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Research Note

Assessing the quality of forest fuel loading data collected using public participation methods and smartphones

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Abstract. Effective wildfire management in the wildland–urban interface (WUI) depends on timely data on forest fuel loading to inform management decisions. Mobile personal communication devices, such as smartphones, present new opportunities to collect data in the WUI, using sensors within the device – such as the camera, global positioning system (GPS), accelerometer, compass, data storage and networked data transfer. In addition to providing a tool for forest professionals, smartphones can also facilitate engaging other members of the community in forest management as they are now available to a growing proportion of the general population. Approaches where the public participates in the data-collection process (inspired by citizen science) may be beneficial for fire hazard issues. This research note demonstrates a smartphone application for measuring forest fuel loading in the WUI by forestry professionals and non-professionals, and evaluates the quality of the collected data. Smartphones and their associated applications may provide new tools for collecting forest structural data in the WUI, but forest managers need to ensure that measurement protocols provide the required precision for analysis and enforce the logical consistency of observations made by a diverse set of data collectors, and that sufficient training is provided. If these recommendations are followed, we conclude that data acquired by volunteers in collaborative projects through smartphone applications can be of acceptable quality to help inform forest management decisions.

Additional keywords: citizen science, geographic information systems, remote sensing, spatial information.

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Introduction

In many wildland–urban interface (WUI) areas, fire is a naturally occurring event. In recent years, policies of fire exclusion have led to changes in forest structure, including an accumulation of fuels. This, in turn, has led to more severe wildfires, which in combination with more people living in the WUI, necessitates the management of wildfire hazards (Radeloff *et al.* 2005). Activities such as fuels modification and reduction are performed with the aim of reducing the intensity and severity of wildfires near priority areas, such as communities (Agee and Skinner 2005). Challenges in prescribing treatments include that (1) forest fuels are spatially variable and can change rapidly due to storm windfall, or other natural changes in forest structure and (2) measuring forest structural components under dense canopies is difficult using remote sensing approaches, due to sensor geometry. Therefore, accurate characterisation of forest fuels depends on frequent measurement by field crews (Keane *et al.* 2001). Data collected about forest fuel loading are an important input into forest management software, including applied geographic information systems (GIS) and fire behaviour models to plan, prioritise, design and implement fuels treatments and fire suppression strategies (Ohlson *et al.* 2003; Lutes *et al.* 2006).

Several methods for the rapid assessment of forest fuels have been developed. The photo series technique involves measuring fuels in reference plots and taking oblique reference photographs allowing field crews to visually match observed site conditions with the photos and record the corresponding quantitative values for fuel loading (Maxwell and Ward 1976). Another method is the photoload technique, where synthetic fuel beds with known fuel loadings are photographed (downward and oblique), also creating a visual guide for assessment (Keane and Dickinson 2007). Sikkink and Keane (2008) compared rapid assessment techniques with traditional direct measurements, such as planar intersect and fixed area plots, and found that there are trade-offs between the methods in terms of measurement accuracy, experience and time required to complete each assessment. All of these methods lay a solid foundation for new approaches that may be advanced by technology.

Recent advances in communication technology, including smartphones, have led to new opportunities for collecting data. A growing proportion of the population use smartphones with Internet connectivity to widely and rapidly share information. These devices are generally less expensive than electronic devices that are purpose-built for forestry and they provide opportunities to easily install applications; deliver instructions and enter data on a touch screen interface; acquire images using the camera; measure location and direction using the global positioning system (GPS) and compass; measure angles using an accelerometer; store data and transmit it over a network. These devices also have the potential to collect forest structural data to compliment Earth observation data collected by satellite remote sensing devices (Ferster and Coops 2013). Several previous projects have utilised smartphones to collect Earth observation data (e.g. Powell *et al.* 2012; Weng *et al.* 2012; Pratihast *et al.* 2013*b*; and others including several commercial offerings).

Approaches for collecting data using smartphones can draw guidance from public participation in scientific research (PPSR), also known as citizen science. In PPSR, people without explicit scientific training may take part in the research process, often leading to personal advances for the participants, occasional scientific breakthroughs and potentially more effective resource management (Shirk *et al.* 2012). There are numerous incentives for utilising PPSR-inspired approaches for wildfire management. Many people have smartphones, providing the potential to collect data covering broad areas (Lane *et al.* 2010). In addition, approaches inspired by PPSR may lead to more effective wildfire management by increasing knowledge and salience of wildfire issues in communities and providing opportunities for forest professionals to work with other members of communities (Ferster *et al.* 2013). This is beneficial because knowledge is required for homeowners to prepare defensible spaces at their residences (Cohen 2000) and public support of wildfire management on public land is linked to knowledge of wildfire and trustworthy citizen–agency relations over time (Toman *et al.* 2011).

