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Visitor Counting and Monitoring in Forests Using Camera Traps: A Case Study from Bavaria (Southern Germany)

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Abstract: A variety of counting methods exist to analyze visitor numbers of outdoor settings such as national parks, recreation areas and urban green spaces, with sensor-based approaches being the most frequently applied. In this paper, we describe the application and practicality of camera traps originally designed for wildlife monitoring for visitor management purposes. The focus of the work is on the practicality of trigger camera traps and data collection for visitor monitoring from a more practice- and management-oriented perspective. Camera traps can provide interesting in-depth and detailed information about recreationists and are flexible and suitable for various uses; however, assessing the visual data manually requires significant staff and working time. To deal with the large amounts of data gathered for numbers of passersby and recreation activities, correlation factors between passersby and pictures were determined, so that the number of passersby related to the number of pictures taken per day or per other time unit could be established. In focusing on using the camera traps and assessing the generated data, it became clear that more studies have to be conducted to compare different methods of visitor monitoring and their accuracy in different outdoor environments.

Keywords: outdoor recreation; recreation use; forests; green space; visitor monitoring; camera traps; legal; Germany

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1. Introduction

Natural and forested landscapes are prime destinations for recreational uses [1]. Especially in urban-proximate woodlands, recreational uses will likely increase due to population growth within urbanized areas and due to climate change [2]. This increased use will also be accompanied by a shift to evening and nighttime use during heatwaves and the emergence of new outdoor recreation activities with respective spatial and temporal uses, for example Geocaching as a recent new recreation activity, which will lead to increased pressure on natural resources and on their ability to provide goods and services [3–6]. Increasing numbers of recreation activities will also lead to more conflicts between different users [7].

With appropriate management of outdoor recreation, the negative impacts on natural resources and conflicts can be reduced [8–11]. Extensive knowledge about visitor numbers and spatial distribution is vital for such concepts [10].

A number of technical methods for visitor counting exist to assess visitor numbers. These mainly include slap sensors, tube sensors, infrared barriers, and pyroelectric sensors, which are used to count visitors [12–15]. These sensors are specialized for counting purposes, are costly, and often there is a need to install them permanently, requiring related construction work at or in trails for long-term monitoring purposes. Some of the counters have weaknesses, e.g., not working during snow cover [15]. Such counting devices do not collect enough detailed information for managers, leaving many questions related to user groups and recreation activities unanswered. For example, they do not provide the numbers of individuals walking dogs and unleashed dogs and do not distinguish between normal walkers, joggers, or Nordic walkers, with the latter groups often having specific requests for trail quality or maintenance and with their advocacy groups demanding dedicated infrastructure. Finally, counts without a visual component sometimes lack clarity, e.g., night counts resulting from passing individuals or wildlife [15].

To collect such qualitative information on visitors, the literature often suggests manual visitor counts, including direct observations as the best way to acquire a more detailed overview of different recreational activities. Such approaches, especially in forests with very limited visibility over a monitored area, are personnel-intensive and costly [16]. Camera-based counting approaches might combine the advantages of collecting both qualitative and quantitative information, delivering 24/7 data independent from availability of staff and offering more flexible and more easily installed applications compared to counting with permanently installed sensors. Research, management, and practice approaches have been successfully applied to collect experiences via camera traps for wildlife monitoring and related management; thus, extending such applications for visitor counting and monitoring purposes appears to be feasible.

Based on these considerations, we conducted a literature review using the search terms “outdoor recreation”, “visitor monitoring”, and “visitor counting”, combined with the search term “camera” or “video”. Assessing the practice-oriented literature published between 2000 and the beginning of our work in April 2014 using both indexed and snowballing approaches, only a small number of camera-based applications for (trigger-induced) visitor counting and monitoring were found [14–24] and video loops were mainly used. The differences between manual counts were considered to be below 15% [24], while Miller et al. [23] drew a more detailed picture of the use of camera-based systems. The rapid technological development of digital cameras in recent years has led to increased data storage capacity, longer operational times, and higher trigger speeds [25], while the costs of such devices have dropped significantly [26]. These developments suggest the better applicability and practicability of camera-based monitoring techniques, e.g., such as reduced maintenance intervals for data collection, battery changes, and data transfer, with the results from wildlife monitoring highlighting the practicability of such applications. Detailed comparisons and reflections on trigger cameras can be found in [25] and [27]. Nonetheless, studies are scarce regarding more detailed information on implementing such approaches, handling the data, and collecting information on visitors.

In our paper, we examine the use of camera traps for visitor counting and monitoring. A case study approach is seen as a flexible way to approach in-depth investigations at small scales that balance breadth and depth [28]. Using case studies from Bavaria (Southern Germany) and due to the need for more information for visitor management, we describe the use of camera traps for visitor monitoring and the possibilities for collecting quantitative and qualitative information, such as for the number of dogs on leashes, types of potential conflicting activities, or whether hikers are properly equipped for alpine terrains. Especially in peri-urban and recreational areas, large amounts of data are collected. Assessing the collected pictures manually would require excessive working time. Without sufficient automated assessment programs being available, we analyze whether simplified approaches can provide the basic information on visitors and develop an approach and routines to handle large datasets for estimation of visitor numbers when resources are limited, in order to conduct a full assessment of the collected photos manually.

2. Materials and Methods

2.1. Initial Considerations for Selection of Cameras and Setup Design

At the start of the study, passive cameras dominated the market. These consist of one piece and are equipped with a so-called passive infrared sensor. This detects moving objects with a different temperature than that of the environment within the camera´s detection zone [28].

To obtain counts in frequented areas and to catch fast-moving individuals such as bikers, a fast trigger speed and a wide range of club-shaped zones that activate the camera are essential in order to obtain good results. According to Weingarth et al. [25], trigger speeds should be faster than 0.3 s and the camera should be activated by the trigger from more than 8 m to be suitable for lynx (*Lynx lynx*) monitoring. Lynx can reach speeds of over 50 kph (>13 m per second) in short sprints. Cameras meeting such criteria will also be suitable for capturing cyclists reaching speeds of around 25 kph. Cameras used for visitor management, especially in highly frequented areas, need a high recovery rate; therefore, cameras were selected that provided the fastest trigger speeds available on the market and that had been successfully used for lynx monitoring (*Lynx lynx*) in the Bavarian National Park [29].

2.2. Privacy Regulations and Implications for Camera Use

While camera use for research is possible in Germany, strict privacy regulations need to be respected when conducting research with camera-based systems according to § 6b BDSG [30]. Systems capturing distinct attributes enabling the identification of faces or car registration plates are not permitted. When taking such photos, faces and registration plates of vehicles have to be blanked out in order to comply with this legislation. Additionally, at the beginning of our study, the use of camera traps and breaches in privacy were being widely discussed by the general public [31,32].

