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Monitoring visitors to natural areas in wintertime: issues in counter accuracy

The sustainable management of vulnerable natural areas requires accurate measurement of visitor flows, especially in mountain and protected areas. Pyroelectric sensors that detect the heat radiation emitted by human bodies are now commonly used in many regions, including Scandinavia and the UK, to count pedestrian traffic in both urban and natural areas. We used four different tests to investigate pyroelectric counters' accuracy in mountain winter conditions. Air temperature, distance to sensor, visitor clothing and visitor volume were all found to affect counter error rates. For tests within moderate winter temperatures (between 0°C and -18°C) counters reported within manufacturer's claimed accuracy at 5% for 2 m range, but for -21°C and below visitor numbers were over reported by 10.9%. Counter accuracy was generally unaffected by visitor clothing within 2 m of the sensor, but at a 4 m distance counters frequently failed to detect individuals in insulating down jackets more than fleece jackets. Counter error rates were slightly higher in outdoor than indoor tests, but still accurate within 5%. Error rates increased with increasing visitor traffic. The findings provide methodological implications for researchers and managers using automated visitor counters to estimate wintertime visitor use in mountain areas.

Key words: visitor monitoring, protected mountain areas, Eco counter, error rates, Norway

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Introduction

The sustainable management of vulnerable natural areas requires accurate measurement of visitor flows. The management of vulnerable mountain areas requires especially accurate visitor counting. Terrestrial ecosystems at higher elevations and latitudes tend to be more sensitive to human impact and slower to recover than tempered or more nutrient rich ecosystems (Forbes et al. 2001; Müllerová et al. 2011). Recent trend in natural area management specifies that policies need to be "knowledge based" incorporating either adaptive management (Plummer and Fennell 2009) or management by objectives (Kajala et al. 2007). Management concepts for protected areas are shifting from "total protection" to "sustainable use" (Hammer 2008), and, therefore, in protected areas especially, a much deeper understanding of responses to anthropogenic disturbance is urgently needed to support sustainable and more flexible management strategies. Management aimed at ensuring the sustainability of tourism and recreational activities (the practical difference between the two is vague and the two are therefore combined here) in sensitive natural areas, such as mountain areas with important habitats, demands accurate estimates of the number of human visitors such areas receive over specific time periods. For all these reasons, counting people in mountain areas has been carried out for many years. Previous tests of automated counters and their accuracy have mainly been carried out in summertime (e.g. Pettebone et al. 2010). There is a urgent need to do similar tests in snow covered situations with temperatures below zero, including factors such as air temperature, clothing, sensor range (over wide ski tracks) and visitor volume (in ski tracks).

This paper concentrates on a relatively small aspect of the many visitor counting issues faced especially in protected areas. It illustrates the attention to detail required to carry out accurate and credible visitor monitoring. Eagles (2014), in his review of the ten most significant and urgent research fields in protected area studies, puts visitor use monitoring as the number one research priority. He goes on to specifically mention the use and value of electronic counters. This paper explains some of the issues with automated counting systems, updating and adding to Cope, Doxford and Hill's 1998 publication in this journal.

Many different types of automated systems for counting pedestrian traffic are currently in use all over the world, and several technical and scientific papers address their applicability and potential shortcomings (Ahlström 2011; Cessford & Muhar 2003; Chi-Chuan 2006; Pettebone et al. 2010; Rupf-Haller et al. 2006; Schneider et al. 2005; Shoji et al. 2008). These studies, however, assess the performance of devices when used in an urban setting (e.g. Lindsey et al. 2007) and/or in a more tempered environment than the extremes experienced in Norwegian and other mountain areas (e.g. Lynch et al. 2002). An important challenge with automatic counting systems is their accuracy, since all types of counters are subject to counting errors (Pettebone et al. 2010; Ross 2005; Yang et al. 2011). Counter accuracy is subject to qualitative errors, caused by movements that do not represent actual visitors, and technical errors, caused by characteristics of the counter and the installation site (Kajala et al. 2007). In this paper, we investigate the effect of technical errors on the accuracy of counters used to record the number of visitors in natural settings in wintertime, of especially great importance in skiing areas. Our tests assessed areas of potential counter error, and offer suggestions for how managers in various settings can deploy and maintain counters to limit the effect that such errors can have on counts of visitor numbers. Our experiences, findings and recommendations have relevance to all users of counting systems, regarding shortcomings and limitations to different counting equipment.