The purpose of this study is to evaluate the quality of forest fuels data collected by volunteers using a smartphone application designed by the research team. We also identify needs and general issues to guide and inspire further development for data collection with smartphones and public participation methods, which may offer considerable potential for wildfire management. Volunteers were recruited from a wildfire-affected community, including professional and non-professional participants, who used a smartphone application to record observations of forest fuels amounts and arrangements in a WUI area. We assess the data acquired by participants with different levels of forestry experience and discuss the fitness of the data for informing wildfire management decisions.

Methods

The study area was located at the University of British Columbia Okanagan campus, in Kelowna, British Columbia, Canada. The study site contained a variety of WUI forest stands, including areas where stems had been thinned and woody debris removed; there was debris from insect-killed trees that had been felled and de-limbed on site; and where no recent stand modifications were observable and the accumulation of forest fuels was considerable. Through contact with local neighbourhood associations, recreation groups, professional foresters and local media, 18 volunteers were recruited. Nine of the 18 volunteers (50%) had extensive working experience in forest fuels management or wildfire suppression.

The research team developed the application for a common smartphone without any additional instruments. The application was run on an Apple iPhone 4 with an iOS 6.1 operating system. The application could be implemented on any smartphone with a touchscreen, data storage, data networking, compass, accelerometer, camera and GPS. The application was inspired by rapid visual assessment techniques such as photo series and photoload (Sikkink and Keane 2008). Each participant was assigned a random, non-personally identifying code, which was recorded and linked to the volunteered plot data and reference data. The assessment included three parts (Fig. 1). First, a series of slides introduced the general concepts of forest fuels management. Second, visual estimations of the quantity and arrangement of fuels on site were made using diagrams and illustrations for reference and, for each component, the closest matching category was selected using menus and buttons. The categories and definitions followed the regional protocol in British Columbia (see Morrow *et al.* 2008) (Table 1), making the results compatible with previous datasets. Third, participants acquired location information from the GPS, slope, aspect and images of the fuel loading at the site (including overall site pictures of each stand and photos of the specific components – not analysed here). The data generated were exported as a comma separated value (CSV) file and JPEG images transferred either by email or attaching the device to a computer with a cable.

Participants, accompanied by at least one member of the research team, walked to WUI areas and used the smartphone application to collect data at locations of their choice (to simulate a volunteered, opportunistic dataset). The research team collected observational notes. The 18 volunteers collected data from a total of 46 plots. A flagging tape marker was placed for revisit by the research team to collect reference measurements. The reference measurements were collected in a similar way to the volunteered measurements and where practical, quantitative direct measures were taken of conifer crown base height, understorey conifer stem density and large woody debris coverage. However, because of equipment limitations, this was not possible for all components. Therefore, the reference measurements served as a relative baseline for comparison, and a more thorough analysis to bound and compare the estimates to other methods was deemed beyond the scope of this research. Nonetheless, the comparisons of repeated measurements were sufficient to lead a discussion of issues of data quality. Comparisons between the volunteered and reference data were made by calculating the root mean squared difference (RMSD) for the quantitative value (determined by the midpoint of the range of values in each category) and the difference in categorical ranking (the number of categories separating the volunteered and the reference observations). Finally, the proportion of measurements within ± 1 category of the reference measurements were counted and a one-sample Chi-square proportion test was used to evaluate if there was a significant difference between the proportion of observations that were above and below the reference value ($\alpha = 0.05$). This statistical test was completed as an exploratory test only, with a more representative (and larger) sample required to draw more conclusive statements about larger populations.