2.3. Pretests, Application for Visitor Monitoring in Outdoor Recreation Settings

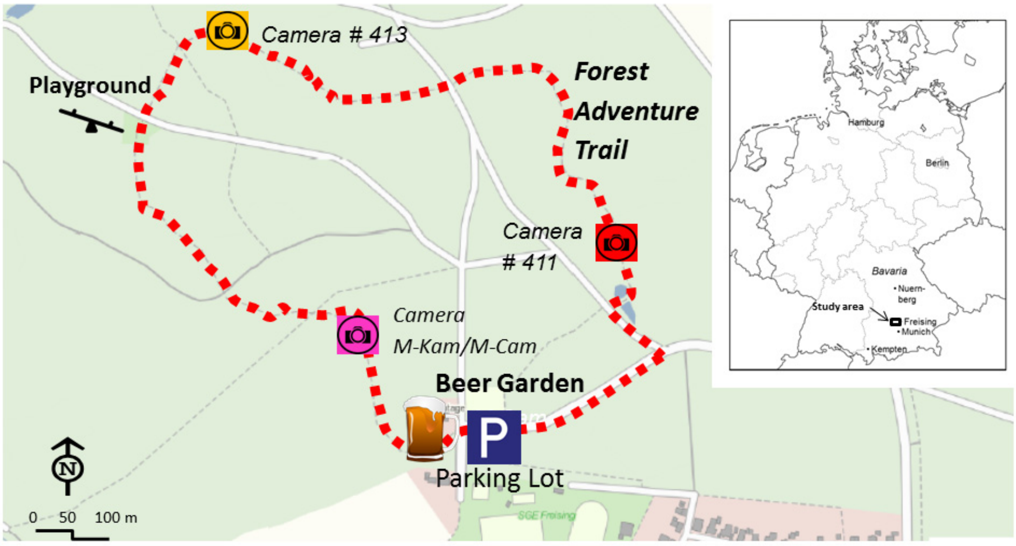
Initial testing took place on the university campus on a scarcely frequented pathway. At this location, we examined the best way to blind and mount the cameras to monitor trail users. In the next step, different camera models were tested to compare trigger speeds and recovery rates, as well as the quality of image capture for passersby and activities.

Two peri-urban woodlands in Freising, around 30 km away from the city center of Munich, were selected as the study area for long-term testing until the termination of the project in late 2017. These are some of the larger forested areas in the densely populated area in the north of the Munich Metropolitan area. The third study area for the cameras was the Grünten mountain in Upper Allgäu. An overview of the setup, including the different cameras, monitoring tasks, and data assessment at the different sites, can be found in Appendix A. This table also provides the key for the colors used in Figures 1–3 and 11–13 for the different cameras at the three sites. During maintenance, passing individuals were observed and counted and their numbers were compared to the pictures taken in this time.

2.4. The Study Sites

2.4.1. “Forest Adventure Trail” (Walderlebnispfad Freising)

The area of the “Forest Adventure Trail” (Walderlebnispfad Freising) directly borders the city of Freising in the west. Being part of the larger Wippenhauser Forest, the dedicated recreation forest is also managed for timber production and measures about 100 ha. Norway spruce (*Picea abies*) and beech (*Fagus sylvatica*) are the main tree species. The interactive “Forest Adventure Trail” provides an attraction for families with small children. It forms a 2 km loop, starting at a beer garden at the forest edge. The Forest Adventure Trail is 2 m wide, and cycling is not permitted. The main interests for monitoring there were the numbers of passersby in different trail sections and the different recreational activities and recreation patterns. Two Cuddeback C3 Black Flash cameras (#413 “orange” and #411 “red” colors in Figure 1) and one Dörr Snapshot 5.1 camera with a GSM module (M-Cam or M-Kam; "magenta" color) were used to monitor three spots at different sections along the trail (Figure 1).



Source: Geobasisdaten: Bayerische Vermessungsverwaltung Nr. 2106-008869

Figure 1. Map of the Forest Adventure Trail and monitoring sites north of Freising, Bavaria, Germany, with color codes for the cameras. For camera types related to the color codes, visitor monitoring questions, and data assessment procedures, see Appendix A, Table A1.

2.4.2. "World Forest" (Weltwald Freising)

The "World Forest" (Weltwald Freising) is a state-owned forest measuring 100 ha in size, located around 4 km west of Freising in a larger forest complex called the "Kranzberger Forst". It is a managed forest for timber production with Norway spruce (*Picea abies*) and beech (*Fagus sylvatica*) as the dominating tree species. Since 1987, it has hosted an arboretum for both the public and the life sciences faculties at the Weihenstephan campus in Freising. By 2016, more than 300 different tree and shrub species has been planted in the forest matrix. In addition to the main routes, several thematic educational trails for the different tree species from different regions of the world provide access to the forest. The total length of the trail network is around 7 km.

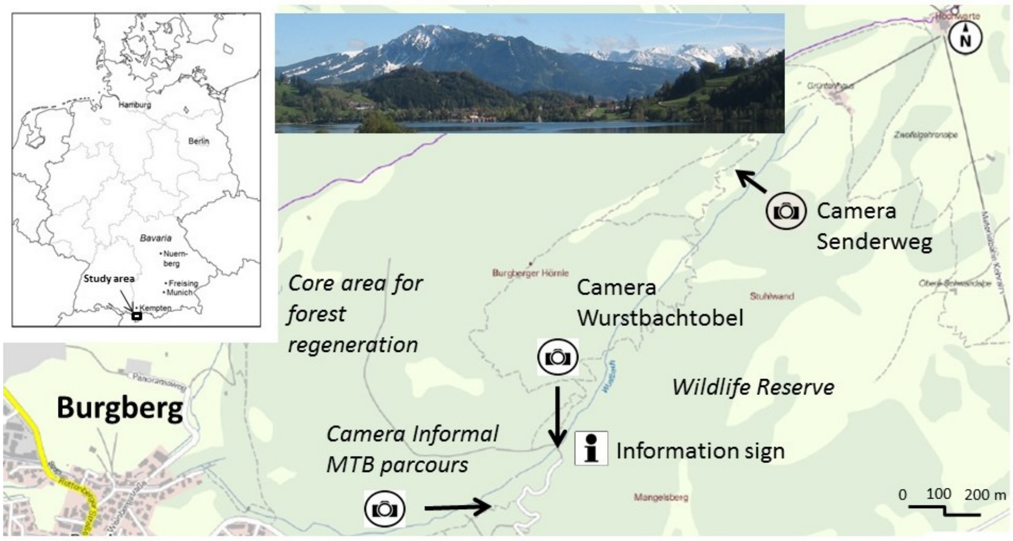
The "World Forest" is characterized by its different entrance points. The main routes in this forest are 3 m wide in order to permit access for timber trucks. Significant numbers of cyclists were expected in certain parts of the forests. Four camera traps (#404, "brown", #405 "yellow", #409 "green", #410 "blue" in Figure 2) were installed at different entrances to the forest; one was placed to monitor a crossroad in the center of the forest. The main route crossed a smaller trail leading to a playground in one direction and an information pavilion and a chapel in the other direction (#412 "grey" color in Figure 2).

