in million hours]
2000	1.3	10	–	–
2008	1.5	10	–	3.9
2014	1.4	10	56	4.8
2020	3.4	6	20	4.9

Unfortunately, when they compared the positional accuracy with actual GPS data, it became evident that the method was highly inaccurate in remote terrain typically used by backcountry skiers.

Langford et al. (2020) conducted a literature review to examine existing methods to estimate the overall backcountry usage. They considered 22 methods and narrowed them down to five categories. If we compare these methods with current research, most studies fit within these categories (Table 2).

1. When conducted properly, cross-sectional surveys can accurately reflect the broader population, yet they typically offer limited spatial or temporal insights, as Winkler et al. (2016) noted.
2. Extrapolation from direct counts provides valuable spatial and temporal information. However, its scalability is challenging over larger areas, a limitation highlighted in studies by Zweifel et al. (2006), Saly et al. (2020), and Sykes et al. (2020).
3. Indirect counts (e.g. Toft et al., 2023),
4. Citizen science counts feature extensive spatial coverage and gather detailed spatial-temporal data (Johnson and Hendrikx, 2021). However, studies have yet to secure a sample size sufficient for national or global statistical validity. The method also assumes that the user-reported trips are representative, which is unlikely, given self-selection bias to participate in crowd-sourced data collection.
5. Online engagement has shown promise, particularly in Switzerland, where extensive user-reported datasets are leveraged (Techel et al., 2015; Winkler et al., 2021). This method can extract spatial and temporal data, assuming the representativeness of user-reported trips as for citizen science counts.

All these methods attempt to capture a representative sample of the population to allow for an accurate estimate of the background information. The different methods have their strengths and limitations. National cross-sectional studies may provide an overarching understanding of the backcountry usage, but have their limitations in providing a detailed description of where and when skiers are out. Direct or indirect ways of counting skiers can provide such details, but have limitations when applied to large regions or entire countries.

3. Methods

3.1. Study area

The study was conducted in a 2589 km^2 area surrounding Tromsø, Norway, located within the Arctic Circle. This region experiences polar nights for extended periods during the winter (Fig. 1). The region was selected due to its large percentage of Norwegian avalanche fatalities, accounting for 56 % of the country's total from 2018 to 2023 (Varsom, 2023). Tromsø's appeal as a tourist destination, particularly for foreign visitors who now represent over half of the regional avalanche deaths, adds to its relevance in avalanche research. The area's Arctic Transitional climate, which alternates between maritime conditions with frequent rain-induced crusts in warmer periods and extensive depth hoar formation in colder seasons (Velsand, 2017).

3.2. Setup and components

The beacon checker is a small waterproof device that constantly searches for avalanche transceiver signals. An avalanche transceiver (combined transmitter and receiver) or avalanche beacon is an emergency locator beacon used to find people buried under snow. They are widely carried by backcountry travelers, for use in the case an avalanche burial (Schweizer and Krüsi, 2003).

When a transceiver signal is within a threshold distance, the beacon checker can be programmed to flash with green LEDs, beep or both. The response is a confirmation to the backcountry skier that their avalanche beacon is on and transmits a searchable signal. Beacon checkers are most commonly used at large ski resorts or popular backcountry trailheads in North America to remind people that they are accessing terrain where an avalanche beacon is recommended, and that it should be in transmitting mode at this point. It is also possible to use the beacon checker to activate a gate, requiring an avalanche beacon to access certain types of higher risk avalanche terrain. This feature utilizes an electrical current being transmitted by the beacon checker when a beacon is within the threshold range. Our methodology is built around this feature, where the electrical current is used for counting the number of people passing by the beacon checker. We present the first data of this type, collected for a large geographic area, an estimate of backcountry usage from avalanche terrain in Northern Norway.

The beacon checker runs on a 12 VDC system, with a power consumption of roughly 15–20 mAh in sleep and power save mode. In sleep mode, the device wakes up every 15 s to search for signals in the area. In power save mode, a red and green LED lights flash instead of being constantly illuminated. The red light shows that there is no beacon within the range, and it turns green when an avalanche beacon is within the threshold distance. Because a lot of the trailheads used in this study are along roads, we disabled the red light to avoid disturbance for road users. The power consumption of the beacon checker is estimated to be 0.42 Ah per day.

Fig. 2 shows the setup of our system for counting backcountry users at trailheads with beacon checkers. To keep the system running from the beginning of December to the end of May, we also added a solar panel

Table 2
Comparing available methods and example studies with their spatial scale, spatial and temporal resolution, length of season and type of sample.

Approach	Examples	Spatial scale	Spatial resolution	Temporal resolution	Length of season	Sample
Cross-sectional surveys	Lamprecht and Stamm, 2000; Lamprecht et al., 2008; Lamprecht et al., 2014; Bürgi et al., 2021	Nationwide	Low	N/A	N/A	Representative[1] (n = 10,652)
Extrapolation from direct counts	Zweifel et al., 2006	Ski resort	Moderate	High	All season	Subset (n = 1868)
	Saly et al., 2020	Slope	High	High	All season	Subset (n = 525)
	Sykes et al., 2020	Slope	High	Low	Selection of 19 days	Subset (n = 136)
Citizen science counts	Johnson and Hendrikx, 2021	Worldwide	High	High	All season	User-reported (n = 482)
Online engagement	Techel et al., 2015	Nationwide	Moderate	High	All season	User-reported (n = 15,586)
	Winkler et al., 2021	Nationwide	High	High	All season	User-reported (n = 7355)
Indirect counts	This study	Regional	Moderate	High	All season	Representative[2] (n = 56,752)

[1] Representative in terms of number of touring days per season.

[2] Representative in terms of time of day, week, and month. No number of overall touring days per season.