The tests were carried out in southern Norway, where wild reindeer (*Rangifer tarandus tarandus*) is one of the most vulnerable species in mountain areas above the timberline (Panzacchi et al. 2013). Norway is currently home to the last remaining wild reindeer populations in Europe (The Wild Reindeer Board, 2012). Norwegian mountain areas are intensively used for recreational purposes in wintertime, mainly by cross-country skiing, but also by many other non-motorized snow related activities (Kajala et al. 2007). Recreational use within the wild reindeer range is one of the main disturbing factors for wild reindeer and we need a better understanding of patterns and intensity of human use within both their summer and winter ranges (Nellemann et al. 2000, Vistnes and Nellemann 2008, Reimers et al. 2000, Panzacchi et al. 2013).

An important criterion for our use of counters in wild reindeer areas was to count all year round in order to produce a more reliable estimate of the number of visits and seasonal changes in the recreational use volume (Strand et al. 2010). The temperature range in Norwegian mountains is between -40°C in wintertime and +25°C in summertime. Additionally to low temperatures, there are harsh climatic conditions including heavy rain, strong winds and drifting snow. It is crucial that the counter is waterproof and has a wide operating temperature in demanding weather conditions. However, it is even more challenging to choose suitable sensors for these conditions. Seismic sensors, cable or pressure pads, reacting to pressure or vibration are unsuitable, because of continuous snowfall and ice on ground during the winter. Sensors based on breaking or the reflection of a sound cone (Ultrasound), infrared light (Optic sensors), “radio wave” (Radio transmitter) or laser, are generally difficult to maintain in harsh climate conditions (Kajala et al. 2007). Consequently, pyroelectric sensors seem to be most suitable for year-round conditions in the Norwegian mountains, and have been widely used in most Scandinavian countries for more than 10 years (Kajala 2006). A pyroelectric sensor contains a lens that is sensitive to infrared radiation emitted by human body. The lens detects that radiation each time a person passes, and can distinguish the direction of the person. Their minimum sensibility is a 1°C difference between the body and the outdoor temperature.

The most used counting system in Scandinavia (several hundred counters in use) and in the United Kingdom (more than 2000 counters in use) is currently a pyroelectric sensor that contains a lens that is sensitive to heat radiation emitted by human bodies (*Eco-Counter model: Eco Twin, Middle range Pyro Lens, hereafter named counters*). These counters are chosen for several different reasons: they are waterproof, function over a wide range of temperatures (-40°C to +50°C), record the direction of visitors' approach, can record and store data at every 1 hour or 15 min intervals, and maintenance is easy and cost-effective. The manufacturer states their mid-range sensor models can be used for distances of up to 4 m. This model is, therefore, commonly used to monitor traffic including pedestrians, bikers, cross-country skiers, and other visitors to Norway's mountain areas. The Norwegian Nature Inspectorate (SNO) deploys more than 65 such counters, and the Norwegian Institute for Nature Research (NINA) uses an additional 34 counters annually to collect its own data on visitor traffic in alpine areas. Most of these counters have been used in both summer and winter conditions since 2009, with some dating back to 2006, and are installed at the main entrances to the national parks of Dovrefjell-Sunndalsfjella, Rondane, Reinheimen, Hardangervidda and Hallingskarvet.