2.4.3. Grünten im Allgäu

Grünten Mountain (1737.9 m elevation) is situated around 20 km south of the city of Kempten inside the Nagelfluhkette Nature Park. On the steep western slope of the mountain, the forests are extremely important for protecting the village of Burgberg from erosion, landslides, rockfalls, and floods. The forest stands are dominated by old Norway spruce (*Picea abies*) plantations suffering from reduced vitality. The western slopes form a project area as part of the Mountain Forest Initiative (Bergwaldoffensive) to support forest owners to establish vital mixed structured forests and to protect the village of Burgberg from natural hazards using an in-depth participatory approach [33,34]. One part of the strategy to naturally support the growth of new vital mixed forests is a wildlife management plan that includes areas with intense hunting in the forest regeneration areas and zones for providing quiet areas for wildlife. A visitor management and information campaign "Dein Freiraum—Mein Lebensraum" (Your Free Space—My Living Space) [35] was implemented on the slopes of this mountain, which included visitor information signs and asking visitors to leash their dogs in this sensitive area. Three camera traps were used to monitor the traffic on the trail and on an informal mountain bike route (Figure 3). A monitoring issue in this area was that in addition to monitoring hikers, mountain bike use, and pedestrians with dogs and unleashed dogs, we also monitored whether the information signs set up as part of the visitor management campaign were noticed.

Source: Geobasisdaten: Bayerische Vermessungsverwaltung Nr. 2106-008869

Figure 2. Map of the World Forest and monitoring sites west of Freising, Bavaria, Germany, with color codes for the cameras. For camera types related to the color codes, visitor monitoring questions, and data assessment procedures, see Appendix A, Table A1.



Source: Geobasisdaten: Bayerische Vermessungsverwaltung Nr. 2106-008869

Figure 3. Map of the monitoring sites at Grünten Mountain, 20 km south of Kempten, Bavaria, Germany. For camera types, sites, visitor monitoring questions, and data assessment, see Appendix A, Table A1.

On this mountain, hikers frequently have accidents due to having inappropriate equipment; therefore, we assessed whether hikers were properly equipped according to the guidelines of the German Alpine Club—high cut hiking boots, backpacks, coats, and drinking water [36]. Two cameras were used for the hiking trail—one at a bridge over a ravine next to the information sign ("Wurstbachtobel") and one at the upper trail section on the mountaintop near the radio tower ("Senderweg"). One camera was mounted at the informal mountain bike trail ("Parcours").

For monitoring applications in outdoor recreation settings, the elements considered important in literature together with elements of importance for forest management according to forest and nature park managers (see Table 1) were selected for assessment for the different study areas.

Table 1. Elements selected for monitoring and collecting data.

Elements	Purpose and Relevance
Number of passersby and their direction: towards the camera, away from the camera, clockwise, anti-clockwise. Use of the Forest Adventure Trail: "in", "out" (World Forest), "up", or "down" the mountain (Grünten)	Basic set of recommended evidence-based data for development of recreation infrastructure and evaluation as the basis for visitor management according to the literature. Also used for marketing activities or target-setting for recreation offers. Investments made in recreation infrastructure, with implications for policy, e.g., assessing values and benefits created for society by offers such as the Forest Adventure Trail [37]
Recreation activities: hiking, cycling, jogging, trail running (Grünten), Nordic walking, walking, walking the dog, or other activities such as horse-riding	Evidence-based data for recreation, collecting evidence-based data for designing recreation infrastructure and dedicated infrastructure such as fitness trails, assessment of expressed demands by advocacy groups with evidence-based data (e.g., requests for more fitness tails and overuse), evaluation of recreation offers and activities with potential conflicts (e.g., mountain bike use, evening activities that might disturb wildlife)
Dogs, leashed and unleased	Relevant for the evaluation of the visitor information campaign at Grünten, potential conflicts with wildlife or other user groups (e.g., small kids)
Number of trail users with walking aids, wheelchairs, prams	Evidence-based data for target group with respective infrastructure, especially for the Forest Adventure Trail and World Forest (marketing, barrier free, inclusive trail design and offers)
Bicycle type (normal bicycle or mountain bicycle)	Trail design and maintenance, assessment of conflicting recreational uses
Interaction with the surrounding forest (in conversation, paying attention to the forest trail, attention to other people, observation of the forest, interaction with the forest, or using mobile devices)	At the World Forest and the Forest Adventure Trail, the forest management focus is also on special aesthetic qualities and individuals are encouraged to interact with the forest
Attention paid to the visitor information sign at the Grünten	Passersby notice the visitor information campaign
Appropriate equipment for mountaineering with backpack and high-cut hiking boots (Grünten)	Increased numbers of accidents might correlate with larger numbers of visitors with inappropriate equipment and the potential need for information signs or campaigns
Gender, number of children, age groups	Evaluation of target groups, e.g., small kids, families (especially Forest Adventure Trail)

In order to deal with large amounts of data and to simplify the evaluation and data creation processes, we compared two different systems of assessing pictures to estimate the time needed for such analyses:

1. Dual-screen evaluation of pictures and manual counting by listing them in an Excel file for a monitoring period;
2. Estimation by correlation using a set of random days that were fully assessed and with pictures selected with events fully visible according to Zahner et al. [38]. We opted for the freeware program XnView.

We created a database to fully assessment and categorize pictures as follows:

- A full assessment of all pictures captured by the Dörr camera between 18 December 2014, and 8 January 2015, mounted on the Forest Adventure Trail, with the data input into an Excel data file. This was the first test run for the camera under real conditions inside the forest;
- From 3 April to 12 April 2015, at the Freising sites, the first run for all cameras after mounting them was until their first maintenance point. This period included both public holidays (Easter) and "regular" days, with mixed spring weather conditions. We monitored a broad variety of forest uses, with special interest in forest management related to an organized event on Easter Monday;
- From 19 April to 3 May 2015, for all cameras at the Freising sites, time series were captured between the first and second maintenance rounds. Special interest was given to forest management related to the first warm and sunny spring weekends and the public holiday on 1 May;
- Two random days were monitored between April 2015 and April 2016 each month for all cameras in the Freising forests using a random number generator to generate a data pool of fully counted days over the course of one year for various statistical tests, such as to assess the validity of selecting different patterns and amount of days for regression analyses and sufficiency levels;
- "Hot days" with a daily maximum temperature above 30 °C were captured on all cameras in both Freising forests. Special interest was given to forest management on these days in order to quantify evening and night uses on such "hot days" and to link this to changing recreation patterns [5];
- "Rainy days" with more than 20 mm of daily rainfall were captured on all cameras in both Freising forests to assess minimum recreational uses, with special interest given to forest management;
- Days with events in the forests and days with noticeably different data patterns were captured (special interest given to forest management and testing of the reliability of the cameras);
- For the Grünten sites, the days between 24 August and 6 September 2015; 4 through 17 October 2015; and 31 October to 6 November 2015, were fully assessed to create a data pool for various statistical tests, such as the validity of selection for different patterns and amounts of days used for regression analyses and sufficiency levels.

