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Built structure identification in wildland fire decision support

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Abstract. Recent ex-urban development within the wildland interface has significantly increased the complexity and associated cost of federal wildland fire management in the United States. Rapid identification of built structures relative to probable fire spread can help to reduce that complexity and improve the performance of incident management teams. Approximate structure locations can be mapped as specific-point building cluster features using cadastral data records. This study assesses the accuracy and precision of building clusters relative to GPS structure locations and compares these results with area mapping of housing density using census-based products. We demonstrate that building clusters are reasonably accurate and precise approximations of structure locations and provide superior strategic information for wildland fire decision support compared with area density techniques. Real-time delivery of structure locations and other values-at-risk mapped relative to probable fire spread through the Wildland Fire Decision Support System Rapid Assessment of Values at Risk procedure supports development of wildland fire management strategies.

Introduction

Recent ex-urban development within the wildland interface has significantly increased the complexity and associated cost of federal wildland fire management in the United States (Gude *et al.* 2008). Reviews by federal oversight agencies and independent review panels convened by the federal government (e.g. Strategic Issues Panel on Large Fire Cost 2004; USDA OIG 2006; GAO 2009) have criticised the inability of federal agencies with wildland fire management responsibilities to demonstrate the value of suppression activities. Specifically, the USDA OIG (2006) directed that the 'Forest Service must determine what types of data it needs to track in order to evaluate its cost effectiveness in relationship to its accomplishments. At a minimum, Forest Service needs to quantify and track the number and type of isolated residences and other privately owned structures affected by the fire, the number and type of natural/cultural resources threatened, and the communities and critical infrastructure placed at risk'.

In response, researchers and technology transfer specialists within the US Department of Agriculture Forest Service developed the Wildland Fire Decision Support System (WFDSS), a risk-based decision support system that has gone a long way in addressing many of the issues identified within the oversight reports. Tools within WFDSS provide fire managers with the ability to identify, in real time, the likelihood that wildfire will affect valuable resources. By focussing on risk, the intersection of threat (fire spread) and values at risk of loss (Finney 2005), fire managers assure that suppression resources are being deployed for the right reasons in the right places, thus improving the agencies' ability to demonstrate the value of suppression to the public, Congress and government oversight agencies. Additionally, risk assessments may be used to identify fires or portions of fires that pose limited or acceptable levels of risk to private and public values and, therefore, where limited suppression responses may be most appropriate.

In the spring of 2009, the Forest Service Office of Fire and Aviation Management officially implemented WFDSS. The WFDSS replaced the existing Wildland Fire Situation Analysis (WFSA) in the case of suppression events and the Wildland Fire Implementation Plan (WFIP) for wildland fire use events. Though WFDSS is a robust tool that facilitates long-term planning and decision documentation, the focus of this paper is the use of WFDSS for incident-level decision support.

The economic effects module of the WFDSS is known as the Rapid Assessment of Values at Risk (RAVAR). The RAVAR Critical Infrastructure module maps structure location, critical infrastructure and jurisdictional boundaries. The identification of primary structure location is one of the most significant components of the RAVAR. Rapid delivery of spatially explicit structure locations relative to predicted fire spread is crucial to developing risk-informed wildfire management strategies.

Structure location maps within RAVAR are developed in two distinct ways: (1) building clusters derived from cadastral data (public valuation records for tax assessment plus GIS data of associated parcels) acquired from the counties; and (2) in the absence of these data through interpretation of aerial

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photographs. To date, the sufficiency of using building cluster data to estimate structure locations has not been rigorously assessed. The purpose of this study is therefore to assess the accuracy and precision of building clusters derived from spatial GIS cadastral data as a proxy for actual structure locations. We discuss advantages over alternative approaches, review potential issues, and identify errors associated with the use of these data for wildland fire decision support.

Structure identification for wildfire management

Two general approaches exist in the United States to identify built structures relative to wildfire threat, area-density mapping and point-specific mapping. Area-density mapping uses US Census block-level data to compute a proxy for housing density by dividing the total number of housing units within each census block by the area of the respective block (Stewart *et al.* 2009). This approach is used to delineate wildland–urban interface (WUI), areas adjacent to vegetated wildlands where human development may be most exposed to hazards posed by wildland fire. Results of WUI mapping are commonly used to plan and prioritise fuel reduction treatments.

Housing density assessments may be of value at broad scales, at county or regional levels, for strategic prioritisation, but are of limited value where more specific knowledge of structure locations is required. The size of census blocks reflects population density, with roughly equal numbers of housing units within each block (US Census Bureau 1994). Generally, census blocks are small in area, reflecting tendency for populations to cluster in urban development. However, census blocks in sparsely settled areas may contain many square miles of territory (US Census Bureau 2001). This can result in large census blocks with a small cluster of homes in one area but large uninhabited regions in the remaining area. This illustrates the limits of applying census-based WUI maps to incident-scale fire management. In moderate- and high-density census blocks (more than one structure per 2 ha; USDA and USDI 2001), the relationship between housing density and actual structure locations may be sufficient for wildfire management purposes. However, this relationship is not expected in rural areas with low populations living in development scattered within large census blocks. To some extent, this limitation is a classic example of the modifiable areal unit problem (Openshaw 1984). Census blocks defined by equal housing units are insufficient to provide consistently useful information about how population is distributed within a census block.

Use of cadastral data for fire management

A systematic method to apply point-specific structure location data to incident-scale fire management was first documented by Calkin *et al.* (2005). County and state cadastral data were used to approximate structure locations. Points derived from cadastral data served as a means to evaluate fire management costs between two fires that burned near Missoula, Montana, in 2003. At that time, the State of Montana had completed and published on an open public site digital cadastral data for the entire state with full cadastral attributes. Approximate structure location points were created from these data by first selecting all parcels where the taxable improved value, the assessed value of built structures and other infrastructure, was greater than US$0. A geometric centroid point was then created for each selected parcel polygon. These points are termed 'building clusters' or a point assumed to represent the location of one or more built structures. Although parcel data commonly report the type of improvement, for example, residential, commercial or agricultural, details about the improvements are seldom provided. The greater than US$0 selection threshold was chosen as a conservative criterion to minimise possibility of missing a very-low-value structure that might be used as a private residence, e.g. an older mobile home.