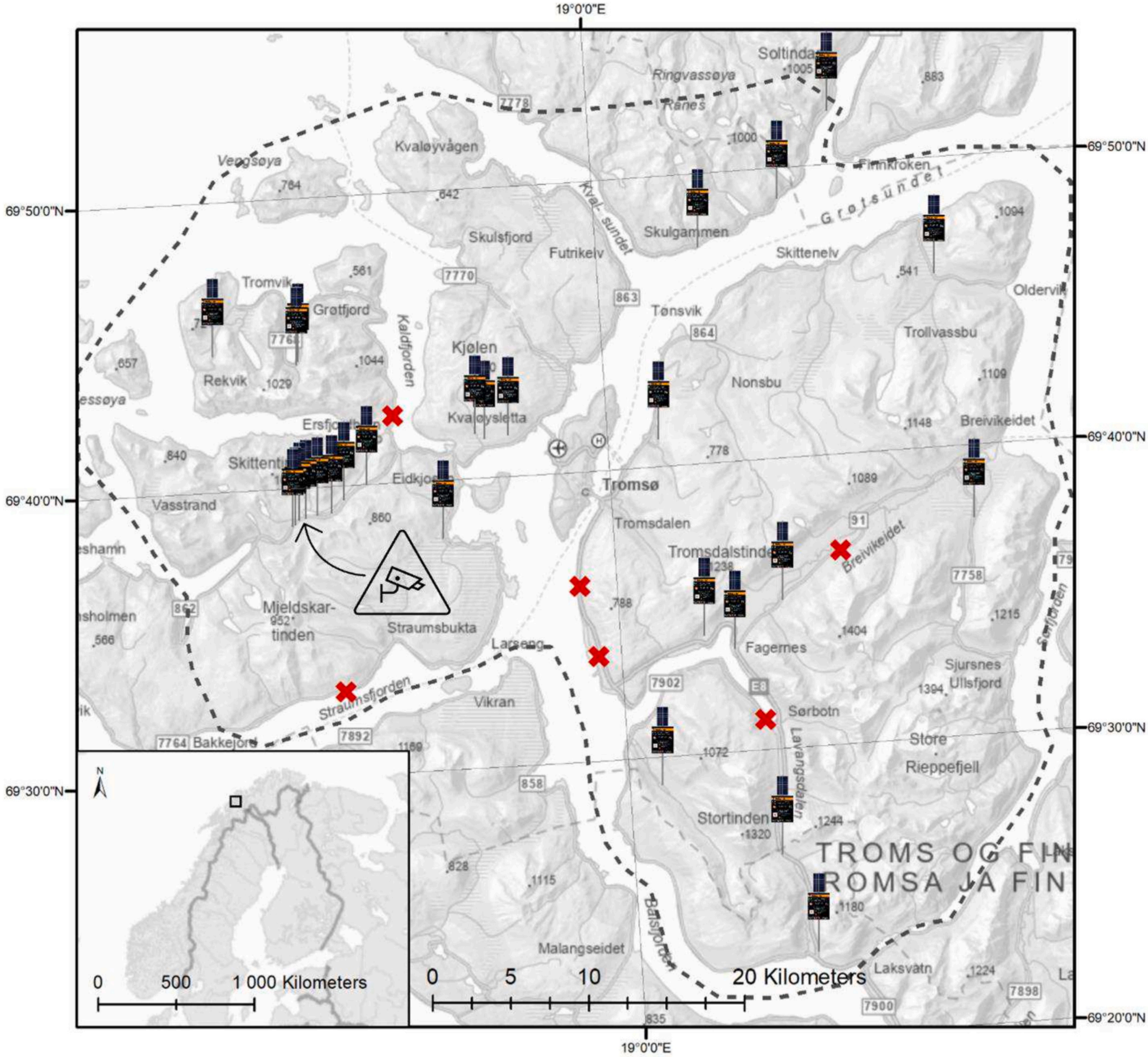

Fig. 1. The study area (black dotted line) in the vicinity of Tromsø, Norway. The location of the 29 signs with beacon checkers deployed during the first season are shown (bottom of the pole marks the spot). The red x's illustrate the 6 locations that were considered, but not implemented. The location of the time-lapse camera is marked with a camera icon. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(12 VDC, 30 W). The solar panel charges the batteries from the beginning of March (halfway into the season) and through May. However, due to the polar latitude of the region (~69°N), it is affected by the polar night for a large part of the winter season, we had to use two 12 VDC LiFePo4 batteries. In total, each beacon checker had a battery capacity of 2 × 24 Ah, which is enough to be running for roughly four months under optimal conditions.

To gather data from the beacon checker every time it's being used, we added a data logger and pulse counter with IoT/LTE capabilities. To translate the 12 VDC current signal from the beacon checker, we added a SPST-NO type of reed relay. When the relay is exposed for a 12 VDC current, it closes the circuit between the two wires from the datalogger, triggering a count each time (Fig. 2). The datalogger was set to record the number of counts per 5-min interval. A total of 32 units were prebuilt by us and shipped to Tromsø, Norway for their deployment and the operational phase.

During the operational phase, the technical system was mounted on a post with appropriate signage. Using the same layout as the information signs in the neighboring municipality, Lyngen, we developed a design for the beacon checkpoints (CPs) using a 90 × 75 cm template (Fig. 3a). The signs were attached 110 cm above the ground using a single pole measuring 270 cm × 60 mm. The upper 70 cm was used to attach the solar panel using brackets, making the whole installation 270 cm in height and roughly 35 kg. The pole was attached to the ground using a metal foundation where a rock surface was available using 12 mm expansion bolts and glue (Fig. 3a). If the ground consisted of mud or soil, an 89 × 900 mm ground screw was used. The material cost of a single CP, including the beacon checker, signage, and pole, was approx. US $1600 (excl. Norwegian sales tax) when purchased in 2021.

To enable convenient transportation and storage of the 32 CPs, with a total weight of 1120 kg, two custom trailers were built using mounting brackets and a canoe stand. This made it possible to bolt each CP to the

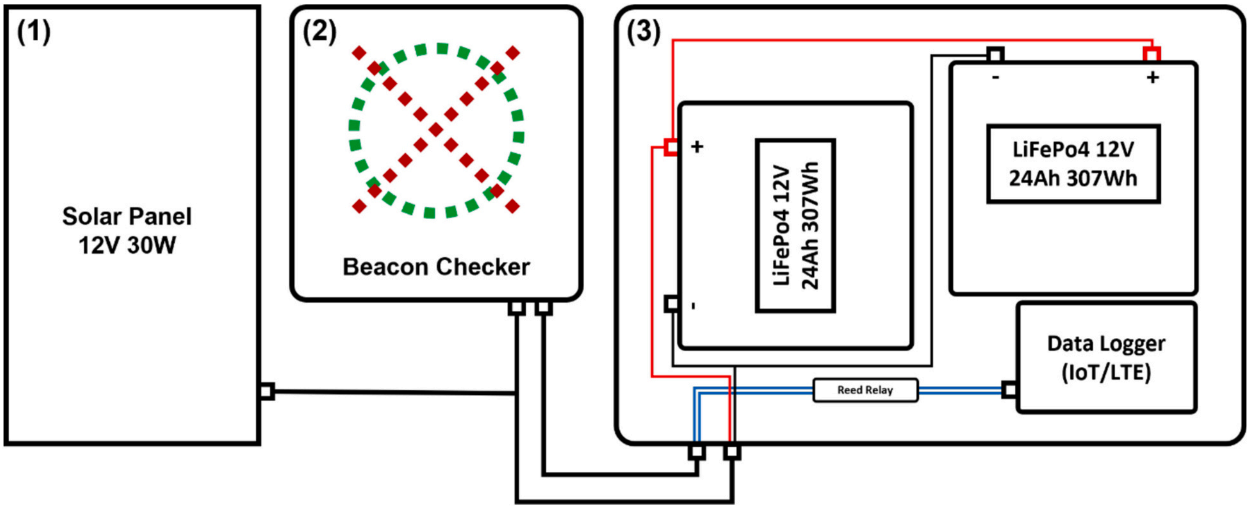

Fig. 2. The technical system consists of three parts: (1) a solar panel, (2) a beacon checker and (3) a hard case with 2 batteries and a data logger.

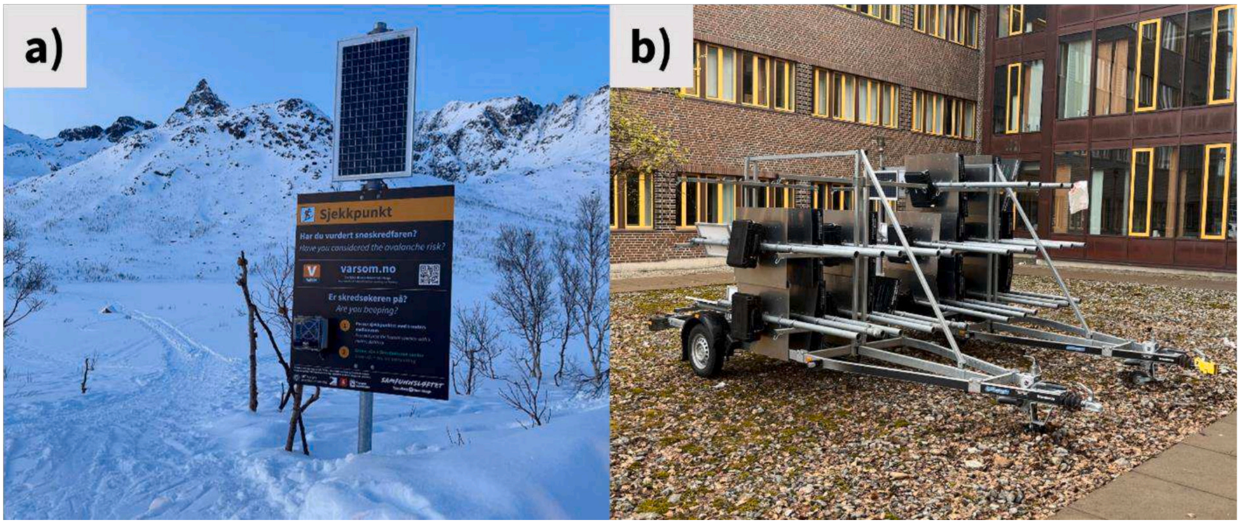

Fig. 3. a) The CP mounted in the field in winter conditions. b) The two custom made trailers to transport the CPs between their operational location and the storage and service site.

trailer, with a maximum capacity of 16 CPs per trailer (Fig. 3b). To make sure that the CP keep running with no malfunction, they were mounted at the end of November and retrieved again at the beginning of June. Retrieving the CPs at the end of each season enables service, including recharging the batteries and making sure that each beacon checker is dry and ready for a new season in a harsh winter climate. The main limitation of the system reliability is the beacon checkers which frequently gets filled with water in the spring season. We have now added silica gel inside each device at the beginning of the season to limit this issue.