Results

Of the 46 plots measured by 18 participants, 22 were measured by participants with professional experience in forestry, and 24 by participants with no previous experience in forestry. Most of the measured components, classified into one of the five ordered categories, had a RMSD between 0.7 and 1.5 categories

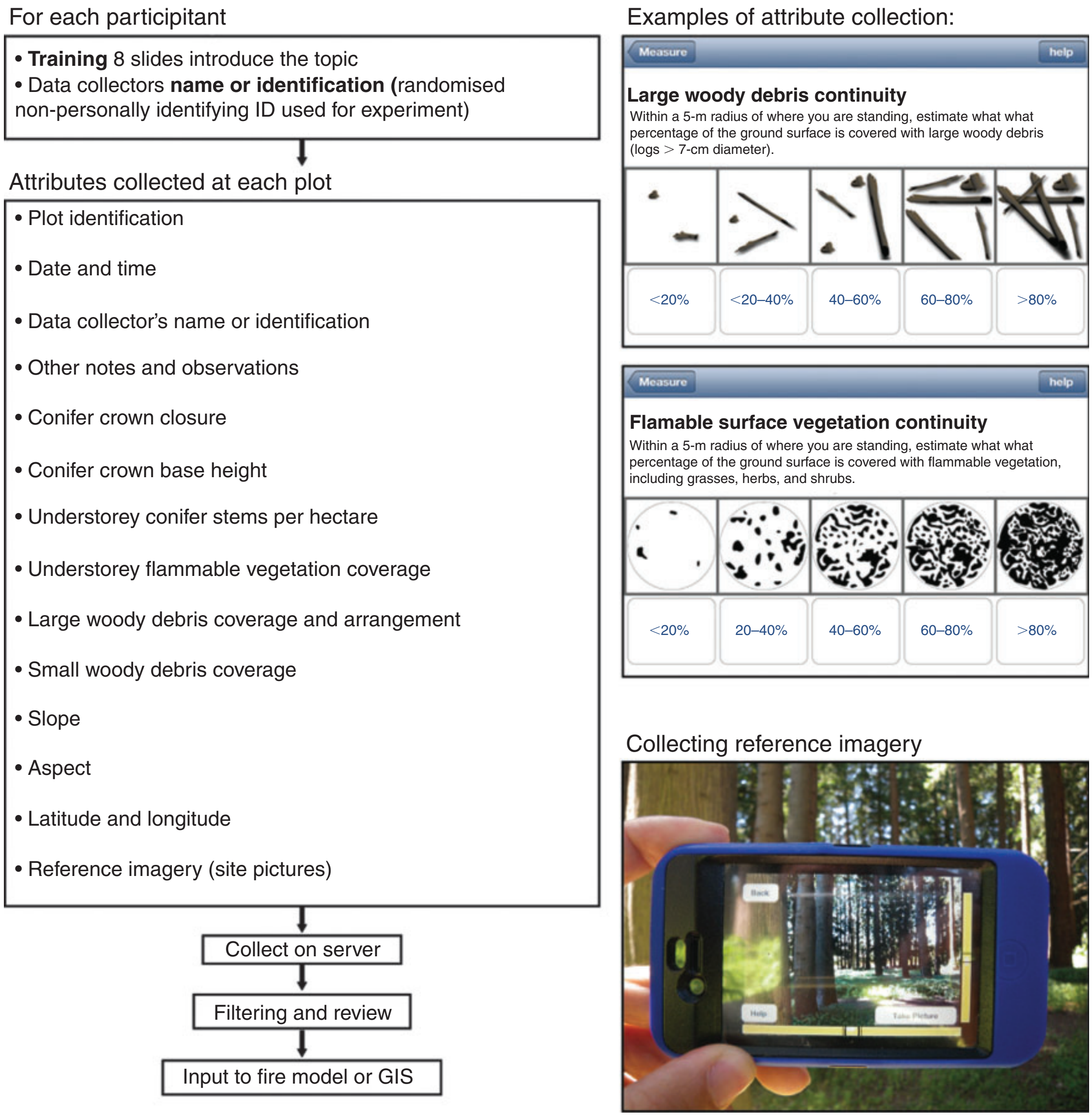

Fig. 1. The forest fuels application and sample screen captures as implemented on the iPhone 4 with iOS 6.1.

compared with the reference measurements, whereas larger RMSDs (1.5 categories or greater) were observed for understorey conifer stem density, height to live conifer crown, and slope and aspect (for non-professional participants) (Table 2). In measured units for professional participants this translated to a RMSD of 15% for understorey vegetation coverage and a RMSD of 436 stems per hectare for understorey stem density. In measured units for non-professional volunteers, the RMSD was 25% for conifer crown closure and the greatest RMSD was 427 stems per hectare for understorey stem density. The details of these differences and why they occurred are examined below.