When these counters were purchased, their manufacturer reported a sampling error level of less than ± 5%. Since then, the manufacturer has altered its phrasing and now reports this level of accuracy as an "estimation" (http://www.eco-compteur.com). Scientific studies that investigated counting systems' use have also included the EcoCounter, with some papers even addressing their accuracy levels (Greene-Roesel et al. 2008; Ozbay et al. 2010; Yang et al. 2011). However these earlier studies were often completed in urban settings, with challenges that are different from those encountered in the less-used mountain areas in Norway and the extreme weather conditions encountered there. Two typical issues investigated in other studies are the effects of simultaneous passing (Hudson et al. 2010;

Ozbay et al. 2010; Yang et al. 2011) and variation in volume intensity (Greene-Roesel et al. 2008; Yang et al. 2011). The first season of Eco-Counters deployments at Norwegian national park entrances generated obviously erroneous count results, prompting us to investigate factors that could have increased the number of technical errors including air temperature, type of clothing, passing range and visitor volume.

Study design

We investigated counter accuracy using 4 different tests during the winters of 2009/2010 and 2010/2011. We used a 15 minute sampling interval for all tests, although total sampling duration varied for different tests. We mounted sensors at approximately 0.2 meters (m) horizontal distance between each sensor and 1.15 m above ground, with sensors positioned perpendicularly to the direction of visitor movement. We calculated error levels for all tests by comparing the number recorded by the automated counter with manual counts of passes made by test subjects ("ground truth"). We expressed counter deviance from the ground truth in per cent, with positive values indicating more recorded passes than the ground truth and negative values indicating missed passes. Twin-sensors are able to distinguish walking direction ("in" or "out"). If the sensors are unable to distinguish the direction of the by-passer, they are programmed to add the count as "in".

Sensor sensitivity is adjustable for five different settings, and are to be used based on location conditions: path width, crowding and temperature. A counter's sensitivity determines two factors: how accurate the sensor distinguishes between people passing closely after each other (i.e., its suitability for measuring crowded areas) and how far the sensor reaches (i.e., its ability to count people passing at a greater distance). An increase in one means a decrease in the other and vice versa. The standard setting (0) is the ideal setting for paths up to 4 meters in width, in moderate temperatures (not extreme hot or cold) and with regular traffic (not especially crowded) whilst the -1 setting is recommended for less crowded areas and/or in hot or cold temperatures. However, sensor setting did not influence results in three of four tests because these tests did not include crowding and all visitor passes were within a 4 m distance to sensor. In the fourth test, we found the standard setting (0) appropriate due to a combination of a wide track and crowding.

Test 1: We placed four counters (inside) at the main entrance to an office building over two days in December 2009, recording visitor passes as they passed counters placed at 2 m and 4 m distances from the counters' sensors. We sampled over eight 15-minute intervals at 2 m distances and five 15-minute intervals for 4 m distance (the effective distance between subjects and sensors was 1.5 m and 3.5 m respectively). Based on the manufacturer's recommendations we received, following the problems we had with over-counting in 2009, we reduced sensor sensitivity by using the -1 setting. Air temperature in the entrance hall was around +15°C, but outside temperatures were -5°C during the sampling. All visitors wore insulating winter clothing that reduced the infrared radiation their bodies emitted to varying degrees. Visitor volume ranged from 13 to 35 persons per 15-minute sampling interval. Three out of four counters recorded data for 15-minute intervals, while one counter (an older version) only recorded data for 1-hour intervals.

***Test* 2:** We used the four same counters from test 1 in an outdoor experiment conducted under different temperatures (-4°C, -18°C and -21°C) during three days in December 2009. While we used 2 and 4 m passing ranges for the experiment at -4°C, we restricted the tests at -18°C and -21°C to a 2 m passing range. A single test participant passed the counters exactly 50 times in each direction within each 15-minute sampling interval, giving a total of 100 observations during a 15 minute sampling interval and 400 observations per hour. The test participant also switched his clothing during the test between each 15 minute sampling interval, from a fleece jacket that was assumed to emit more infrared radiation to a down jacket that was assumed to emit less infrared radiation. Sensor sensitivity was again set to -1.