Building clusters were first used for real-time wildfire risk assessment and fire management decision support during the 2005 and 2006 wildfire seasons during prototype development of the WFDSS-RAVAR project. The count and approximate value of building clusters were geospatially analysed relative to predictions of potential fire spread. Limits to this approach were recognised, and caveats for the use of building cluster data were established. The intended application was for strategic use only. It was clearly understood that a low-value taxable improvement could as well be a non-habitable outbuilding. Users were cautioned to defer to local knowledge for specific locations of structures and warned that spatial accuracy of building cluster points decreases with increasing parcel size based on the simple logic that the larger the parcel, the more likely it is that any structures on the parcel will not be located in the centre of the parcel. A further limitation was noted: improvements on parcels not logged in public records would not be identified in the building cluster spatial data.

Following the successful prototype demonstration of building clusters for risk-based decision support, RAVAR developers and the Cadastral Subcommittee (CSC) of the Federal Geographic Data Committee (FGDC) partnered to identify and collect all available parcel data in 11 western states to support the WFDSS-RAVAR project (Stage *et al.* 2005). As of 30 September 2009, cadastral data have been collected, processed and staged for 293 of 413 (71%) of the counties in the 11 western US states. The CSC previously demonstrated the value of the use of parcel data for emergency response in North Carolina following Hurricane Isabel in 2003 (Stage and Von Meyer 2004). Two reports from The National Academy of Sciences have since been published that explicitly support the need to compile parcel data across the nation and to have it available to apply for emergency response (National Research Council 2007*a*, 2007*b*). The CSC identified over 28 federal agencies whose missions will benefit as spatially enabled parcel data become available across the US (FGDC Cadastral Subcommittee 2008).

The compiled building cluster datasets have been incorporated as one of three core component datasets of RAVAR that describe values at risk. The other two datasets are critical infrastructure, e.g. powerlines, oil and gas transmission lines and communication towers, and natural and cultural resources. Where a wildfire escapes initial containment efforts and burns in conditions of high spread potential, fire behaviour analysts can use a fire spread model (FSPro) to create a digital map of probable fire spread within WFDSS. This map is combined in a GIS with the values layers to build a finished RAVAR map (Fig. 1) and values report. It is intended that the spatial analysis

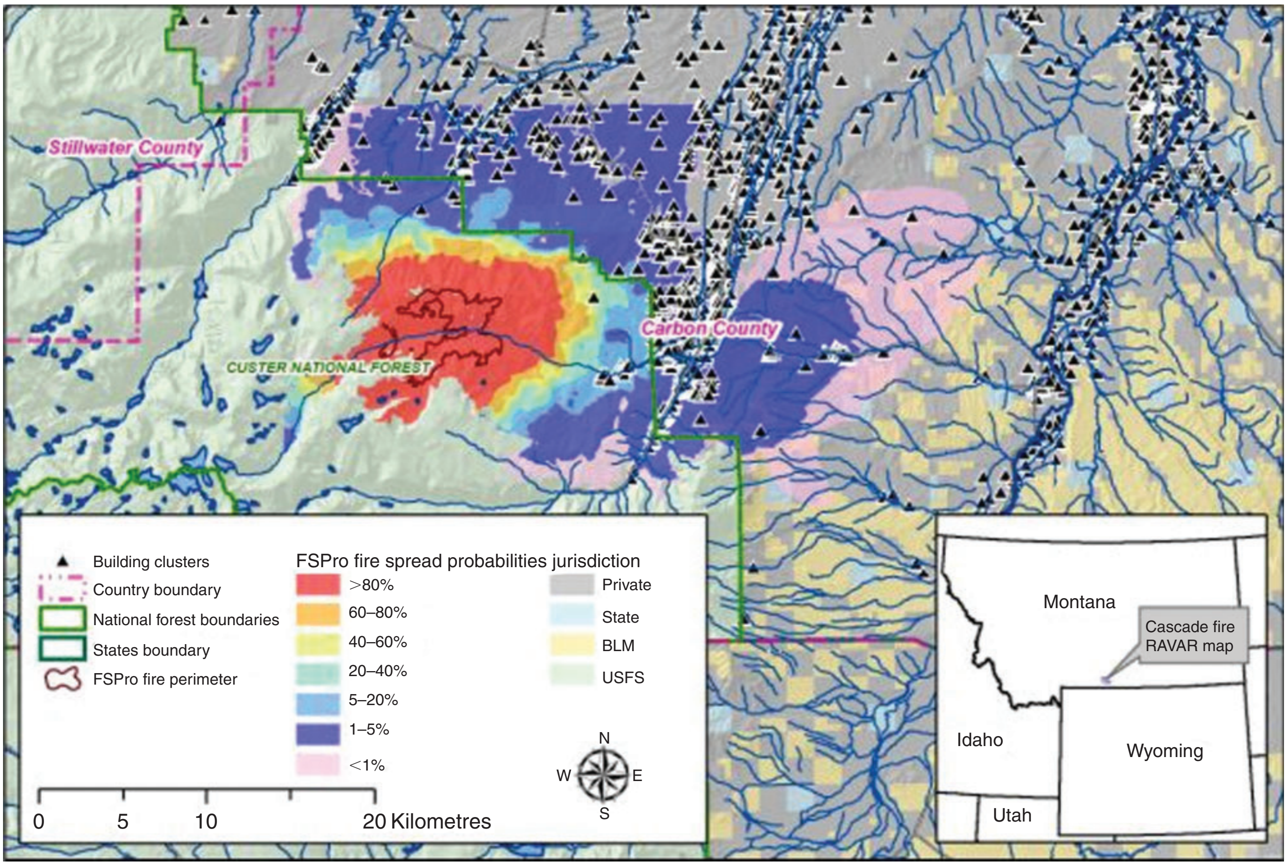

Fig. 1. Example RAVAR (Rapid Assessment of Values at Risk) map displaying building clusters for the Cascade Fire in Carbon County, MT, July 2008. (USFS, United States Forest Service; BLM, Bureau of Land Management.)

of structures relative to probable fire spread zones will help define the fire response decision space by confirming where structure protection might be required and where, in the absence of structures or infrastructure that could be damaged by fire, less aggressive and less costly management actions may be appropriate. Since 2007, over 300 RAVAR analyses have been completed for large fires throughout the United States. Analysis maps and summary reports were delivered in real time through the web-based WFDSS application (http://wfdss.usgs.gov/wfdss/WFDSS_Home.shtml, accessed 5 January 2011).