For most components, the professional measurements were slightly closer to the reference measurements than were the volunteered measurements, but for some measurements, such as slope and aspect, the professional volunteers were notably more accurate than the non-professional volunteers. This was likely due to previous experience using a compass and inclinometer (the application interface was styled after these instruments). Non-professional participants overestimated slope and aspect. With further training, non-expert data collectors could be expected to improve. Likewise, for fine woody debris, professional measurements were closer to the reference measurements than were non-professional measurements, and this was likely due to greater familiarity identifying fine woody debris and estimating surface coverage. For height to live conifer crown, the non-professional participants provided measurements closer to the reference measurements than did professional participants. This most likely occurred because, in general, non-professionals were observed to closely follow the instructions given in the application, while some of the forestry professionals, already familiar with the terms, did not refer to the instructions as closely, and used working definitions that differed from the instructions given and the definitions used by

Table 1. Description of forest structural components measured as adapted from Morrow *et al.* (2008)

Component	Unit	Description	Categories
Conifer crown closure	Percentage coverage	Percentage crown closure of overstorey conifer trees. Volunteered and reference observations were made using visual estimates with crown closure diagrams for reference (Fig. 1).	A, <20%; B, 20–40%; C, 40–60%; D, 60–80%; E, >80%
Conifer crown base height	Metres	Estimate in metres in height to base of dominant and co-dominant veteran stems. Volunteered observations were visual estimates. Reference measures were taken using a pole and measuring tape to measure the height from ground level to continuous live conifer crown.	A, >5 m; B, 3–5 m; C, 2–3 m; D, 1–2 m; E, <1 m
Understorey conifers	Stems per hectare	An estimate of the number of suppressed and understory coniferous trees. Volunteered observations were visual estimates. Reference measurements included stems within a 5-m measured plot radius.	A, <100; B, 100–200; C, 200–400; D, 400–600; E, >600
Understorey vegetation coverage	Percentage coverage	The total surface area coverage of all flammable vegetation surface fuels. For both volunteered and reference observations, a visual estimate was made using diagrams from reference (Fig. 1).	A, <20%; B, 20–40%; C, 40–60%; D, 60–80%; E, >80%
Large woody debris coverage	Percentage coverage	Coverage and depth of dead and down particles greater than 7 cm indiameter and with less than 50% of its circumference buried. Volunteered observations were visual estimates using diagrams for reference (Fig. 1). For reference measurements, the ground area covered by large woody debris was measured with a tape within a 5-m radius plot.	A, <1%; B, Scattered, <10%; C, 10–25%; D, >25% not elevated; E, >25% elevated
Fine woody debris	Percentage coverage	Coverage of dead and down particles larger than conifer needles and less than or equal to 7 cm in diameter. For both reference and volunteered observations, a visual estimate was made using diagrams for reference (Fig. 1).	A, <1%; B, Scattered, <10%; C, 10–50%; D, >50%, <10 cm deep; E, >50%, >10 cm deep
Slope	Percentage ratio of vertical change to horizontal change	The angle of the average ground slope in the area. Measured with device inclinometer.	A, <15%; B, 15–30%; C, 30–45%; D, 45–54%; E, >55%
Aspect	Cardinal direction	The direction of slope, relative to true north, or flat. Measured with device compass.	A, north; B, east; C, flat; D, west; E, south

Table 2. Metrics for comparison of the volunteered measurements with the reference measurements

Comparisons were made for all volunteered measurements, measurements volunteered by people with professional experience (Pro) and people without professional experience (Non-pro). The metrics include (1) root mean square difference (RMSD) in measurement units, (2) RMSD in number of categories separating the volunteered data and the reference measurements (CRMSD) and (3) the proportion of measurements within ±1 category of the reference measurement or greater than two categories difference (a higher category number indicates a higher fuels load). A one-sample Chi-square test of proportions was used to evaluate if there was a significant difference ($\alpha = 0.05$) between the proportion of measurements that were over and the proportion of measurements that were under the reference measurement (asterisks indicate significance)