Test 3 We tested for variation in accuracy levels among counters with indoor and outdoor experiments using seven counters in December 2010. The indoor experiment took place in a vacant assembly room at + 20°C and involved 12 sampling intervals of 15 minutes each at a 2 m passing range and 19 sampling intervals at 4 m distance. The outside tests took place in a desolate area along a slope with little vegetation at -10°C, involving 12 sampling intervals at both 2 and 4 m passing ranges. In both tests, counter sensitivity was set to standard and the test participant wore a thin fleece and shell jacket, similar to normal outfits worn in alpine areas during autumn and winter.

Test 4 We assessed counter accuracy under extreme traffic volumes with a test conducted during the 54 kilometers cross country ski race that goes from Rena to Lillehammer, Norway—the *Birkebeinerrennet*—with approximately 16,500 participating athletes (www.birkebeiner.no/English/Rennet/). Sensor sensitivity was again set to "standard". We placed nine counters along a slightly downhill sloping ski trail approximately 5 kilometers before the finish line that including three parallel ski tracks. Passing range varied from 0.7 m for the closest track to 4.7 m for the most distant track. Sampling duration was 2 hours, with air temperatures between -5°C to -6°C. Each athlete was counted manually when passing the counters in the sampling period.

-----Table 1 about here------

Analyses

We used t-tests to test for variation in miscounting rate (the deviance between the "ground truth" and the number an automated counter recorded, hereafter: error rates) for both over counts (positive values) and under counts (negative values) as functions of different passing ranges, temperatures and types of clothing. We used one-way ANOVA to test for variation in error rates between individual counter units (test 3 and 4). Estimates of accuracy were based on replicate counters. We used a Tukey's HSD test to identify significant differences in error rates between counters. We compared the relationship between manual counts and automated counter numbers and visitor volume (test 4). The data satisfied the assumptions for the tests used (normal distribution of errors), and all tests were conducted with alpha <.05, using SPSS v 18.0.

Results

Test 1 and 2

Counters often produced visitor pass counts that were outside of the manufacturer's accuracy claims (figure 1). At the 2 m distance, counters over reported visitor numbers when temperatures were below freezing point and underreported numbers in temperatures above 0°C. However none of the groups' means were significantly outside of the ± 5% claimed accuracy range and the variance was often a result of miscounts by one single counter in a single 15 minute interval. Counter error rates were also outside the manufacturer's claimed ± 5% accuracy range when subjects passed 4 m from the counters' sensor in both warm (+15°C) and cold (-4°C) temperatures (figure 1), although neither results were significant (t_3 = 1.01, P = 0.81 at +15°C and t_3 = 0.11, P = 0.54 at -4°C). At -18 °C, counters only registered a passing subject when that subject wore a fleece jacket, which is an outfit commonly used by cross-country skiing athletes, while other groups of recreationalists normally wear more insulated outfits under such temperatures. Counter accuracy also fell outside of manufacturers claims at 2 m distances at -21°C (over recording) and +15°C (under recording). Note that sensor sensitivity during these tests was set to -1 (as earlier described). The effect of our subject's jacket type on counter error rate depended on the distance to counter at -4°C ($F_{1,8}$ = 15.6, P > 0.0001): a result entirely due to counters' decreased ability to detect a visitor at the 4 m distance when wearing a more highly insulating quilted jacket.