3.3. Site selection

Using the Strava Heatmap (Strava, 2023), we identified locations that are the main trailheads being used for skiing within the study area of roughly 1-h drive from downtown Tromsø, Norway (Fig. 1). After identifying the most used routes, we shared the map with three local avalanche experts to check whether we had missed any relevant locations, and to confirm the relevance of the selected sites. The process led to 35 sites being identified, but only 30 got approval from the land owner, and one was discarded due to construction (Fig. 1; Table 3).

The last step to confirm the final selection of our CP locations, was to obtain permission from the relevant landowner at each location. Fortunately, 86 % (30/35) of the requested locations were approved by the respective landowners, and we could proceed with these locations (Table 3). One location was later dropped due to a highway being built at the intended location. We therefore deployed 29 CPs during the first season from 2021 to 2022 (Fig. 1).

The beacon checkers do not search for unique individual frequencies or individual people when counting the number of people passing each CP (adjusted to a detection range of 2–3 m). The range is like many typical trail counters, but the CPs have the advantage that there is a benefit for the skier to go past the beacon checker. This means that if one person is curious and walks back and forth to the sign 10 times, that person would be counted 10 times. It also means that for some trailheads, where the path leading away from the parking lot is very defined, it's hard to avoid being counted in both directions. We have illustrated this problem in Fig. 4, using two scenarios. In the one-pass scenario, the CP is placed in such a way that there is no detour to pass it on their departure, but on their return, there is the potential for people to go around the CP (e.g. skiing an adjacent slope to another point along the road). Therefore, in the case of one-pass, it is up to the backcountry skier to elect if they chose to pass or avoid the CP on their return. In a two-pass

Table 3
A list of all the locations grouped by region that were considered, and whether they had landowner permission and when they have been active during the last two seasons from 2021 to 2023. A qualitative assessment of whether each location is a one-time, or two-time, pass type is also presented as type.

ID	Location	Permission	Active	Type	Used in time-lapse validation
Kvaløya					
1	Tverrfjellet	Yes	21–23	one-pass	Yes
2	Durmålstinden	Yes	21–23	one-pass	Yes
3	Skittentinden 1	Yes	21–23	one-pass	Yes
4	Skittentinden 2	Yes	21–23	two-pass	Yes
5	Straumsaksla 1	Yes	21–23	one-pass	Yes
6	Straumsaksla 2	Yes	21–23	one-pass	Yes
7	Straumsaksla 3	Yes	21–23	one-pass	No
8	Storsteinnestinden 1	Yes	21–23	one-pass	No
9	Storsteinnestinden 2	Yes	21–23	one-pass	No
10	Steinskarfjellet	Yes	21–23	one-pass	No
Ringvassøya					
11	Bjørnskarstinden[2]	Yes			
12	Nordfjellet	Yes	21–23	two-pass	No
13	Skulgamtinden	Yes	21–23	one-pass	No
Rekvik					
14	Storstolpen	Yes	21–23	one-pass	No
15	Hollendaren	Yes	21–23	one-pass	No
16	Styrmannstinden[2]	Yes	21-22	one-pass	No
17	Buren	No			
Kvaløysletta					
18	Rødtinden	Yes	21–23	one-pass	No
19	Akselkollen	Yes	21–23	one-pass	No
20	Finnlandsfjellet[2]	Yes	21-22	one-pass	No
21	Botnfjellet	Yes	21–23	one-pass	No
22	Gråtinden	No			
Tromsø mainland					
23	Ullstinden	Yes	21–23	one-pass	No
24	Rundfjellet[1]	Yes	21-22	one-pass	No
25	Tromsdalstinden	Yes	21–23	two-pass	No
26	Middagsaksla	Yes	21–23	two-pass	No
27	Fagerfjellet	Yes	21–23	one-pass	No
28	Stormheimfjellet	Yes	21–23	two-pass	No
29	Gårdselvtind[3]	Yes	22-23	two-pass	No
30	Andersdalstinden	Yes	21–23	two-pass	No
31	Blåtinden	Yes	21–23	two-pass	No
32	Storkollen[4]	Yes			
33	Sollidalsaksla	No			
34	Bønntuva	No			
35	Gabrielfjellet	No			

[1] Malfunction during the first season. Not in use during the second season.

[2] Did not capture the traffic as expected during the first season. Not in use during the second season.

[3] Malfunction during the first season. New path established outside of beacon checker; counts are probably not accurate during second season.

[4] A new highway is being built at the intended location.

scenario, there is some level of geographic confinement which makes it impossible to not go pass the CP on both their departure and return. Careful consideration was given to each site, and adjustments were made to the data to reflect these scenarios. We have included a column in Table 3 showing what category each CP is in terms of one-pass or a two-pass scenario.

3.4. Validation using a time-lapse camera

As it is not possible to count the number of unique people using the beacon checker method, we need to validated the number of counts received from the beacon checkers relative to the number of people entering backcountry terrain at each CP. To do this, we mounted a time-lapse camera on an adjacent mountain ridge taking frequent images (every 30 s).

According to Norwegian privacy law, a time-lapse camera taking images frequently is considered surveillance if it is possible to identify people on the images. It was therefore necessary to have a long distance between the camera and the CP to get the approval from the Norwegian Agency for Shared Services in Education and Research (SIKT). The data could only be used for validation of the time-lapse camera and had to be deleted immediately afterwards its intended use.

Due to limitations in terms of resources and location, we placed the camera on a single spot on Kvaløya with a direct line to three high-use trailheads with two CPs mounted at each location (some specific trailheads have access to backcountry terrain at both sides of the road, hence two CPs). This enabled us to get data from six different CPs including both one-pass and two-pass scenarios (as per Fig. 4 and Table 3). There are also challenges with weather and low visibility, but even though it occasionally would impossible to count people on a section of images, it was mostly possible to observe the presence of new cars. And we did not have any indication that we missed incoming or departing skiers by observation of arrival or departure of cars. Optimally, we would have moved the camera to other CPs, but due to landowner permissions and terrain characteristics that allowed images being taken from several hundred meters to kilometers away, the options were limited.

The time-lapse camera was built using a custom built hard-case box that could be pivoted in both vertical and horizontal planes. A digital single-lens reflex (DSLR) camera with an APS-C sensor was used in combination with a 140–560 mm zoom lens and an external digital time-lapse controller. The whole installation was powered by two LiFePo4 12 V 24 Ah batteries identical to the ones being used in the CPs. The camera was maintained every two weeks by replacing the memory card, batteries and resetting all camera settings from the 14th of February to June 1st during the 2023 season. Every two-week period, the camera was rotated between the three trailheads as the camera field of view could only cover one trailhead at the time. The time-lapse camera captured images every 30 s for a total of 108 days (194,400 images) between 08:00–09:00 and 23:00–24:00 (depending on daylight saving time).

To compare the number of skiers with the counts received from each CP, we manually went through all images. For every day, we noted the valid timeframe of the images (e.g. start, blurred periods, end) and the number of skiers entering backcountry terrain. We also noted how many that returned from backcountry terrain, but this data was not used for the analysis. Finally, we compared the number of skiers entering backcountry terrain with the counts from each CP during the day (e.g. if 24 skiers entered avalanche terrain and the CP logged 30 counts, the ratio would be 0.80).