A second method is also used to map point-specific structure locations. Where parcel data are not available, the RAVAR operations staff requests immediate assistance from the US Geological Survey (USGS). A team of GIS specialists manually digitises structures visible on high-spatial-resolution aerial photography. This labour-intensive process serves immediate fire support needs well, but is not sustainable or cost-effective for a long-range solution to precise identification of structure locations.

At the national level, a layer defining precise structure locations is being compiled through the National Map Program of the USGS (USGS 2008). This program is coordinated with each state and is primarily directed by the needs of the Department of Homeland Security. These priorities contrast those needed to support wildland firefighting; high-density urban areas are emphasised. Additionally, in 2010 Montana developed a state-wide structure point layer (L. Brotman, pers. comm., 17 September 2009; M. Fashoway, pers. comm., 13 October 2009). The layer was developed through a combination of address points, structure locations mapped using GPS and interpretation from air photos. Suitability for wildfire and other emergency response has yet to be determined.

Methods

To quantify the accuracy of building clusters as an appropriate representation of structure locations, we compared the presence and absence of building cluster point data generated from Montana state parcel data with recorded GPS structure point locations collected by GIS personnel of Gallatin County, Montana. For this study and intended applications, a building cluster point is considered accurate if it is located in a parcel where a GPS structure point is mapped. Errors in building cluster assignment, whether by omission or commission, were analysed through visual inspection of 1-m spatial resolution colour aerial photographs acquired from the National Agriculture Imagery Program (NAIP) collected in August 2009. Random samples were selected from the building cluster and GPS point data and analysed for specific error type and frequency of identified errors. Finally, we compared the distance between identified building clusters with their associated structure point locations to assess the precision of the building cluster method.

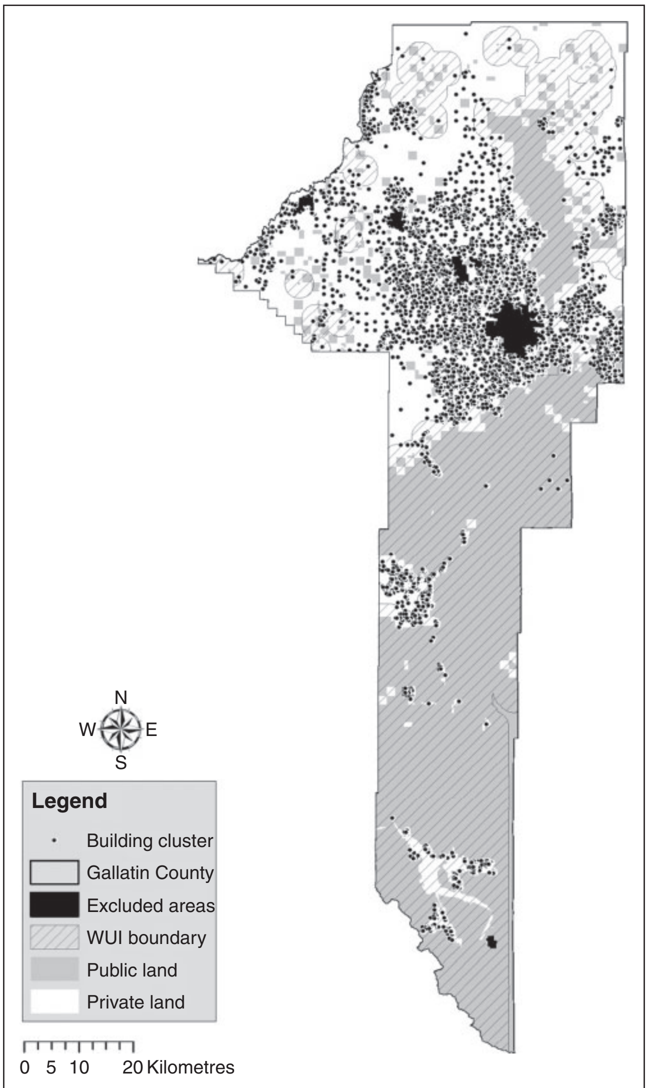

Fig. 2. Detailed map of study area displaying wildland–urban interface (WUI), building clusters, private and public lands, and excluded areas.

Study area

The study area is located in Gallatin County, in south-west Montana, USA (Fig. 2). Gallatin County was selected because both GPS structure locations and cadastral data are available for the county. Gallatin County covers 681 389 ha; five urban zones were excluded (see next section for explanation), resulting in an adjusted study area of 674 719 ha. Nearly one-half of the study area is managed for mixed agriculture use and most of the remainder is publicly managed wildlands. A further breakdown of jurisdiction within Gallatin County is presented in Table 1. There are 89 824 people living in Gallatin County, with 37 136 of those people residing within the study area (US Census Bureau 2008).

Snowfall dominates the semiarid precipitation regime under montane climate conditions with strong continental influences. Evergreen forest dominates the land cover (42%) (USGS 2009), followed by herbaceous cover (22%), and shrub (18%). The dominant tree species are Douglas fir (*Pseudotsuga menziesii*) and lodgepole pine (*Pinus contorta*). The wildfire season typically runs from July through September. According to the Forest Service Northern Region Geospatial Library, 11 wildfires were recorded in the study area since 2000, ranging in size from 1.2 to 33 085 ha (USFS 2009). The largest was primarily a grassland fire along the northern county border in area of very low population. The entire WUI has been substantially unaffected by wildfire for the past century.

Table 1. Distribution of land management jurisdictions in Gallatin County

Jurisdiction	Area (ha)	%
Private	357 733	53.0
US Forest Service	263 257	39.0
State of Montana	26 046	3.9
National Park Service	25 548	3.8
US Bureau of Land Management	2953	0.4

Data used in this study

GPS structure points were collected by the Gallatin County GIS Department by driving to the location of a structure and offsetting the collected point to the front door of the structure (A. J. Armstrong, pers. comm., 2008). The points were collected using a GPS unit with 1–3-m horizontal accuracy. The Gallatin County GIS department has been collecting and updating GPS structure points for 10 years and updating the database semiannually. The areas inside the city limits of five cities in Gallatin County were removed from the study because the GIS staff did not collect GPS structure points within city limits (Fig. 2). The structure-point data used for analysis were last updated on 31 August 2009. The GPS structure-point data have been differentially corrected and were assumed to be accurate and complete as received from Gallatin County; no independent verification was attempted. However, evaluation of divergence between identified building clusters and structure points, through aerial photograph assessments, identified likely errors within the Gallatin County structure-point dataset. The errors were minimal and are accounted for in the analysis.