-------Figure 1 about here------

Test 3

Variation among counter units indoors was negligible, and not significant at either 2 m ($F_{6,77}$ = 0.83, p = 0.55) or 4 m ($F_{6,126}$ = 0.008, p = 1.00) distances. Error rates at 2 m distance ranged from 0 to 1%, and error rates at 4 m distance ranged from 0 – 5 %. Error rates were slightly higher at the outdoor tests, but generally within the manufacturer's claimed level of 5% (Table 2). Variation among counters was not significant at 2 m distance ($F_{6,77}$ = 2.58, p = 0.068). At the 4 m distance, however, a single counter (D) produced an mean error rate that was significantly greater than the other six ($F_{6,77}$ = 4.637, p = 0.001), but still within the manufacturer's claimed accuracy.

------Table 2 about here-------

Test 4

We recorded manually 5574 cross-country skiers during the 2-hour test period, with volume ranging from 534 to 880 athletes per 15-minute sampling period. This frequency range is the equivalent of one visitor passing every 1 to 1.7 seconds, and is far beyond visitor volume where this type of counters are used in Norwegian natural settings but certainly relevant for urban environments. The mean error rate for all counters during the sampling period was -32.8 ± 1.29% (± S.E.), but varied from -7.5% to -63.1%. One counter (nr. 8) systematically under reported visitor passes (average error: -56.6%, ranging from -48% to -63%; Figure 2). Variation among counters was significant ($F_{8,63} = 17.37$, $p = 0.001$), but counter nr. 8 was excluded from the analysis, post-hoc tests showed no significant differences (all $p > 0.142$) in error rates among the other counters.

-------Figure 2 about here------

Discussion

Our tests demonstrated that air temperature, distance to the counter, type of clothing and visitor volume can all affect counter accuracy within the range of conditions in which they are used for monitoring visitor numbers in Norwegian natural areas. However, these results also provide guidance for how counter accuracy could be improved when planning site location, installation, and monitoring and we believe these principles are applicable to other counting systems. Mean counter accuracy was within the manufacturer claim of 5 % error rate when visitors passed within 2 meters from counter sensor. The accuracy diminished dramatically at 4 m distances in tests when the counters' sensor sensitivity was manually decreased (the *-1* setting) as suggested by manufacturer: an effect further compounded by cold temperatures. In tests where sensor sensitivity was set to "Standard," however, we obtained counter readings that were within five per cent of true values. Counter installation should therefore be as close to the path of travel as possible to ensure that people pass within short distances of the counter sensors. In situations where this is not practical, sensor sensitivity should be adjusted to match the distance between visitors and counters, and the sensitivity setting should be verified with simple experimentation.

Infrared sensor accuracy is expected to increase with decreasing air temperatures because colder air generates a greater contrast between ambient temperature and body temperature of passing subjects. For tests within moderate winter temperatures (between 0°C and -20°C), counters over reported visitor numbers—even at a reduced sensor sensitivity setting—but within manufacturer's claimed accuracy. The counter model we tested is claimed to be suitable at even lower temperatures (down to -40°C), although our test at -21°C produced even substantial over reporting of visitor numbers. The results of our third test indicate that summer temperatures should be unproblematic for counter accuracy. Our results from test 2 indicate that clothing effects counter accuracy, suggesting that the underreporting error rate in test 1is due to the winter attire that test subjects wore because outside temperatures was quite cold (- 15°C). . Under reporting was only slightly outside of manufacturer accuracy claims at the 2 m, but did become worse at the 4 m distance.

Counter accuracy was particularly poor in the test conducted during the Birkebeiner ski race with its high volume of visitor traffic (a person passing every 1-2 seconds). This test was intended to assess counter variations under high visitor volumes and we did not account for the speed at which visitors passed the sensors. Other tests of counter accuracy have produced similar results (Greene-Roesel et al. 2008; Hudson et al. 2010; Yang et al. 2010). Such inaccurate reported may be preventable if counters can be placed where visitors must pass sensors in single file and not side by side. However, the degree of under reporting visitor counts we observed in this test is unlikely to be a problem for monitoring visitor numbers at Norwegian national park entrances, since numbers are generally very low (Gundersen et al. 2011).