The attributed metadata were imported to MS-Access for assessment in R-statistics (Version R3.2.5). Based on around 50 fully assessed and attributed days, we analyzed data patterns. R Package statistics was used to fit linear models and nonlinear least squares models [39].

Task analysis was conducted in order to evaluate the time required to analyze pictures using both methods and to count out the picture content of each pictures [40,41]. We used a self-recording approach [40], whereby individuals in charge of the analysis documented the time needed to assess the pictures. The outcome of this analysis could help to evaluate whether it might be feasible to allocate time and resources to a full assessment of the pictures or whether a reduced approach, assessing pictures only to a certain extent and conducting regression analyses, would be more target-oriented.

In the next step, we assessed correlations between the numbers of pictures taken by the camera traps and visitor numbers. Based on a set of fully assessed pictures in the first full assessment, we used regression analyses to detect and compare correlations. Finally, we compared these correlation predictions with the data from the content analysis of the random days.

3. Results

3.1. Pretest to Fulfill Legal Frameworks

In an initial pretest, we tested the positions and blanking methods used for the camera. According to privacy regulations and suggestions by Czachs and Brandenburg [22], cameras were mounted 4 m above ground, pointing to the middle of the trail at a distance of approximately 15–20 m. To generate camera data according to the privacy regulations, we had to attach a transparent strip of plastic to the lens to eliminate the visibility of faces and the readability of registration plates. Using the plastic strip, recreational activities such as Nordic walking and leashed and unleashed dogs were still visible and could be distinct.

Before monitoring at sites in outdoor recreation settings, we first conducted a test run with different camera models and tried out different camera arrangements (see Appendix B). All three cameras were test run by being mounted 4 m above the ground on a tree next to each other. A less frequented path on the campus was chosen for the testing. For five individuals, a dog, and a bicycle, different speeds and passing situations were tested to evaluate the capability of the cameras and their trigger ranges (Figure 4). Then, regular movements on the trail were observed and evaluated. The results of this test run can be found in Appendix B. With poor performance in this pretest, one initially selected camera model considered capable of the task was taken out for the long-term applications.

Figure 4. Picture taken by camera trap during the testing at the Freising University campus in late 2014, Bavaria, Germany.

3.2. Handling of the Cameras

Handling of the cameras was quite simple. Maintenance intervals to change batteries and reading out SD cards was done just once a month, even in highly frequented places. In cold conditions, the intervals were shorter due to reduce battery power. On-site maintenance and data collection took around 15–20 min for one camera with two individuals (according to the German work safety standards, safety equipment and certified ladders were used, and a second person was needed to spot the other person climbing the ladder).

3.3. Data on Visitors, Activities, and Their Behavior

Although the pictures taken by the camera were blurred, a variety of information could be assessed, including the activity (Table 2, Figure 5) and direction, as well as shares or numbers of people with leashed and unleased dogs, single pedestrians, pairs of pedestrians, groups, and guided groups. Additionally, people's attention could be assessed, e.g., were they having a conversation with other individuals, paying attention to their dog, looking at a mobile device, or interacting with the forest (Figure 6). In more than 50% of the photos, a gender was assigned based on the shape of the body (more "boxlike" for males, more "round" for females) or distinct colors of clothing. Different age groups of children could be identified to provide the numbers of babies, toddlers, children of primary school age, and adolescents. Additionally, in many cases, a gender was assigned to the children based on their body shape and clothing.

Table 2. Assessable attributes of visitors using trigger trail cameras and estimated identification rates based on assessing the pictures.

Assessable Elements	Distinction between	Estimated Identification Rate Based on Study Sites
User groups	Hikers, pedestrians, cyclists, joggers, Nordic walkers, horse-riders, pedestrians with dogs, number of dogs, leashed and unleashed dogs, wheelchairs	Above 95% of passing individuals
Gender	Male or female	Around 50% of passing individuals
Groupings	Single, two individuals, family, group, guided group	Around 95%
Age classification	Baby, toddler, 7–10 years old, 10–14, teenagers above 14, adults	Around 75%
Walking direction	Clockwise–anti-clockwise (Forest Adventure Trail), in–out, use of different paths at crossroads	Above 95%
Attention level	On the trail, on the forest, on information signs in the nature park (Grünten), interaction with forest, interaction with camera used for monitoring, using mobile device	Around 90%

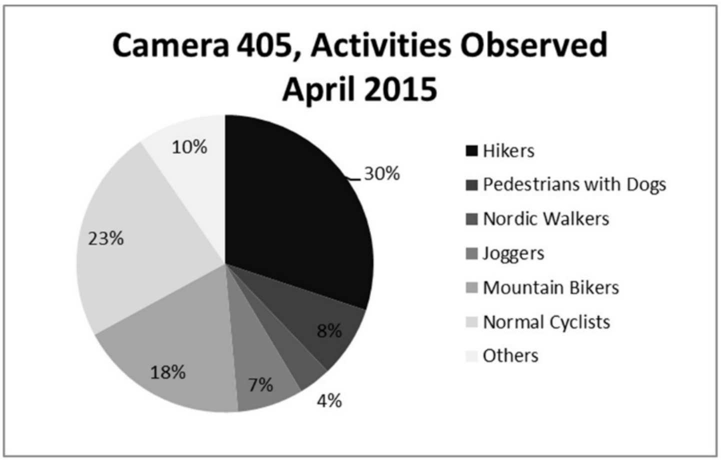


Figure 5. Percentages of observed activities at the monitoring site of camera 405, eastern entrance of the World Forest, Freising, Bavaria, Germany; during the monitored period, 2883 passersby were photographed.

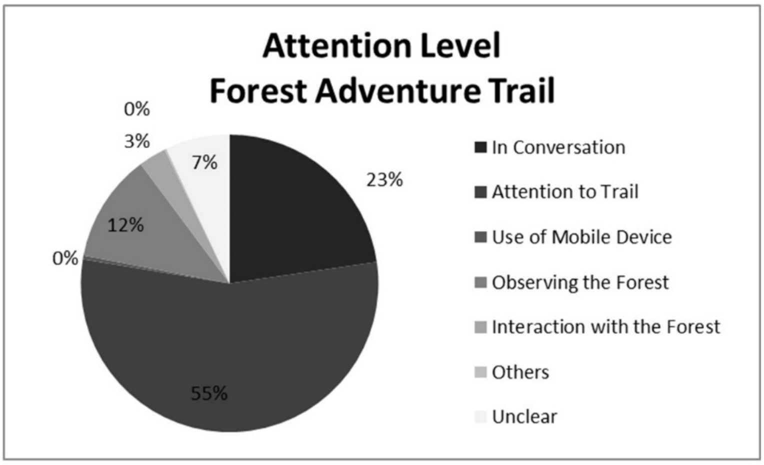


Figure 6. Percentages of attention at the monitoring site "M-Kam/M-Cam" at the Forest Adventure Trail, Freising, Bavaria, Germany, averaged for the period from 19 December 2014, until 6 January 2015; 1804 passersby were counted during this monitoring period.