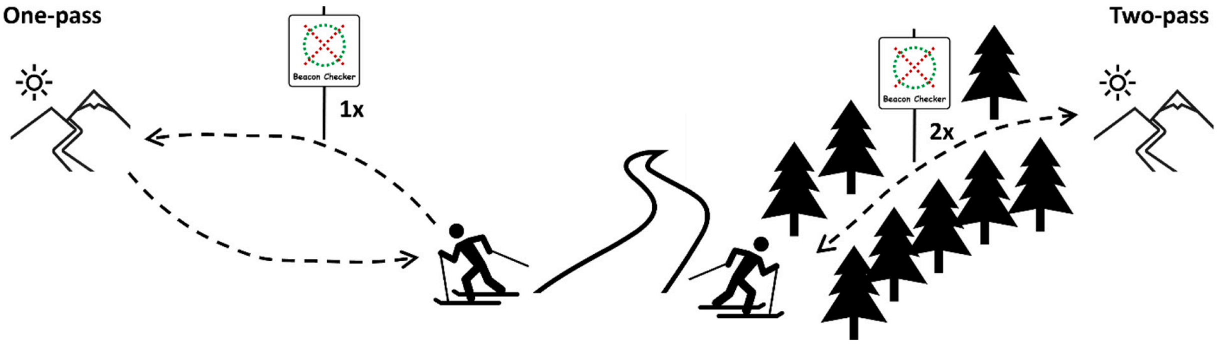

Fig. 4. In most locations, the CP is placed so that it is logical to pass it on the ascent, while there is much room to avoid it on the descent (one-pass). However, in some locations, it is most convenient to pass it on both the ascent and the descent (two-pass).

3.5. *Operational issues with the CPs*

During the period of deployment, various operational challenges impacted the data collection process at several CPs. These interruptions and malfunctions are crucial to acknowledge for accurate data interpretation and analysis.

3.5.1. *The 2021–2022 season*

During the first season from 2021 to 2022, we intended to set up 29 CPs. However, due to the limited availability of parts as a result of the Covid-19 pandemic and resulting supply-chain issues, only 22 CPs were placed out from 1st of December (Table 3; Appendix-1).

Unfortunately, *Straumsaksla 2* never commenced operation due to a technical error that went unnoticed, so we do not have data from this location during the first season. Furthermore, the CP at *Skittentinden 1* experienced a data logger malfunction, ceasing its operation from 1st of December through 8th of December 2021. Later in December, a widespread power outage occurred on Kvaløya (Table 3; Appendix 1) as these CPs were set up in early November. This happened due to lower solar input than expected. The problem leads to significant data gaps from the 18th of December 2021 to 4th of January 2022. The problem was rectified by adding a second battery to all CPs (Fig. 1). Another short outage on the Tromsø mainland (Appendix-1) occurred from January 21st to 23rd, 2022.

Additional seven CPs were installed on March 25th, 2022, when the final parts had arrived. These were strategically selected for late installation due to their low expected traffic in the first half of the season, or low priority (Appendix-1). Due to failures with equipment, we quickly realized that we would have to reduce the number of locations to allocate spare parts. Bjørnskarstind and Rundfjellet was therefore decommissioned instantly due to the unavailability of replacement parts and low priority.

Some CPs faced individual challenges as well. *Gårdselvtind* malfunctioned and was eventually discontinued due to a shortage of essential spare parts and the placement of an erroneous data logger at the site. From the 13th of February until 7th of March 2022, the beacon checker at *Botnfjellet* malfunctioned. The error came from the gain module which adjusts the detection distance. The error made the CP count all beacons within range, and not the threshold distance of 2–3 m. Although the period was easy to identify due to the unusually large traffic data reported, the issue was discovered too late to prevent the recording of inaccurate data during that specific timeframe.

3.5.2. *The 2022–2023 season*

From the start of the season, 25 CPs were placed out (Table 3; Appendix-2). Two CP (*Ullstinden* and *Straumsaksla 3*) never commenced operation. The failure of these stations went unnoticed due to an oversight in the routine data monitoring and verification processes. For *Straumsaksla 3*, the detection of the issue was particularly challenging due to its typically low traffic in the early part of the season.

The same error that occurred during the 21–22 season at *Botnfjellet* was identified at *Stormheimfjellet* from the 10th of February, 2023. The error was quickly identified, and the beacon checker was replaced by the 17th of February, 2023.

In conclusion, the data collected during the two skiing seasons should be analyzed with consideration for these operational challenges. These outlined issues provide context for the data gaps and anomalies observed in the recorded backcountry skier data, ensuring a more accurate and informed interpretation and analysis.

4. Results

The intention was to set up 29 CPs for the first season from 2021 to 2022. Unfortunately, two CPs were never commissioned, and one CP never commenced operation. The remaining 26 CPs had an overall downtime of 4.7 % (207 out of 4424 days).

During the second season from 2022 to 2023, we intended to set up 25 CPs. Two CPs failed to collect data. The remaining 23 CPs had an overall downtime of 0.2 % (8 out of 4163 days), which is a large improvement from the previous season.

4.1. *Validation using a time lapse camera*

When we reviewed the time lapse camera images, a substantial number of the images were unusable due to erroneous set-up, including focus and camera settings (i.e. ISO, shutter time and aperture). This left a total of 75 days from February 14th to April 30th (135,000 images) where skiers could be identified. Roughly 22 % of these images were unusable due to darkness within the 15-h period between 08:00–09:00 and 23:00–24:00. The polar nights are longer in early winter, meaning that a larger proportion of these unusable images occurred in the early season. Another 4 % the images where unusable due to bad visibility such as fog, and dew on the lens. This left us with 101,470 images to analyze. After manually reviewing all the images, we found a total of 1399 people passing the six CPs within the periods of the time-lapse camera being operational. This means that for one-pass CPs, 0.87 of people counted by the CP are observed to have passed the site on average, with values ranging from 0.41 to 1.14 (i.e., almost 1 count per person). For two-pass CPs, 1.92 of people counted by the CP are observed to have passed the site on average (i.e. almost 2 counts per person) (Table 4).

4.2. *Adjust for validation metrics*

Using the findings from the validation with time lapse camera, we can empirically adjust our data accordingly. For one-pass CPs, we have divided the counts from the beacon checker by 0.87 to get the number of unique trips. We do the same for two-pass CPs, where we divided the counts by 1.92 to get the number of unique trips (Table 5; Fig. 5).

Table 4

A time-lapse camera was placed out taking images of six different beacon stations at three different locations. The number of days, images, skiers, and accuracy for each location is presented in each column.

	Station ID	No. of days	No. of images	No. of skiers	No. of counts	Ratio
One-pass	Straumsaksla 1	29	33,746	70	29	0.41
	Skittentinden 1			414	449	1.08
	Durmålstinden	15	17,488	384	232	0.60
	Tverrfjellet			395	363	0.92
	Straumsaksla 2	18	22,768	120	137	1.14
	Summary	**64**	**74,002**	**1399**	**1211**	**0.87**
Two-pass	Skittentinden 2	18	22,768	115	221	1.92
	Summary	**18**	**22,768**	**115**	**221**	**1.92**

4.3. *Skier traffic by hour*

To better understand the distribution by time of day, we grouped our dataset from all CPs by hour. To do this, we only used one-pass CPs. Type 2 CPs would not be representative in this context as we expect each skier to pass the CP two times, making it impossible to know which registration accounted for heading out time. The data shows increasing traffic from 06:00 to about 09:00, with increasing traffic levels until around 09:00. From 09:00 to around 20:00, there is a gradual decrease in people starting their trips. There is also some traffic late in the evening and through the night (Fig. 6).

4.4. *Skier traffic by day week*

A distinct difference between weekdays and weekends characterizes the distribution of traffic throughout the week. The highest level of activity was observed on Saturdays and Sundays. In contrast, the weekdays, from Monday to Friday, show relatively lower and consistent counts of skiers per day. However, there is a slight increase in traffic from Monday (~6200) to Friday (~7500) (Fig. 7).

4.5. *Skier traffic by month*

To get a better understanding of the seasonal variations, we excluded any CPs that experienced failures for periods exceeding two weeks (specifically, CPs 7, 12, 13, 15, 16, 20, 23 and 29). Ideally, the analysis would consider only CPs that provided uninterrupted data across both seasons. However, the extensive power outage in the first season, particularly in December, necessitated the inclusion of CPs with partial data to maintain a viable sample size for comparison.