	Metric	Fine woody debris continuity (%)	Large woody debris continuity (%)	Surface vegetation continuity (%)	Understorey conifers (stems per hectare)	Conifer crown base height (m)	Conifer crown closure (%)	Aspect (degrees)	Slope (%)
All	RMSD	34.6	21.2	21.7	431.7	2.6	23.5	113.8	22.5
Pro	RMSD	33.3	14.6	14.5	436.9	2.9	21.6	87.7	14.8
Non-pro	RMSD	35.9	25.8	26.5	426.8	2.2	25.1	135.0	28.2
All	CRMSD	1.2	1.2	1.1	2.0	1.7	1.2	1.3	1.6
Pro	CRMSD	1.1	1.1	0.7	2.0	2.0	1.1	1.1	1.0
Non-pro	CRMSD	1.2	1.3	1.3	2.0	1.4	1.2	1.5	2.0
All	+2 or more	0	9	4	9%	26%	9	13%	5
All	±1	75	80	87	57%	59	83	80%	65
All	−2 or less	25*	11	9	35%*	15	9	8%	30*
Pro	+2 or more	0	5	0%	9%	36%	5	0%	10
Pro	±	77	91	100	64%	45%	86	90%	85
Pro	−2 or less	23%*	5	0	27%*	18%	9	10%	5
Non-pro	+2 or more	0	13	8	8%	17%	13	25%*	0
Non-pro	±	73	71	75	50%	71%	79	70%	45
Non-pro	−2 or less	27*	17	17	42%*	13%	8	5%	55*

others. These issues could be problematic for building databases using measurements from multiple sources.

Many of the participants (including professionals and non-professionals) underestimated the number of understorey conifer stems, and only a small number of volunteers were able to consistently estimate the density of stems. Therefore, this component requires greater skill to make reasonable visual estimations. One possible approach to overcome this issue may be to provide more extensive training for new volunteers. Some of the experienced volunteers suggested that using a low-cost plot measurement cord and diameter gauge (to determine eligibility of stems), and providing more specific criteria on what constitutes understorey trees would have improved their estimates and thus reinforced logical consistency across users and locations.

For the other components – conifer crown closure, large woody debris, fine woody debris and surface vegetation continuity – the RMSD ranged between 0.7 and 1.5 categories. For fine woody debris, participants underestimated coverage. For the other components, no systematic bias in either direction was observed. The measured RMSD may be partly attributed to variation in visual interpretation. Several incomplete plots were submitted, so adding an alert may help make participants aware of missing fields before submitting the data.

Discussion

When using a rapid visual assessment method, variations in measurements are expected because of differences in visual interpretation. However, in this study, several consistent differences were observed between users, which points the way to improving the approach. Initially, the motivation for this study was to design and provide a tool that could be accessible to a large number of people with minimal equipment and training, and that allowed users to make forest measurements related to fuel loads. Nonetheless, more precise yet potentially more time-consuming data collection methods may also be feasible. For example, measuring devices could be used for a subset of measurements to provide feedback about the accuracy of visual estimates.

Attribute accuracy of data collected by professionals and non-professionals has been compared in other studies. For example, Pratihast *et al.* (2013*a*) found that forest inventory and land use change data collected using mobile devices by untrained personnel were comparable to data collected by professionals. Other studies reported similar findings (e.g. See *et al.* 2013). Additionally, many voluntary projects use self-selected volunteers with considerable expertise (Brabham 2012). The findings of this study indicated that data collected by professional participants were somewhat more similar to reference measurements than were the data collected by non-professional participants. Where differences were due to experience and training, inexperienced participants could be expected to improve over time with suitable feedback and access to training. In other cases, where differences were due to logical interpretation of instructions, making instructions for measurement protocols more clear could improve the consistency and comparability of observations contributed by professionals and non-professionals alike.

Limitations

A limitation of this study is that some of the reference measurements were collected in a similar way to the volunteered measurements (i.e. visual assessment). In future studies, the measurements could be compared with multiple measurement methods to bound the observations (following Sikkink and Keane 2008), and collected over a broader range of sites and with more participants. It is important to note that several major considerations in implementing a public participation project involving wildfire are risk, liability and personal privacy. This work is intended as a starting point to demonstrate proof of concept for an approach that has considerable potential for data collection in forestry and wildfire management.

Summary

Management of forest fuels in the WUI requires data about the location, type, arrangement and amount of fuels. Smartphones can facilitate new methods of collecting forest fuel loading data in the WUI. In addition, they offer a way to engage members of the public that may not normally measure forests. This approach is compelling because it may enable data collection over broad areas and building of large databases of comparable and consistent data collected by a diversity of people. In this study, the quality of data collected by volunteers was similar to those collected by forest professionals. Fire managers need to consider the required accuracy of their analysis, that digital data collection methods reinforce logical consistency of observations and that data collectors receive adequate training and feedback on the quality of data that are collected. If these recommendations are followed, data collected by volunteers can be suitable to help inform forest management decisions. Approaches using smartphones to collect forest fuel loading data show considerable promise and warrant further investigation and development.

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