Building clusters were created from Gallatin County cadastral data obtained from the Montana State Library, Natural Resource Information System (NRIS) GIS portal (see http://nris.mt.gov/gis/, accessed 22 September 2009). The Montana Department of Revenue supplies NRIS with the updated cadastral data on a monthly basis. For this study, we used data archived to the NRIS ftp site on 2 July 2009. The parcel data were stripped of all attributes except the following fields: shape, area, parcel identity number and building improvement value. The parcel data were then queried in the GIS for any building value greater than US$0. The selected parcels were exported to a new Shapefile as an improved parcel layer. A building cluster point file was created using the Feature to Point (Data Management) *ArcInfo* command, forcing the centroid point to reside inside the corresponding parcel polygon.

Table 2. Relationships expected between building clusters and GPS structure points

Case	Description	Relationship
(*a*)	A building cluster is identified in a parcel where a single structure point is present	1 to 1; accurate identification of parcel with inhabitable structure
(*b*)	No building cluster is identified and no structure point is present	0 to 0; accurate identification of an undeveloped parcel
(*c*)	A single building cluster is identified in a parcel where multiple structures are present	1 to many; accurate identification of a developed parcel with undercount of structures present
(*d*)	A building cluster is identified where no structure point is present	1 to 0; an error of commission, false positive identification
(*e*)	No building cluster is identified where a structure point is present	0 to1; an error of omission, false negative identification
(*f*)	No building cluster is identified in a parcel where multiple structures are present	0 to many; an error of omission, false negative identification and undercount

Assessment of spatial accuracy

The set of all potential relationships between the building cluster points derived from cadastral data and structure-point datasets relative to each parcel are described in Table 2*a–f*. These relationships were quantified through GIS analysis for the entire study area as well as for an identified WUI buffer of 1.5 miles (2.4 km) outside large public land polygons ($>$100 acres, $>$40 ha). Evaluation of possible explanations for errors reported in cases (*d*) and (*e*) were completed by visual assessment of high-quality aerial photographs. The error evaluation was conducted using two separate random samples of 100 parcels selected from the study area. *Hawth's Analysis Tools for ArcGIS* was used to select the random sample. The Create Random Selection tool from Hawth's is non-weighted and is truly random (Beyer 2004). A sample size of 100 was deemed sufficient to ensure a 95% confidence interval in the derived estimates. We calculated a sample of 85 was need for the 1 : 0 relationship, and a sample of 92 for the 0 : 1 relationship (Creative Research Systems 2010). The first sample represented the case of false positive identification (case (*d*)), selecting parcels where a building cluster was created and no structure point was mapped. The second sample selected parcels where a structure was mapped and no building point was created (case (*e*)) or false negative identification. Visual analysis was conducted using 1-m spatial resolution digital aerial photography from 2009 NAIP imagery. Each parcel sample was overlaid on the air photos to determine if a structure could be identified within the parcel boundary. The associated tax information from the cadastre was used to help explain the identified error.

Additionally, we assessed the distance between all building cluster points and associated structure point for correctly identified inhabitable structures (case (*a*)) and demonstrated the relationship of distance between points as a function of parcel size. Distance was calculated in the GIS using the ET Geo Wizards tool (Tchoukanski 2009). In order to assure distances calculated were for the correct parcel and associated GPS structure point, we spatially joined the GPS structure points to the Gallatin County Parcels Shapefile. The Parcel_ID field was then used as the unique identifier to calculate the distance between the two different point types. A building cluster was considered precisely placed if it fell within 100 m of a GPS structure point mapped in the same parcel. The 100-m threshold was chosen arbitrarily based on general knowledge of fire spread behaviour and intended application, which is to support strategic fire management decisions for large fires from several hundred to tens of thousands of hectares.

Table 3. Accuracy assessment for entire study area

Relationship case		Count	%	Assessment
(*a*)	1 : 1	12 049	41.1	Accurate
(*b*)	0 : 0	12 996	44.3	Accurate
(*c*)	1 : many	1282	4.4	Accurate : undercount
(*d*)	1 : 0	2018	6.9	False positive
(*e*)	0 : 1	752	2.6	False negative
(*f*)	0 : many	207	0.7	False negative
		29 304	100	

Results

The correspondence between building cluster and structure points for the entire study area is presented in Table 3 following the relationship cases previously defined. Of 29 304 parcels, 25 045 (85.5%) were accurately identified as having a single structure present or being undeveloped. Building clusters were accurately located in an additional 4.4% (1282) of the parcels where multiple GPS structure points were mapped (case (*c*)). This condition fits the working definition of building clusters, identifying parcels where one or more structures may be present. The total qualified accuracy is 89.8%. Building clusters were placed in 2118 or 6.9% of the parcels where no structure point was identified (case (*d*)). Structure points were identified in 1282 parcels, 3.3% of total parcels, where no building cluster was assigned.

Case (*c*), accurate building cluster assignment where multiple structures are mapped, was further quantified. A known limitation of the use of cadastral data is the identification of only a single building cluster where multiple inhabitable structures may exist. Multiple structure points on an individual parcel may occur under several conditions: multiple private residences are built on an undivided parcel, multiple agricultural outbuildings exist, or where a parcel contains detached rental properties, apartments, condominiums or mobile home parks. Of the 1282 parcels, 892 (70%) have only two structure points assigned to a parcel, whereas 103 have six or more GPS points identified per parcel (Fig. 3). It is also possible that the published cadastral data used for the study have summarised the more detailed assessment information where multiple buildings may have been identified. Based on the authors' direct experience with cadastral data from over 350 counties in the western US, it is common for published cadastral data to summarise improved values by 'rolling up' all improvements into one reported value.

The building cluster–structure point correspondence for parcels within the WUI is similar to the entire area (Table 4), with a total qualified accuracy of 89.4%, total false positive of 7.2%, and total false negative of 3.4%. Twice as many WUI parcels are undeveloped compared with nearly equal numbers developed or undeveloped for all study parcels.