If we compare the distribution of skier traffic throughout the season by month (Fig. 8), we can see that the trend in traffic is gradually increasing from December to April. There is approximately the same amount of traffic in January and February. March and April represent the most popular months, with April being the peak. In May, the traffic decreases to a level just below January and February, but significantly higher than December. The traffic for the 2021–2022 season was higher than the 2022–2023 season in all months except for December and March, where the 2022–2023 season saw more traffic. When comparing the two seasons using the Pearson correlation coefficient, we find a value of 0.89, indicating a strong positive linear relationship between the datasets. Additionally, the p-value of 0.016 suggests that this correlation is statistically significant.

4.6. *Seasonal variations*

To maintain consistency in our analysis, we again excluded CPs that experienced failures for periods exceeding two weeks, specifically CPs 7, 12, 13, 15, 16, 20, 23, and 29. A cumulative data visualization reveal that the traffic is fairly consistent for both seasons. Notably, the 21–22 season show a marginally more pronounced mid-season peak in February, although the 22–23 season bridges that gap over the next month and a half. In the final month of the 21–22 season, we found a

Table 5

A summary of counts from all stations is provided below (rounded to closest 10s). For more detailed information on each station throughout the season, see Appendices-1 and 2.

		No. of beacon checker counts		No. of unique trips	
ID	Location	2021–2022	2022–2023	2021–2022	2022–2023
1	Tverrfjellet	2120	1840	2420	2100
2	Durmålstinden	260	790	300	900
3	Skittentinden 1	720	1510	820	1720
4	Skittentinden 2	1830	1440	950	750
5	Straumsaksla 1	290	150	330	170
6	Straumsaksla 2	0	640	N/A	730
7	Straumsaksla 3	360	N/A	420	N/A
8	Storsteinnestinden 1	2540	1900	2900	2170
9	Storsteinnestinden 2	410	110	470	130
10	Steinskarfjellet	3060	1700	3490	1940
12	Nordfjellet	190	220	100	120
13	Skulgamtinden	230	180	260	200
14	Storstolpen	240	2060	280	2350
15	Hollendaren	160	60	190	70
16	Styrmannstinden	10	N/A	10	N/A
18	Rødtinden	2390	1700	2730	1940
19	Akselkollen	2630	3210	3000	3660
20	Finnlandsfjellet	110	N/A	130	0
21	Botnfjellet	3200	1770	3650	2020
23	Ullstinden	3390	N/A	3870	N/A
25	Tromsdalstinden	2380	2880	1240	1500
26	Middagsaksla	250	150	130	80
27	Fagerfjellet	2400	1340	2740	1530
28	Stormheimfjellet	1430	660	740	340
29	Gårdselvtind	810	230	420	120
30	Andersdalstinden	250	60	130	30
31	Blåtinden	630	280	330	140
	Sum	**32,290**	**24,880**	**32,050**	**24,710**

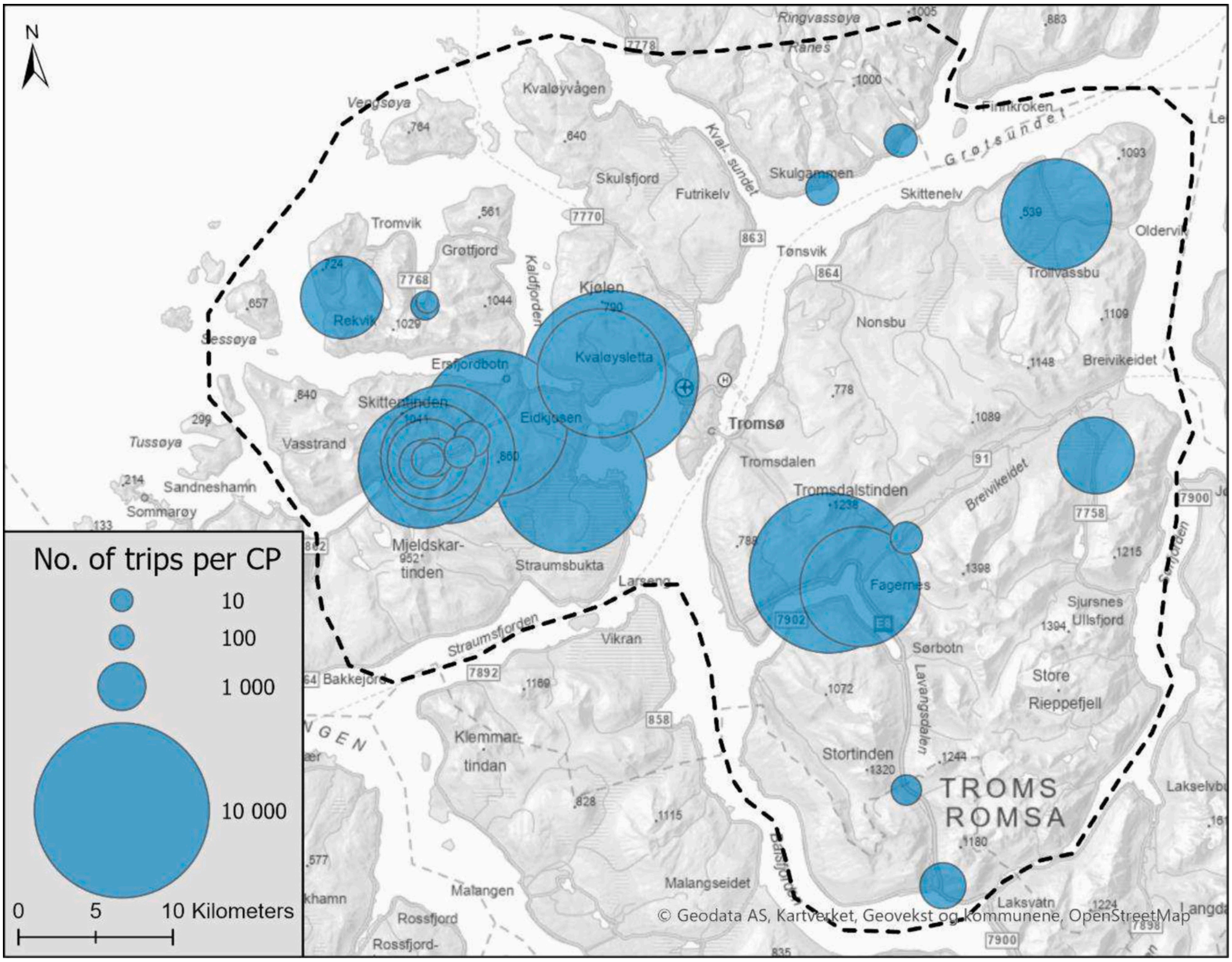

Fig. 5. The number of unique trips from each CP illustrated. The larger the circle, the more trips is being made in the area (one circle per CP).

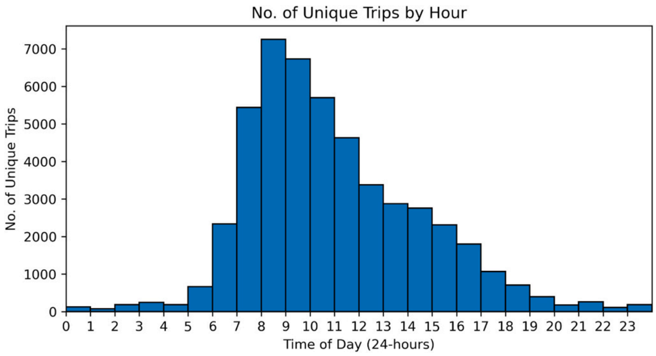

Fig. 6. The distribution of skier traffic throughout the day is shown above. Most people are out between 06:00 and 18:00, with the peak between 08:00 and 09:00. Some skiers are out during the night which is not uncommon in this region with modern headlamps. Only one-pass CPs are used here, as two-pass CPs would not be representative in this context, as we expect each skier to pass the CP two times.

relative increase compared to the 22–23 season, culminating in the highest number of unique trips for the entire season (Fig. 9).