Colder temperatures may require decreased sensor sensitivity to avoid over reporting visitor numbers, but not if counter sensors cannot be mounted within 2 m of where visitors will pass. Warmer temperatures (> 10°C) should not require decreased sensitivity. As described by many others, counters need to be calibrated in their installation sites to secure an accurate count. Counters sensitivity should also be refined seasonally if counters are deployed for long periods, so that sensitivity settings reflect changing both temperatures and visitor attire. Although we did not address these issues in our tests, it is also important to note that sensors should be mounted with the lens parallel to the ground surface and directed towards a background (e.g. open air or cliffs) at a 1 m height to reduce the risk of counting non-human activity (e.g. domestic sheep, *Ovis aries*) in the background of the counting location.

For our applications in Norwegian national parks in alpine terrain, we attempted to position counters at sites were most people were walking along a path and visitor volume was low to moderate. However, in some instances we needed to monitor visitor traffic along gravel roads where the visitor volume was quite high and sensors could be positioned no closer than 5-6 m from passing visitors. Where these locations often had more than one visitor every 5 minutes, we have determined that accurate estimates of visitor numbers requires on site manual observation to calculate the appropriate correction coefficients.

Our tests addressed potential technical and qualitative errors with the use of one type of automatic Eco-Counter: Eco Twin model with a middle-range Pyro Lens. Our focus was also on applications in winter conditions for a sub-arctic climate, and our tests illustrated factors that affect counter accuracy. Visitor reporting data must accurately reflect actual visitor traffic to be useful for natural resource managers and park administrators. We recommend exercising caution when using this kind of counters in wintertime, especially in very low temperatures. It is crucial that efforts to count park visitors include consideration of potential sources of error in the planning, installation, monitoring of counters and calculating correction coefficients for each counter and site, regardless of the counting system in use.

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Andersen et al. 2013. Counter accuracy

Table 1-2 and Figure 1-2

Table 1. The experimental conditions for tests assessing accuracy of counters equipped with pyroelectric sensors.

	Distance to sensor		Clothing		Temperature		Volume per 15 min.	
	Tested	Details	Tested	Details	Tested	Details	Tested	Details
Test 1	√	2 and 4 meters		Attire: not controlled for	√	15 °C	√	13 to 35
Test 2	√	2 and 4 meters	√	Attire: altered between fleece and down jacket	√	-4 °C -18 °C -21 °C	√	100
Test 3	√	2 and 4 meters		Attire: thin fleece and shell jacket	√	20 °C -10 °C	√	100
Test 4		0,7 -4,7 meters		Attire: not controlled for		-5/-6 °C	√	534 to 880

Table 2. Counter error rates (mean ± 1 SE) from tests of variation among counters involving 12 trials of 100 passes each (1200 total passes), Results in bold indicate error rates that were significantly different form other counters within a single test of temperature and distance.

	Indoor (+18 °C)		Outdoor (-10 °C)	
Counter	2 m	4 m	2 m	4 m
A	0.0 ± 0.0 %	2.8 ± 2.7 %	0.0 ± 0.0 %	0.1 ± 0.1 %
B	0.0 ± 0.0 %	2.9 ± 2.7 %	0.0 ± 0.0 %	0.6 ± 0.2 %
C	0.1 ± 0.1%	3.0 ± 2.6 %	0.3 ± 0.1 %	-0.5 0.8 %
D	0.0 ± 0.0 %	2.8 ± 2.7 %	0.1 ± 0.1 %	**-4.4 ± 2.1 %**
E	0.0 ± 0.0 %	2.8 ± 2.7 %	0.0 ± 0.0 %	0.1 ± 0.1 %
F	0.1 ± 0.1%	3.5 ± 2.7 %	0.3 ± 0.1 %	1.2 ± 0.5 %
G	0.0 ± 0.0 %	2.9 ± 2.6 %	0.3 ± 0.1 %	0.4 ± 0.3 %