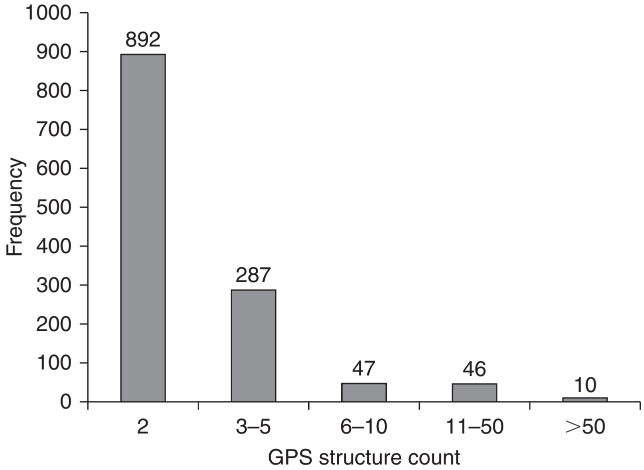

Fig. 3. Structure point count identified by GPS.

Table 4. Accuracy assessment for wildland–urban interface area only

Relationship case		Count	%	Assessment
(*a*)	1 : 1	2549	28.2	Accurate
(*b*)	0 : 0	5187	57.4	Accurate
(*c*)	1 : many	347	3.8	Accurate : undercount
(*d*)	1 : 0	648	7.2	False positive
(*e*)	0 : 1	207	2.3	False negative
(*f*)	0 : many	97	1.1	False negative
		9035	100	

Assessment of building cluster errors

The visual assessment of the 100 randomly selected parcels where a building cluster was identified but no structure point was mapped (case (*d*)) resulted in four categories of errors described in Tables 5 and 6 and Figs 4–7. From the visual assessment, it became clear that in many instances the identified building cluster was associated with a proximate structure point incorrectly associated with an adjacent parcel (the first two categories in Table 5[A]). In these instances, the distance between the identified building cluster and associated structure point in an adjacent parcel was calculated. A total of 39 of the 100 sample points indicated building clusters with structure points located in adjacent parcels. Distances between the two points for these 39 observations ranged from 12 to 671 m. A total of 77% (30 of the 39 observations) were within 100 m of the actual structure point. Accepting the assumption that 100 m is considered sufficiently accurate for strategic fire management purposes, these results suggest that 30% of the 'false positive errors' may, in fact, correctly identify that a structure is present.

Assessment of parcels where a structure point was mapped without an associated building cluster again revealed four dominant themes (Table 6). Some structures visible on air photos are not reflected in cadastral records either owing to entry error or because the improvement had not been assessed. This accounts for two-thirds of the errors in the sample set where a visible mapped structure was not captured by a building cluster. A total of 24 of the 100-parcel sample contained structure points with building clusters located in adjacent parcels. This generally occurred on smaller parcels where a shift in parcel location moved the structure visible in the air photo outside the parcel bounds. The spatial error in the parcel data may be caused by errors in the Public Land Survey System (PLSS) corner locations that are then propagated to errors in parcel locations. In some cases, the lack of monumented and accurately measured corner locations contributes to the errors in the PLSS (A. J. Armstrong, pers. comm., 21 August 2008).

Table 5. Characterisation of errors of commission: building cluster but no structure point

Identified error	Possible source of error	Fig.	*n* of parcels with error
Parcel location does not align with proximate identified structure point	Accuracy of parcel map – building cluster may be within acceptable bounds	4	25
Cadastral data assigned building cluster to adjacent empty parcel with same ownership	Cadastral data entry error – building cluster may be within acceptable bounds	5	18
Coded in cadastre with value, nothing in image	Cadastral data entry error – value assigned but no improvement	N/A	25
Structure point not mapped, building identified through visual assessment of air photo	Unexplained omission in structure point dataset	N/A	32

[A]Four of the eighteen observations in the second error listed in Table 5 had building clusters in multiple adjacent parcels under the same ownership where a single building cluster was appropriately identified, whereas the other 14 had a building cluster identified in an adjacent parcel under the same ownership of a correctly identified structure point with no building cluster identified in the appropriate parcel.

Table 6. Characterisation of errors of omission: structure point present, but no building cluster mapped

Identified error	Possible source of error	Fig.	*n* of parcels with error
Structure present in photo, no taxable improvement in cadastral data	Cadastral data error or improvement not assessed	N/A	65
Structure point location does not align with parcel boundary	Accuracy of parcel map – a building cluster may be within acceptable bounds	6	24
No structure in image, vacant in cadastre	Structure-point data error	N/A	18
Cadastre data assigned building cluster to adjacent empty parcel with same ownership	Cadastral data entry error – a building cluster may be within acceptable bounds	5	3