5. Discussion

5.1. Validation using time-lapse camera

In our study, we needed to validate skier count data from CPs, as they do not represent unique skiers. We employed a time-lapse camera set to capture images every 30 s to achieve this. The 30-s interval was defined to have as few images to process while still being frequent enough to detect all skiers passing through the picture frame. Our impression from the manual validation is that this interval was suitable for our purposes, as skiers are not likely to pass through the camera field of view within the 30 s timeframe.

During February’s shorter daylight hours, the camera operated from 09:00 to 22:00. After the switch to summertime on March 26th, the timing shifted to 08:00 to 21:00. Looking back, extending this operational period would have been beneficial as daylight hours increased towards the spring.

To reduce the processing time of manually going through all the images, we noted how many people passed each CP daily combined with timestamps defining the counted period. This allowed us to compare daily counts at each CP for the specific time frame. However, the accuracy varied daily, influenced by the number of people using the trailhead and their interactions with the CP. For example, a single individual passing the trailhead without using the CP results in a 0 %

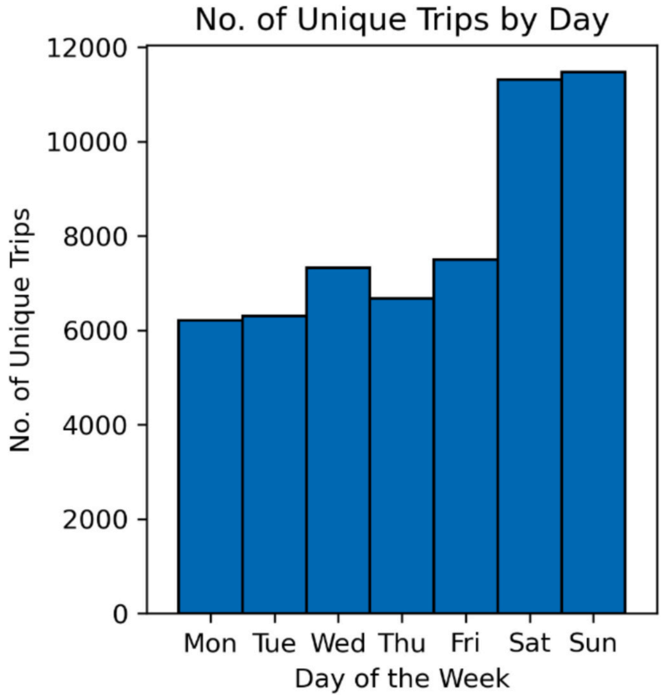

Fig. 7. The distribution of traffic throughout the week. Most people are out during the weekend, but there is also a significant amount of traffic during the weekdays.

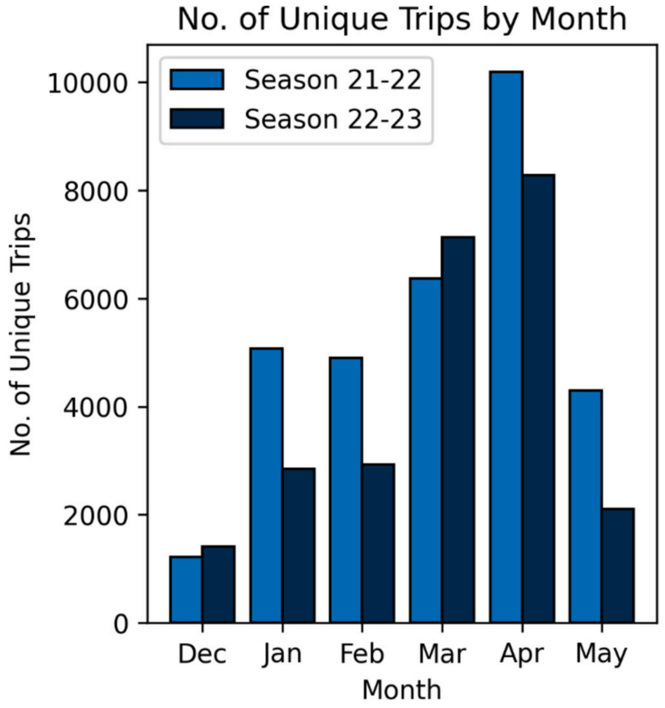

Fig. 8. The data illustrates a monthly distribution of unique skiing trips, with the lowest number of trips occurring in December, and a notable spike observed in March and April.

validation rate for that day. Conversely, if one person passes multiple times, curious about the sign, it might result in a count of five for a single individual. During days with more counts, this effect decreases.

Through this method, we observed that the accuracy rates converged over several days to an average of 0.87 for one-pass CPs and 1.92 for two-pass CPs. One-pass CPs were validated at five different locations with ratios ranging from 0.41 to 1.14. We believe the ratio differences are primarily due to the placement of each CP. For example, at the Durmålstinden trailhead, the parking lot is situated on a plateau, with the CP positioned lower and not as visible, contributing to a lower rate. Similarly, the Straumsaksla 1 CP is located 20–30 m off the natural path to the mountain, with optimal placement hindered by a large swamp. Given the nature of these examples, it is more appropriate to evaluate the validity of the CPs based on these multi-day averages rather than making day-to-day comparisons.

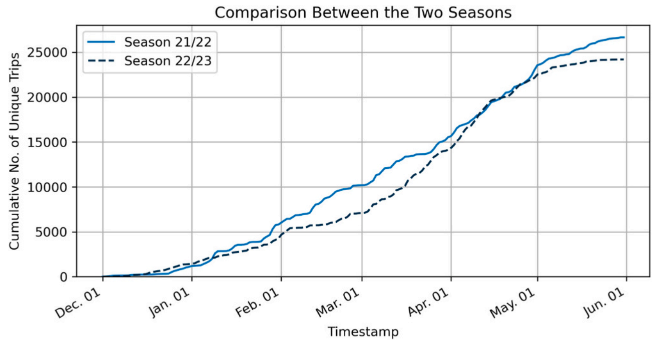

Fig. 9. A cumulativ comparison of no. of unique trips from both seasons. CPs that experienced failures for periods exceeding two weeks (specifically, CPs 7, 12, 13, 15, 16, 20, 23 and 29 are excluded).

5.2. Limitations

Although we find our results promising, we must acknowledge certain limitations in our methodology. The CPs are mounted in harsh and remote areas. Even though we made all precautions possible, it is inevitable to avoid technical errors such as low battery voltages, moisture in electronics and the CPs falling over due to strong winds (e.g. 30–50 m/s). To limit these issues, we always had a person available to do maintenance on short notice. In most cases, this allowed us to keep the CPs running with a low downtime.

Compared to other methods for counting skiers (e.g. the use of light barriers) this method only counts people wearing an avalanche beacon. Even though we do not have a direct overview over how many that do or do not carry an avalanche beacon, results from a large co-hort study from the same area show that 98,2 % (Mannberg and Hetland, 2022) carry a beacon. In addition, our validation demonstrates that difference between the real traffic registered from our time laps camera and our results derived from the beacon checker closely match. The benefit of using beacon checkers instead of other methods is that it provides the participants with motivation to check their beacon and may therefore lead to more people passing the beacon checkers compared to other means of counting.

Another limitation for the study itself is the dependence on a landowner permission to mount a CP at each trailhead. While we rarely faced this restriction in our desired locations, it could be a big issue if the study where to be recreated somewhere else. Additionally, we operate under the assumption that the ratios derived from our validation are applicable to all CPs. We would also like to emphasize that our sample size for two-pass counting points was smaller than ideal, making two-pass CPs more uncertain. We also rely on the assumption that our categorization into one-pass and two-pass CPs is accurate.

Not all locations are suitable for CPs. Examples where a CP is challenging is locations with no designated trailhead or parking lot. Many popular backcountry trips in Norway could begin at different locations, making it hard to cover all usage with a single CP. Furthermore, we believe the actual placement of each CP in relation to the parking lot could have a big impact on the ratio we are able to count. An example of this could be if the CP is mounted in a way that makes it a detour in contrast to something that is right in front of you when leaving the trailhead. In some cases, the material cost of multiple CPs, including the beacon checker, signage, batteries, datalogger and pole could make the study infeasible for many, making it a limitation.