With the metadata from the pictures, including the time and date information, which was automatically assigned to the data when each photo was taken, it was possible to visualize total numbers of passersby per year, per day, or per hour. For management purposes, recreational uses on days with rainfall and for different temperature ranges and respective user groups were of interest. For example, "rainy days" with more than 20 mm of rainfall (17 April, 1 May, 5 June, 6 August, 15 August, and 20 November 2015) were extracted and assessed (Figure 7); while there was an average of 111 passersby per day on average at camera 405, on "rainy days", only 33 individuals were counted. Pedestrians with dogs were regular visitors to the forest and their number only decreased slightly. The numbers of passing joggers and to a lesser extent Nordic walkers were stable on rainy days. Camera data from other monitoring spots showed similar patterns.

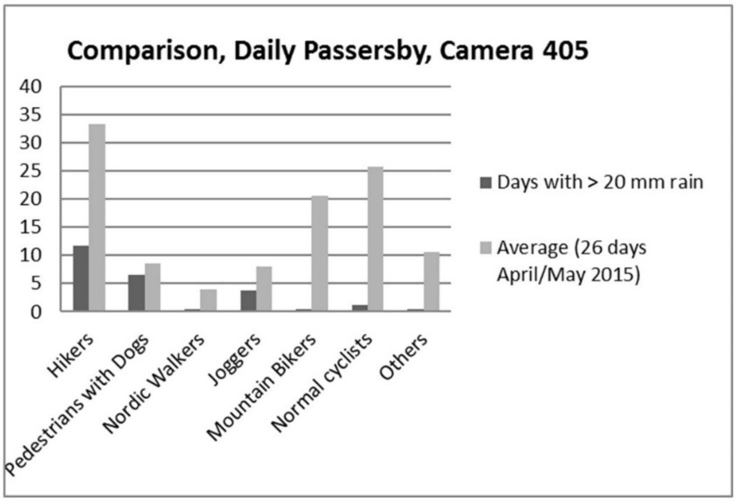


Figure 7. Comparison of passersby at the camera sites on "average days" and on "rainy days" (>20 mm of rain per day) at the eastern entrance of the World Forest, Freising, Bavaria, Germany.

For Grünten Mountain, the given monitoring tasks included whether dogs were leashed according to the voluntary code of conduct for this area, whether individuals had noticed the information signs as part of the visitor management concept of the Nagelfluhkette Nature Park, and whether hikers were properly equipped (Figures 8–10).

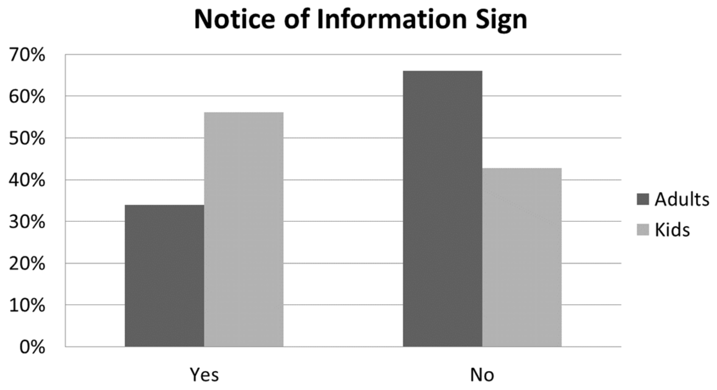


Figure 8. Number of information signs at the Wurstbachtobel monitoring site, Grünten, Bavaria, Germany, based on periods with in-depth analysis of data (12,008 passersby).

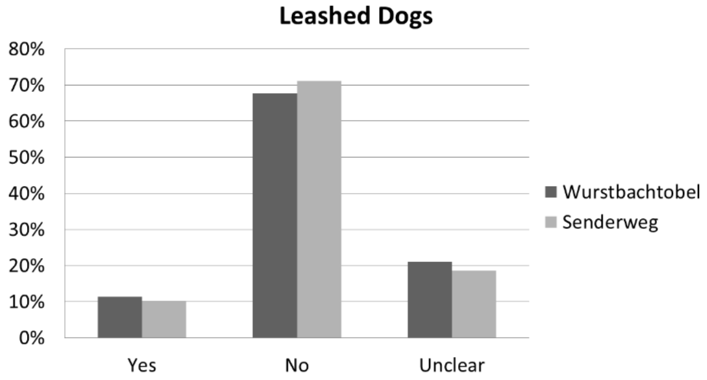


Figure 9. Percentages of dogs leashed at the Wurstbachtobel and Senderweg monitoring sites, Grünten Mountain, Bavaria, Germany, based on periods with in-depth analysis of data (12,008 passersby).

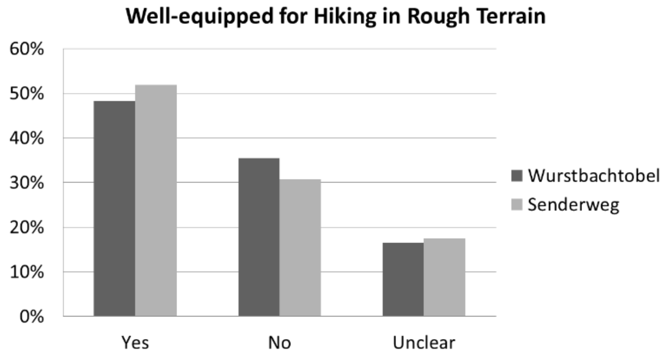


Figure 10. Percentages of individuals well-equipped for hiking in rough terrain in the Wurstbachtobel and Senderweg monitoring sites, Grünten Mountain, Bavaria, Germany, based on periods with in-depth analysis of data (12,008 passersby).

3.4. Assessing Large Amounts of Data

In our study, all cameras took around 500,000 images over one year of intense testing; therefore, we decided to use an approach to develop a model and to only select certain days for a full assessment of the pictures taken on those days. We opted to add work file data for the camera images such as the date and time when each picture was taken, and added attributes using XnView software.

When adding attributes to pictures, "events" were formed. Owing to the fast trigger speeds and quick camera recovery rates, pedestrians passing the camera trap were usually photographed three times and joggers twice. Faster moving objects such as cyclists or cars triggered the camera only once. Only the best picture was selected to be attributed in order to create data for further assessment.

According to the self-reported time sheets, an experienced person analyzing pictures was able to transfer information for around 20 events per hour into an Excel file or could select and add attributes with XnView, including in-depth information such as genders or age groups of children related to an event.