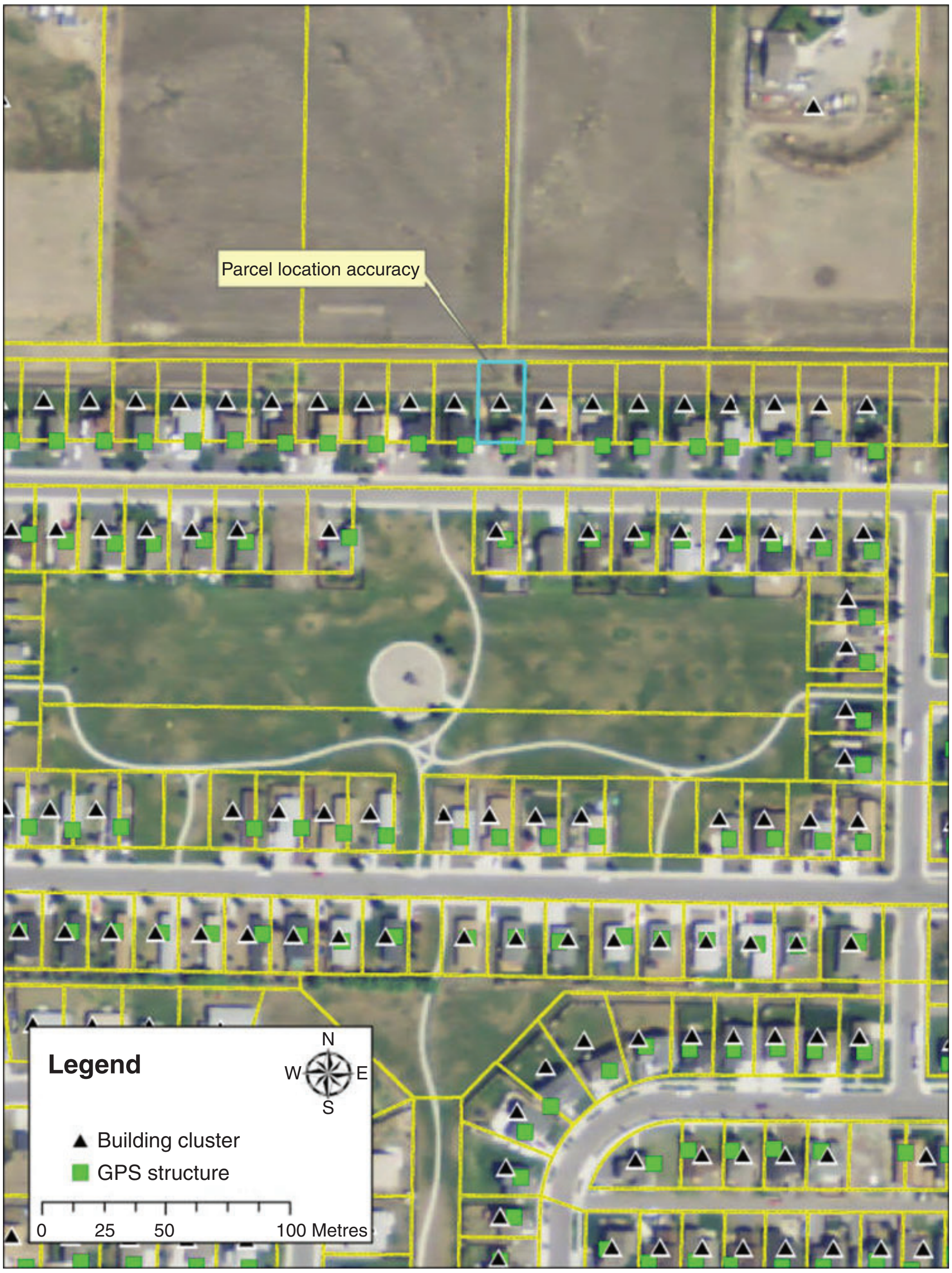

Fig. 4. Parcel location accuracy.

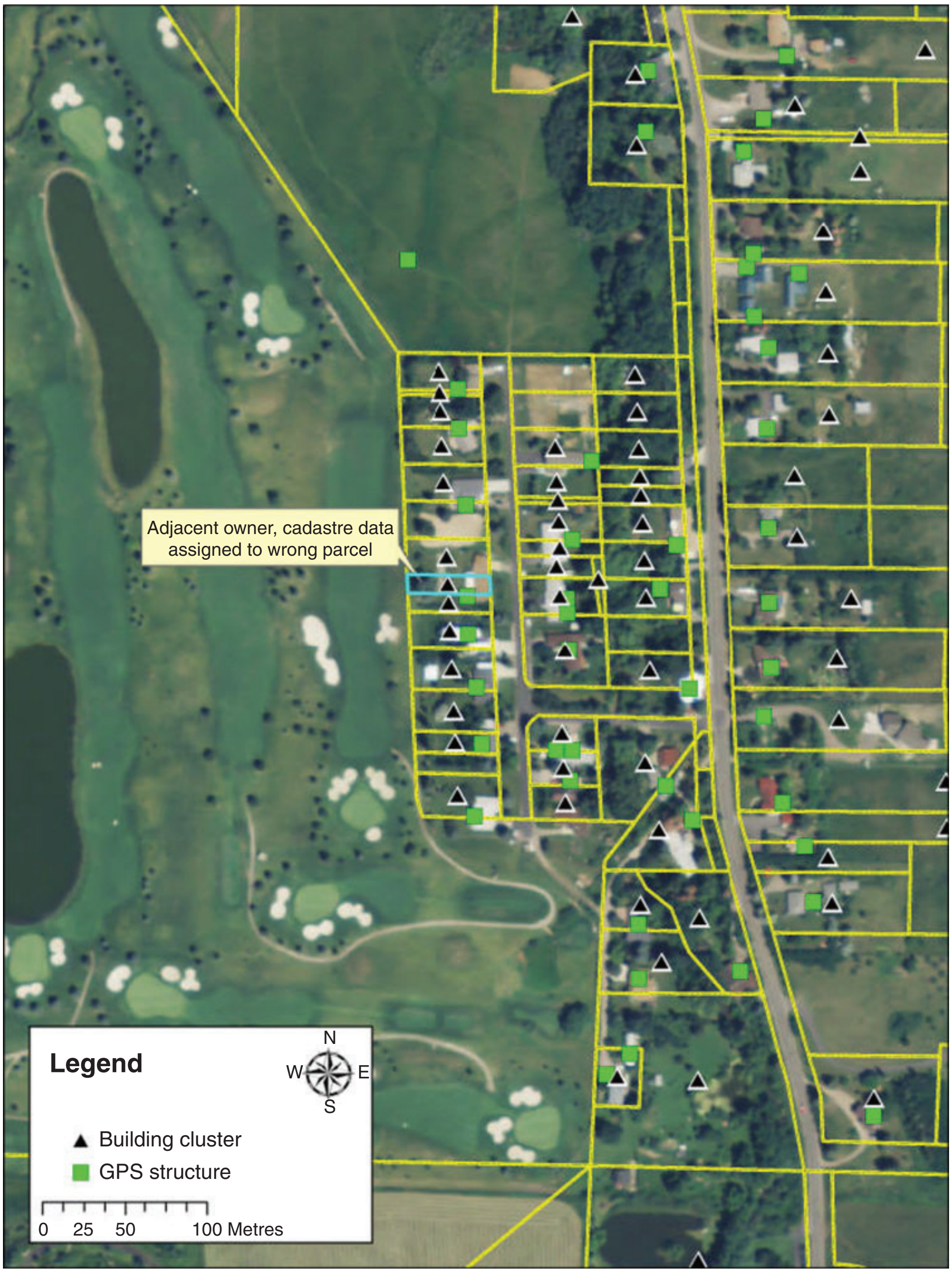

Fig. 5. Adjacent owner: cadastre data assigned to wrong parcel.

Distances between the two points for these 24 observations ranged from 11 to 556 m. A total of 79% (19 of the 24 observations) were within 100 m of the associated building cluster. Again, if 100 m were considered sufficiently accurate for strategic fire management purposes, the results suggest that 19% of the 'false negative errors' previously reported are misleading; disregarding parcel boundaries, building cluster points are mapped proximate to actual structure locations with reasonable accuracy. This finding for false negative errors and the similar finding for false positive errors indicates that the errors reported in Table 6 are somewhat overstated. The third structure point error, a structure point is identified but no structure is visible in the imagery, is attributed to unknown errors in the structure point database. Finally, there were three parcels in the sample where a structure located on a parcel with no taxable improved value was adjacent to a parcel deeded to the same owner with a positive taxable value generated a building cluster point.