5.3. Temporal distributions

Our results show the hourly, daily, and monthly distribution of backcountry trips across the Tromsø region. The results are in line with what we expected with most skiers starting their backcountry trip before noon (Fig. 5). There is also some activity during the night, which is not uncommon in Tromsø with headlamps in the early winter and 24-h daylight from the end of April.

Saturdays and Sundays have the highest daily rate of skiers, but only accounts for 40.1 % of the overall traffic. Weekdays have a relatively lower daily rate, but accounts for 59.9 % of the overall traffic (Fig. 6). The fact that there is a high amount of backcountry skier usage during weekdays could be of high value to the Norwegian Avalanche Warning Service (NAWS) when they allocate their resources.

Our results indicate that nearly half (56.3 %) of the backcountry touring days take place in March and April. This trend aligns closely with data on avalanche incidents (including fatalities, injuries, being caught in an avalanche or near misses) within the study area over 15 seasons from 2008 to 2023 (Varsom, 2023). Notably, 55.8 % of the incidents (48 out of 86), also happened during these two months. While we could analyze fatalities, injuries, and avalanche incidents (caught but not buried or injured) individually, the relatively small sample size could lead to statistical issues. A small sample size can result in unreliable or skewed statistics that might not provide a valid representation of broader trends or risk factors. We considered comparing our data with regional bulletin website usage. However, we do not trust the analytics from the study period as NAWS transitioned from Universal Analytics to Google Analytics 4 during this same period.

5.4. Future work

Our methodology represents an initial step towards achieving a representative sample for an entire region. Future work could include the potential to approximate the overall seasonal background information in the study area by collecting a large dataset of GPS tracks through crowd sourcing. With a comprehensive set of GPS data, we could conduct a GIS analysis to determine the proportion of tracks that originate from each CP. This approach would enable us to estimate the percentage of total traffic captured by our CPs relative to the data collected through crowd sourced methods.

Expanding our methodology to regions with different characteristics from our current study area would also be beneficial. This expansion could provide insights into regional variations in backcountry usage patterns. Additionally, there might be room for technological advancements in beacon checker technology. Enhancements could include the ability to identify number of unique signals within a range or to detect other prevalent signals like WLAN (i.e. Wi-Fi) or Bluetooth, thereby offering a more accurate and nuanced understanding of skier counts and patterns.

5.4.1. Recommendations for future application

In this section, we would like to provide some advice for future application of this method. After two seasons of data collection, maintenance, and lots of *what ifs* that we were not able to anticipate:

- Make sure to always have enough spare parts on hand, as something will fail occasionally, or simply be lost. We have found it easier to swap all electronics (beacon checker, datalogger, batteries) with a new setup, and resolve the error in the lab.
- Use glue when mounting the foundation for the CPs, do not trust expansion bolts. The vibration from the wind will over time unscrew the bolts, making the CP fall over.
- Always have a person available to do maintenance when needed, and make sure that there is more than one person that can do maintenance. Furthermore, make everything modular and use wire connections with clear markings, (or connectors) making it less likely to connect something wrong. It only takes one wrong wire connection to burn a beacon checker or a datalogger. These precautions make it easier to have multiple people do maintenance.
- Use silica gel in the beacon checker housing. They are not 100 % waterproof.
- Make sure that the datalogger and beacon checker is dried-out after each season, and make sure that everything is working properly before a new season. It is much easier to fix errors in the lab, compared to in the field.
- Always make sure to test the CP before leaving the site.

6. Conclusion

We believe our study is a proof-of-concept using beacon checker technology increasing our understanding of the backcountry usage at regional scales. We have managed to quantify a large proportion of the backcountry skiing population over a 2589 km^2 area, offering valuable insights into various timescales, including hourly, weekly, and yearly distributions of backcountry usage.

Over two seasons, from December to May from 2021 to 2023, we recorded 56,760 individual trips from 26 to 29 trailheads. Saturdays and Sundays see the highest daily activity rates, comprising 40.1 % of total weekly traffic, while weekdays, though less busy per day, account for the remaining 59.9 %. The peak season for winter backcountry skiing is during March and April (when counts from December to May are considered), accounting for 56.3 % of all traffic. This monthly usage aligns with avalanche incident data, where 55.8 % of incidents occur during the same two months.

While our methods still have some limitations, we argue that a large scale spatially distributed system as presented here, provides the best method to currently estimate backcountry usage across a remote and dispersed region. However, our findings also highlight the need for further research to build upon the groundwork we have laid to be able to calculate the usage for an entire region.

Ethics statement

During the preparation of this work the corresponding author used ChatGPT 4.0 from OpenAI in order to improve readability and language. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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CRediT authorship contribution statement

Håvard B. Toft: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Kristoffer Karlsen:** Writing – review & editing, Investigation. **Markus Landrø:** Writing – review & editing, Supervision. **Andrea Mannberg:** Writing – review & editing, Supervision. **Jordy Hendrikx:** Writing – review & editing, Supervision. **Audun Hetland:** Writing – review & editing, Supervision, Investigation, Funding acquisition.

Declaration of competing interest

Haavard Boutera Toft reports financial support was provided by SpareBank 1 Nord-Norge. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

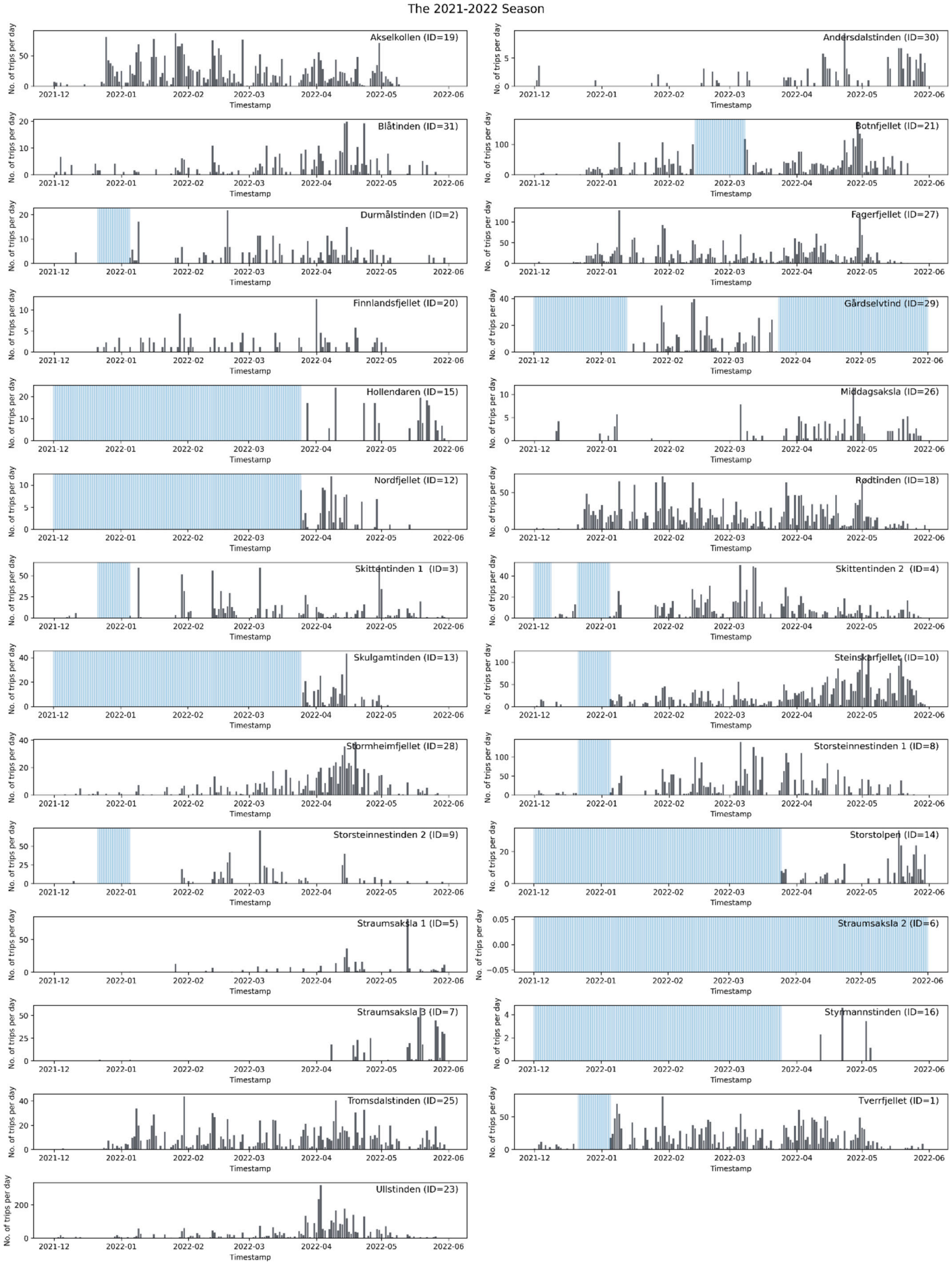
Data availability

The data from this study are available from the corresponding author upon request.