Based on around 50 fully assessed and attributed days, we analyzed data patterns. After testing different statistical models, the results were similar. Close correlations between the numbers of photos taken and the numbers of individuals assessed in the pictures (Figure 11) were evident at all camera sites. Correlation factors were unique for each camera, ranging between 0.58 and 1.05, and were highly significant for all cameras (see Figure 12). The formula for the prediction model for the number of passersby per selected time unit (e.g., hour or day) drawn from the analysis was:

$$\text{Number of passersby} = \text{Number of pictures taken} \times \text{Correlation factor}$$

There was only a slight variation in the counting factors during the 20 days right after the installation of the cameras or when calculating the factors based on the random days over a year. In calculating counting factors generated by 5, 10, 15, and 20 random days, factors stabilized when data for 10 days were used to calculate the counting factor (standard deviation of the correlation factor was between 0.12 and 0.2 for 5 days, between 0.07 and 0.17 for 10 days, and between 0.05 and 0.11 for 15 randomly selected days).

The model predicted the actual numbers of individuals well; however, the model tended to underestimate passersby on days with high visitor frequency and overestimated passersby on days with low forest use (Figure 13).

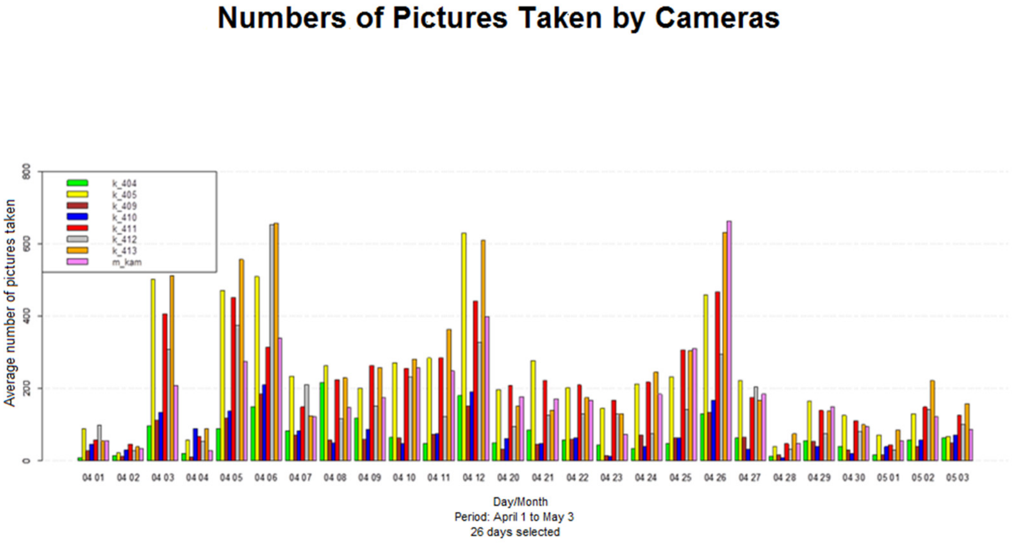


Figure 11. Daily numbers of pictures taken by the cameras at the eight different monitoring points in both monitored forests in Freising, Bavaria, Germany. For color codes and locations of the camera traps, see Figures 1 and 2, and Appendix A, Table A1.

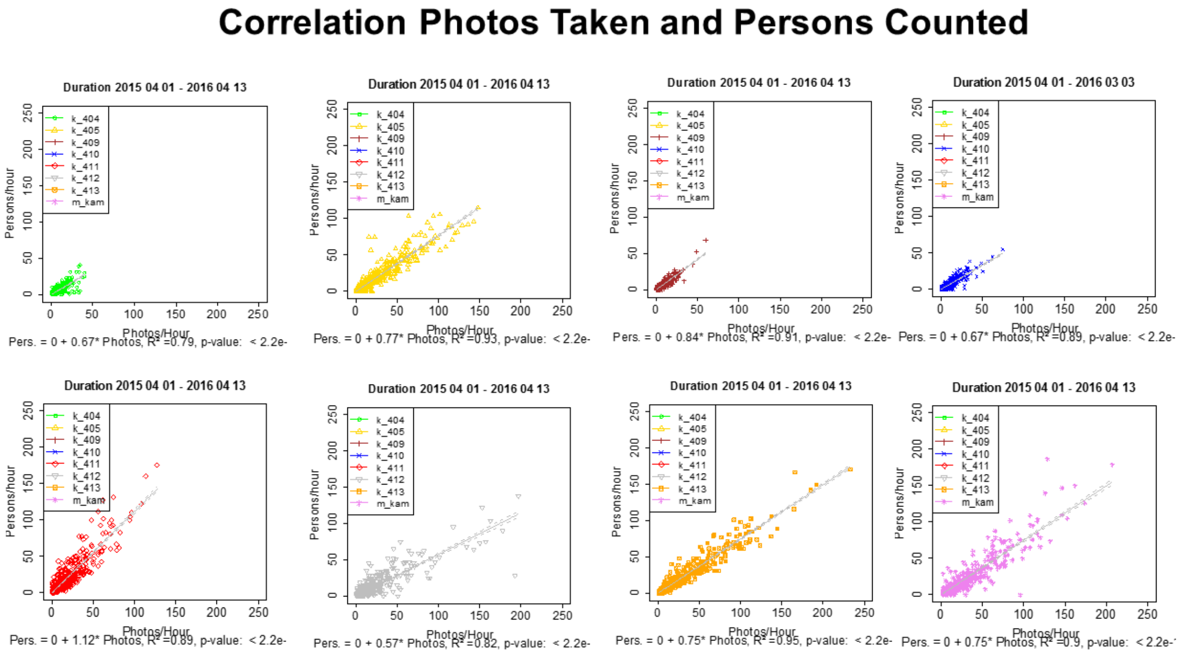


Figure 12. Correlations between pictures taken by cameras and individuals counted in photo assessment process in both monitored forests in Freising, Bavaria, Germany. For color codes and locations of the camera traps, see Figures 1 and 2 and Appendix A, Table A1.