Figs 4–6 illustrate the errors of commission and omission listed in Tables 5 and 6. Fig. 4 is an example where the parcel location does not align with a proximate identified structure point. Fig. 5 shows the situation where the cadastral approach incorrectly identified a building cluster in an empty parcel adjacent to a parcel with a structure under the same

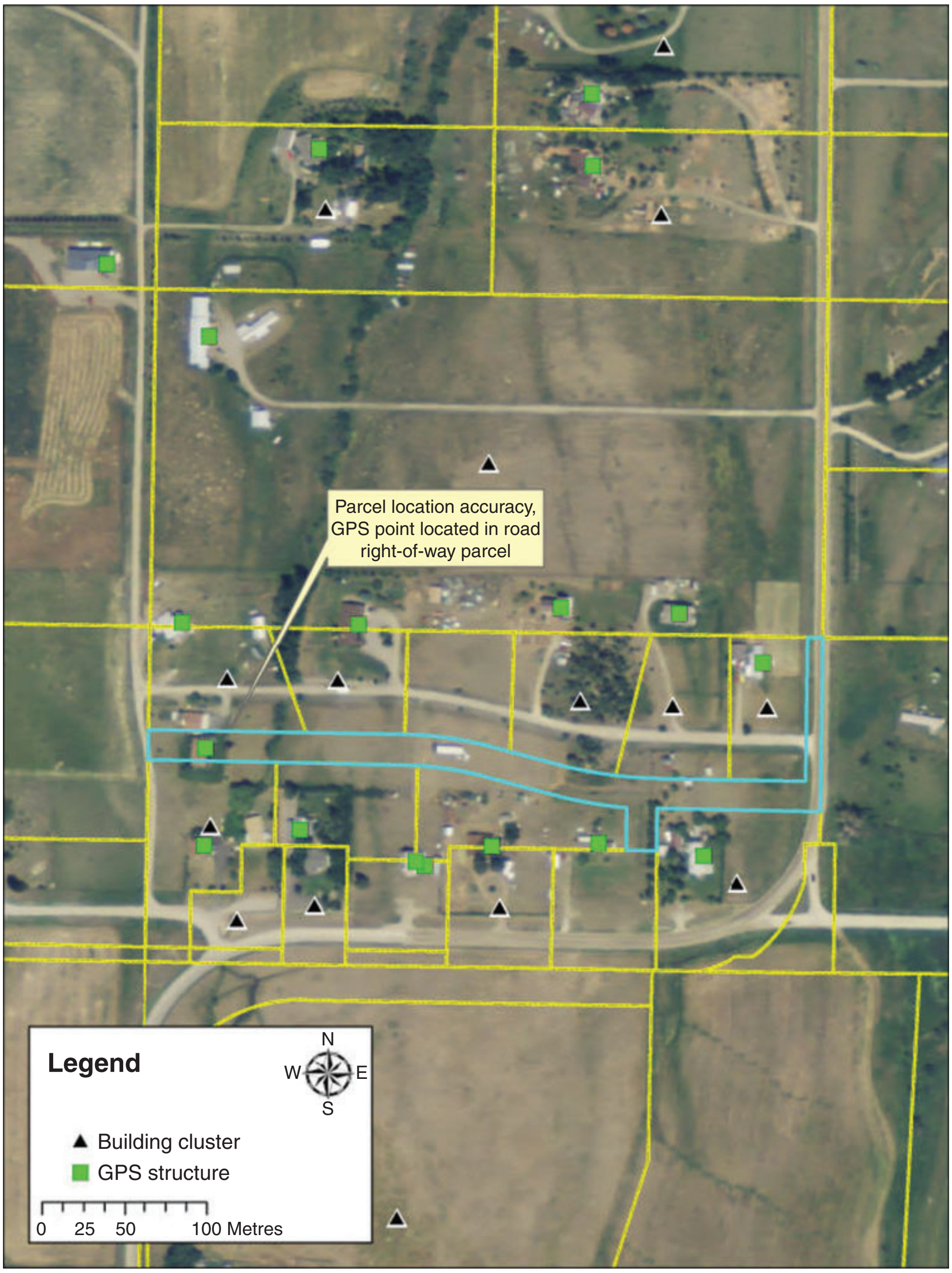

Fig. 6. Parcel location accuracy, structure point mapped in road right-of-way parcel.

ownership. Fig. 6 demonstrates where the parcel data have shifted owing to the lack of monumented corner locations for the PLSS.

Distance between building clusters and structure points

Another known limitation of the building cluster method relates to the distance between structure points and building clusters in parcels where both methods identify a single point. For small parcels, this is of limited concern, because the distance between the centroid and the actual structure cannot be very large. However, for larger parcels, the distance between the centroid and actual structure location may be large enough to have implications to strategic fire management planning. Fig. 8 plots the distance between the building cluster and structure point against parcel size for all parcels with a 1 : 1 relationship where both a single-building cluster and GPS structure point are present. Approximately 88% of all parcels, independently of parcel size, were within 100 m, 8.6% within 100–200 m, 2.5% within 200–400 m, and 0.9% further than >400 m.