Acknowledgements

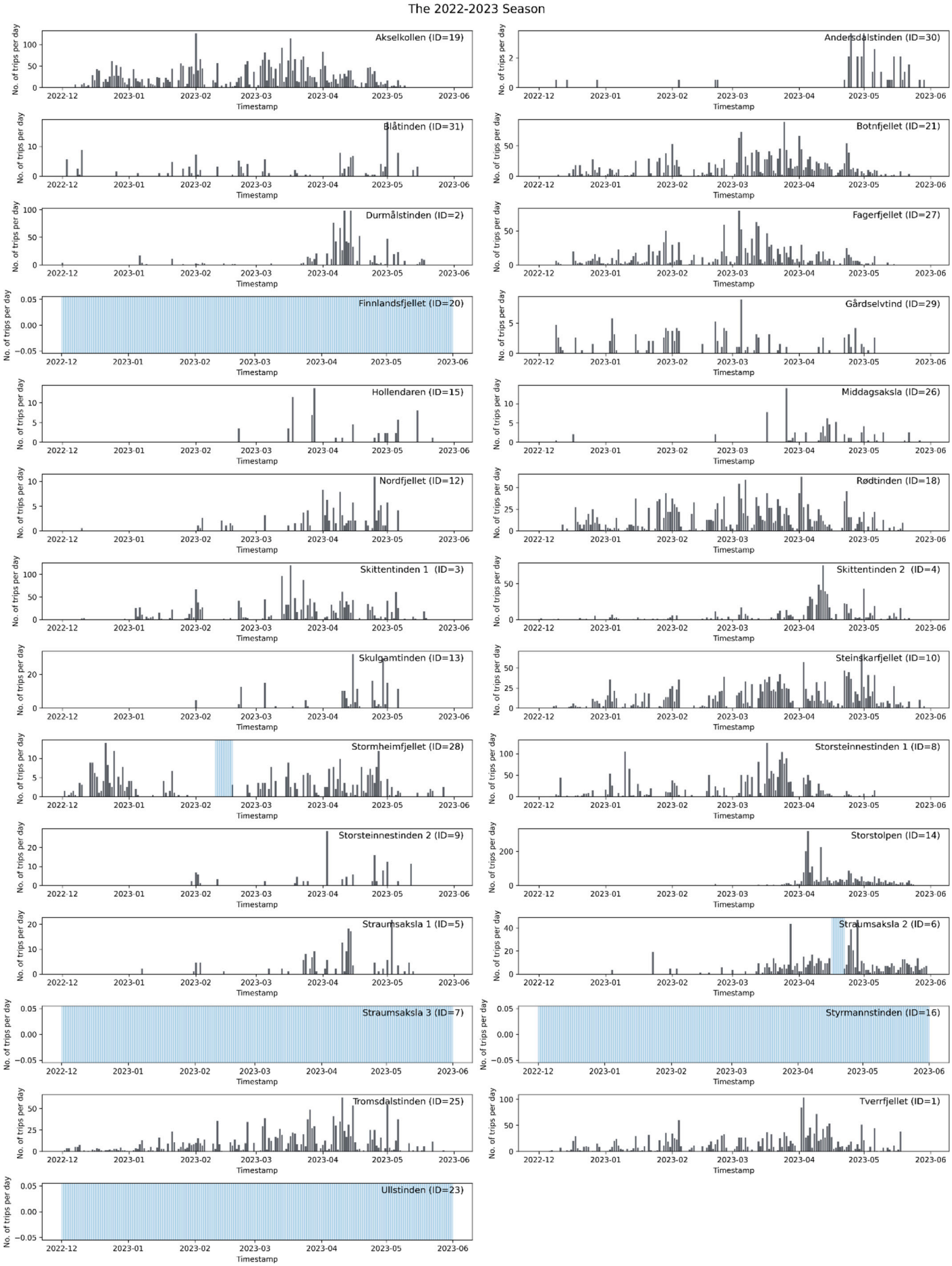
Furthermore, we would like to acknowledge Knut Møen for his technical contributions to the development of the CPs. A special thanks go to Tarjei Skille for meticulously reviewing each image from the time-lapse camera, contributing significantly to our validation process. Finn Hovem deserves recognition for his assistance in fieldwork and in resolving initial technical issues during the first season. Lastly, we express our gratitude to all the landlords who permitted us to install CPs on their land, with a special mention to Helsehjelp Norge, GIBNOR, and the GB Group of Companies at Kattfjordeidet, for their cooperation and support.

Appendix A. Appendix


The 2021-2022 Season

Akselkollen (ID=19)
Andersdalstinden (ID=30)
Blåtinden (ID=31)
Botnfjellet (ID=21)
Durmålstinden (ID=2)
Fagerfjellet (ID=27)
Finnlandsfjellet (ID=20)
Gårdselvtind (ID=29)
Hollendaren (ID=15)
Middagsaksla (ID=26)
Nordfjellet (ID=12)
Rødtinden (ID=18)
Skittentinden 1 (ID=3)
Skittentinden 2 (ID=4)
Skulgamtinden (ID=13)
Steinskarfjellet (ID=10)
Stormheimfjellet (ID=28)
Storsteinnestinden 1 (ID=8)
Storsteinnestinden 2 (ID=9)
Storstolpen (ID=14)
Straumsaksla 1 (ID=5)
Straumsaksla 2 (ID=6)
Straumsaksla 3 (ID=7)
Styrmannstinden (ID=16)
Tromsdalstinden (ID=25)
Tverrfjellet (ID=1)
Ullstinden (ID=23)

Appendix-1. : A plot for each station during the first season from 2021 to 2022. Timesteps with blue shading mark periods where the beacon checker has malfunctioned, or no data collecting was in progress.


The 2022-2023 Season
Akselkollen (ID=19)
Andersdalstinden (ID=30)
Blåtinden (ID=31)
Botnfjellet (ID=21)
Durmålstinden (ID=2)
Fagerfjellet (ID=27)
Finnlandsfjellet (ID=20)
Gårdselvtind (ID=29)
Hollendaren (ID=15)
Middagsaksla (ID=26)
Nordfjellet (ID=12)
Rødtinden (ID=18)
Skittentinden 1 (ID=3)
Skittentinden 2 (ID=4)
Skulgamtinden (ID=13)
Steinskarfjellet (ID=10)
Stormheimfjellet (ID=28)
Storsteinnestinden 1 (ID=8)
Storsteinnestinden 2 (ID=9)
Storstolpen (ID=14)
Straumsaksla 1 (ID=5)
Straumsaksla 2 (ID=6)
Straumsaksla 3 (ID=7)
Styrmannstinden (ID=16)
Tromsdalstinden (ID=25)
Tverrfjellet (ID=1)
Ullstinden (ID=23)
No. of trips per day
Timestamp
2022-12
2023-01
2023-02
2023-03
2023-04
2023-05
2023-06

Appendix-2. : A plot for each station during the first season from 2022 to 2023. Timesteps with blue shading mark periods where the beacon checker has malfunctioned, or no data collecting was in progress.

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