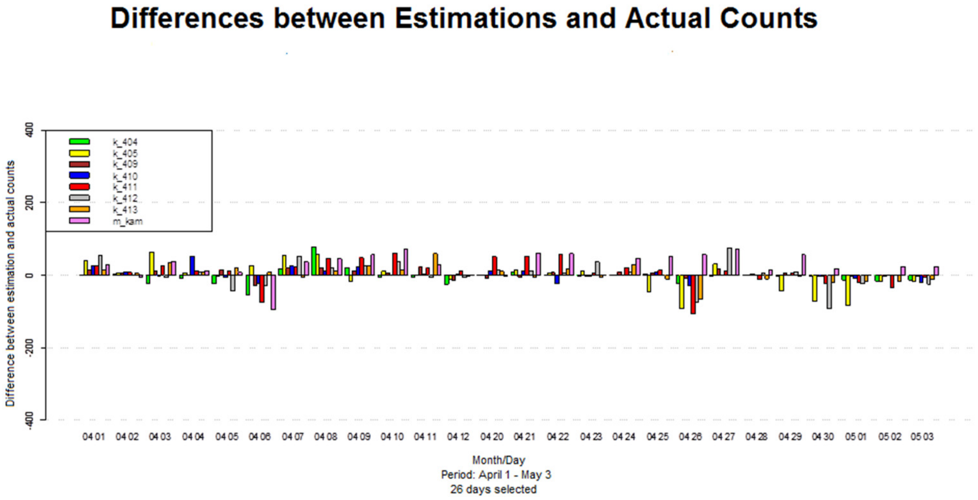


Figure 13. Differences between estimated passing individuals and photo content assessment in both monitored forests in Freising, Bavaria, Germany. For color codes and locations of the camera traps, see Figures 1 and 2 and Appendix A, Table A1, Note: Different time frame for camera #410 (color code blue) only until March 2016.

Taking a closer look at correlation factors for different group of recreationists, the R^2 was very high for hikers as well. This suggests a close correlation between camera clicks and number of hikers. The linear correlation between camera clicks and joggers or pedestrians with dogs was much weaker. The patterns showed that these groups form a rather stable basic user number independent from the weather conditions.

4. Discussion

4.1. Comparison with Other Visitor Counting Approaches

The use of trigger trail cameras provides a number of advantages compared to other means of visitor counting. Based on Rupf and Wernli [11], compared to other technical counting methods with infrared, pyroelectric, or slab sensors, cameras are cheaper to buy and provide a clear distinction between user groups with special demands for trail infrastructure. For example, the numbers and shares of Nordic walkers, joggers, individuals with perambulators, and wheelchairs or wheeled walkers, which are target groups for the Forest Adventure Trail, can be assessed. For these groups, a more costly method of trail design and maintenance is applied, and attracting these target groups is a part of the evaluation task. In addition, groups that may cause conflicts such as the number and share of unleashed dogs can be detected by using the camera traps.

The numbers of passersby can be obtained quite easily using correlation factors. Full data analysis and counts for user groups such as cyclists are more time-consuming than using a combination of sensor-based systems.

Compared to manual counting, the advantage is that selected days can be analyzed without the need for time-consuming fieldwork. Potential days for recreation management, e.g., for designing maximum capacities, can be picked out easily by looking at the data patterns, such as days of minimum and maximum use, which determine maximum demands for planning dimensions of the respective recreation infrastructure, such as parking lots and types of recreational use [1]. Additionally, interesting days for recreation monitoring, such as night uses, Christmas, or New Year’s Eve, can be monitored when it is difficult to recruit staff or volunteers.

4.2. Accuracy of the Trigger Cameras

Arnberger et al. [24] compared manual counting with that of using cameras. The differences between the two methods amounted to below 15%. With few passing individuals, cyclists were undercounted by video, while with direct counts, there undercounting occurred, especially in places with high numbers of passersby.

In our work, we observed a tendency to undercount due to technical features associated with the cameras. The trigger range was around 15–20 m, although in some conditions, ranges of up to 50 m were observed (e.g., in the pretest run); however, the trigger speed and reaction time of the cameras slowed down when the black flash mode was activated at dusk, dawn, or at night to around 0.25 s, with a recovery time of 1 s [42]. In extremely frequented areas, this led to undercounting, especially in unfavorable light conditions. Although we selected camera locations with slower cyclists, it was observed that several cases, some cyclists were still moving too fast to be captured. Another factor for undercounting was the 3–4 m width of the trigger range in the “wide range” mode; therefore, in the Allgäu study area, when monitoring visitor traffic on a 5–6 m wide bridge crossing the Wurstbachtobel ravine, individuals were not counted when walking on the far left side of the bridge. We estimated that around 10–20% of the passersby did not trigger the camera based on unsystematic observations and counting while conducting interviews close to this site and during camera maintenance.

In our Grünten study area, it was observed that on some days around noon, the camera mounted at Senderweg in a sparsely forested location close to the tree line took only one picture on average of a passing hiker instead of three pictures during other times of the day. According to the manufacturer information [42], trigger cameras depend on differences in temperatures between the moving objects and the surrounding areas. While this is not such a serious issue in dense forests in Central European settings, it becomes an issue in open space settings and light forests, where the ground in the picture capture area can heat up significantly. The manufacturer [42] mentions that pyroelectric sensors only work properly up to temperatures of around 30 °C.

Miller et al. [23] tested a number of setups when mounting the cameras at 0.5 m above ground and using different angles. The best results were achieved at an angle of 20° towards the trail with this setup. Capture rates for faster-moving individuals in their studies decreased above speeds of 8 kph and were similar to the results found by Fairfax et al. [43] in a setup combined with infrared detectors and digital cameras mounted 4–5 m above ground. It seems that mounting cameras 4 m above the ground, aiming the camera to a spot around 20 m away in the center of the monitored trail, and using the built-in triggers provide better results, especially for faster-moving objects such as cyclists.

4.3. Further Work

Our study focus was on the practicability of the use of trigger camera traps for visitor monitoring from the perspectives of practitioners and forest managers in order to gain a better understanding of recreational activities in the forest, use by groups with special demands such as joggers or Nordic walkers, and other issues such as unleashed dogs.

The disadvantage of our work was that we had only limited staff and resources available for the systematic comparison between camera traps and other forms of systematic visitor counting. With only very few studies available on this topic, more systematic observations and comparisons would be worthwhile in further investigations.

To ensure precise quantification and the highest possible counting accuracy, systematic comparisons using a number of different approaches, such as systematic observations and other equipment using slab sensors and tubes, seem to be the best way to quantify the strengths and weaknesses of each method. Nonetheless, we demonstrated the practicability of trigger cameras and obtained useful results for a number of day-to-day visitor monitoring purposes for forest and outdoor recreation management.

In the next few years, the rapid development of automated analysis technologies and associated software will grow the market and could make manual picture assessments obsolete. The challenges for automated assessments will be coping with different monitoring settings, changing light conditions, different approaches for photos taken at nighttime with IR or black flash, correlations between pictures taken and numbers of passersby, and the blurring of pictures to comply with various privacy regulations.

5. Conclusions

Camera traps can provide in-depth and detailed information about recreationists and are capable of various functions. Before monitoring, privacy issues and related regulations need to be included in the study design. To obtain greater accuracy, selected camera models should provide very fast trigger speeds and quick recovery. Mounting the camera 4 m above the ground and pointing the camera towards the trail at a distance of 20 m provided good results. The monitored trail width should not exceed 3 m, and we recommend monitoring places where cyclists and other fast-moving individuals have to slow down. The disadvantage of a trigger camera is the time needed to assess the pictures. Nonetheless, quite accurate correlations can be drawn between pictures taken and passersby; at least 10 separate dates with a respective workload of at least 10 full working days for one camera should be considered in order to acquire sufficient data for an accurate correlation factor. Although cameras might be cheap to buy, the working time required might turn out to be a considerable cost factor. At the time of writing this paper, no sufficient automated routines were available, although rapid software development will change this in the near future. We summarize that camera traps provide valuable data for understanding certain uses and can help in forming a differentiated impression about recreational use and behavior in natural areas. They also offer in-depth qualitative information for visitor management. Due to the staff and working time required, they can best be compared with direct on-site observations. The major advantage compared to on-site observations is that it is possible to obtain continuous monitoring data, along with the flexibility to choose days for in-depth assessment ex-post, e.g., days with significant data patterns that might be of interest. This also allows for added monitoring of issues or topics arising during or after collecting the data.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board on 25 July 2014. Handling of the collected data, maintaining anonymity and securing privacy followed the legal basis for the EU, Regulation (EU) 2016/679 of the European Parliament and of the Council from 27 April 2016 on the protection of natural individuals with regard to the processing of personal data and on the free movement of such data, and repealing GDPA Directive 95/46/EC (General Data Protection Regulation) and the corresponding country-specific regulations for the Federal Republic of Germany. In line with the Research Ethics Procedures of the Technical University of Munich for such monitoring and data collection, the study and research design was developed to ensure that persons maintained anonymous at all times and no data was collected that could identify or linked to individuals.

Informed Consent Statement: Written informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Appendix A

Table A1. Overview of camera types, sites, visitor monitoring questions; data for analysis weret.

Site	**Forest Adventure Trail, Freising**			**World Forest, Kranzberg/Freising**					**Grünten**		
Camera Name	M-Cam	#411	#413	#404	#405	#409	#410	#412	Wurstbach	Sender	Parcours
Color Code in Figures 1–3, and Figures 11–13	Magenta	Red	Orange	Brown	Yellow	Green	Blue	Grey			
Camera Model	Dörr Snapshot 5.1 GSM	Cuddeback C3 Black Flash		Cuddeback C3 Black Flash					Cuddeback C3 Black Flash		Reconnyx Hyper Fire
Operation Time of Cameras	18 December 2014–30 April 2016	1 April 2015–30 April 2016		1 April 2015–30 April 2016. For camera #410 (color code blue) data for analyses was only taken until 3 March 2016. Modified setup required after logging spruces in this trail section to prevent spreading of bark beetle					23 August–7 November 2015		
Periods of In-depth Analysis of Data	18 December 2014–8 January 2015										
	3–12 April 2015; 19 April–3 May 2015; Two random days per month between April 2015–April 2016, all "hot days" with max. temperatures above 30 °C, "rainy days" with a precipitation of 20 mm of rain during the day, special days of interest (e.g., with events and noticeable data patterns), full assessment of all days in April 2015								24 August–6 September 2015; 4–17 October 2015; 31 October–6 November 2015		
Visitor Counting											
Number of Passersby	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Number of Dogs	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Clock/Anticlockwise Use of Trail	✓	✓	✓								
In/Out of the Forest				✓	✓	✓	✓				
Crossroads: Four Different Directions								✓			
Uphill/ Downhill									✓		

Table A1. *Cont.*

Site	**Forest Adventure Trail, Freising**			**World Forest, Kranzberg/Freising**					**Grünten**
Activities									
Walking/Hiking	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nordic Walking	✓	✓	✓	✓	✓	✓	✓	✓	
Jogging	✓	✓	✓	✓	✓	✓	✓	✓	
Trail Running									✓
Cycling	✓	✓	✓	✓	✓	✓	✓	✓	
Mountain Biking	✓	✓	✓	✓	✓	✓	✓	✓	✓
Other Activities, e.g. Horse Riding	✓	✓	✓	✓	✓	✓	✓	✓	✓
Wheelchairs, Prams	✓	✓	✓	✓	✓	✓	✓	✓	
Dogs Unleashed	✓	✓	✓	✓	✓	✓	✓	✓	✓
Activities Related to Forestry/Farming	✓	✓	✓	✓	✓	✓	✓	✓	✓
Qualitative Information									
Attendance to Forest or Other Things	✓								
Attendance to Visitor Information									✓
Gender	✓	✓	✓	✓	✓	✓	✓	✓	✓
Number of Kids	✓	✓	✓	✓	✓	✓	✓	✓	✓
Age Group of Kids	✓	✓	✓	✓	✓	✓	✓	✓	
Dogs Leashed	✓	✓	✓	✓	✓	✓	✓	✓	
Proper Equipment for Hiking in Mountains									✓
Data Assessment									
Manual/Excel	✓								
XNView/Access/R-Statistics	✓	✓	✓	✓	✓	✓	✓	✓	✓
Time Needed for Coding (Self-Reporting)	✓	✓	✓	✓	✓	✓	✓	✓	

Appendix B

Table A2. Results of the test run with selected cameras, conducted 2 December 2014, 14:10–16:50 in windy weather.

	Time	**Doerr (GSM Module)**	**LTE Acorn (GSM Module)**	**Cuddeback Attack IR Model 1149**
Pictures taken during test run	-	99	41	701
Pictures sent by E-mail	-	33	4	-
Pictures with individuals within the defined 20 m range	-	40	16	46 + 7 (camera range was almost 50 m)
		Events		
Simulated meeting walker, dog, cyclist	14:12–14:13	6 pictures	9 pictures	12 pictures
Cyclist with blue backpack	14:40	1 picture	1 picture	2 pictures
Woman and two children with dog	14:49	3 pictures (1 person missing)	-	3 pictures + 2 pictures further than 20 m
Bobble-hat woman with unleashed dog and two other passersby	14:58	7 pictures (dog only slightly visible in picture #4)	1 picture (dog was not photographed)	8 pictures + 2 pictures further than 20 m
Passersby	15:02	2 pictures	-	1 picture
Cyclist	15:05	3 pictures	1 picture	1 picture
Woman with small unleashed dog	15:14	3 pictures	-	2 pictures (one only contained unleashed dog)
One person from team for control	15:21	3 pictures	-	2 pictures
Control return walk	15:21	-	-	5 pictures
Jogger	16:02	3 IR pictures	1 IR picture	2 picture + 2 picture further than 20 m
Fast downhill cyclist	16:07	-	-	1 picture
Pedestrian	16:24	3 IR pictures	1 IR picture	2 pictures
Pedestrian with large dog	16:27	3 IR pictures	-	1 picture + 1 picture further than 20 m
Pedestrian + author and assistant	16:29	1 IR picture	1 IR picture	1 IR picture
Fast downhill cyclist	16:34	-	-	1 IR picture
Cyclist walking bike	16:35	1 IR picture	1 IR picture	1 IR picture
Slow downhill cyclist	16:35	2 IR pictures	-	1 IR picture

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