Discussion

The overall accuracy of building cluster points relative to structure points created by GPS survey was greater than 90% after accounting for parcel alignment errors. Accepting that a

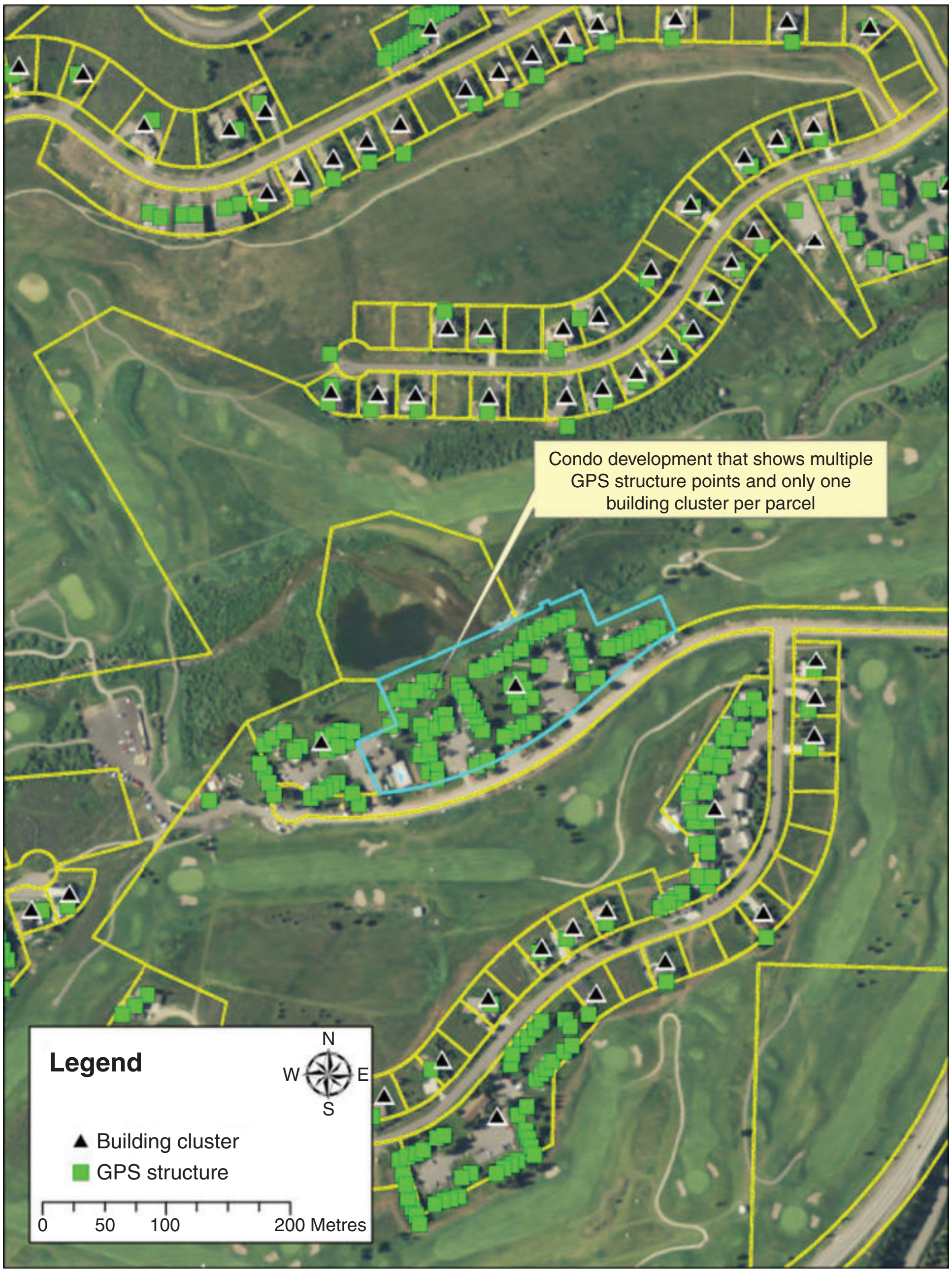

Fig. 7. Condo development that shows multiple GPS structure points and only one building cluster per parcel.

distance tolerance of 100 m is reasonable for strategic application, most of building cluster points met this criterion. Arguably, the location precision is sufficient to support refined, if provisional, strategic use where decisions depend on knowledge of structure locations. Where tight location tolerance is critical, ground-truthing must always be implemented. As understood from initial use of building clusters in RAVAR, building clusters are for strategic use only. The overall positional accuracy does support that building clusters are a reasonably accurate and complete first approximation of structure locations and are more readily attainable than precise GPS structure locations.

Application for wildfire decision support

The use of building clusters to identify structure locations directly addresses the USDA OIG (2006) directive to 'quantify and track the number and type of isolated residences and other privately owned structures'. Spatial knowledge of the distribution of structure locations relative to probable fire spread informs initial decision space. The building cluster–structure point association error due to misalignment of the parcel boundary causes no limitations in current RAVAR practice. The building cluster points are mapped independently of parcel boundaries. Knowledge of approximate structure locations is

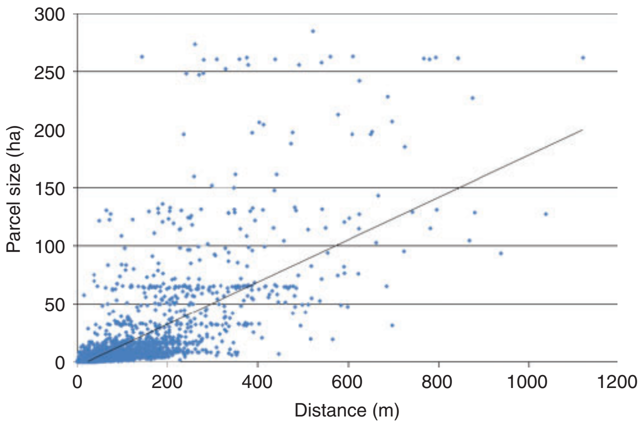

Fig. 8. Scatter plot of parcel size *v.* distance.

arguably more critical in wildland fire decision support than knowledge of parcel boundaries. The issue of increasing spatial inaccuracies of building clusters on large parcels is most critical where rapidly spreading range fires are possible. Privately owned parcels in open rangeland are typically very large. This is especially the case throughout the Great Basin, extending from southern Idaho south through Utah and Nevada. Under extreme fire conditions, wind driven grassland fires may spread thousands of hectares within a few hours. Local knowledge is critical to determine which isolated ranch structures may be at risk. A strategic map that displays groups of building clusters on small parcels of towns and hamlets may help inform evacuation planning where a range fire escapes initial attack.

Comparison with alternative methods

The alternatives to the building cluster approach do not effectively address the comprehensive need for consistent, nationwide identification of structure locations. Structure-point layers created on demand where building clusters are not available provide an essential stop-gap. Dense vegetation common to WUI areas confounds consistently accurate identification of occupiable structures on the aerial photographs (S. Stitt, pers. comm., 15 July 2009). 'Heads-up' digitising is impractical in the urban fringe with high-density development. The general labour demands of this method render it infeasible for broad application. Broad-scale area-density summaries such as WUI data layer developed by the SILVIS lab (see http://silvis.forest.wisc.edu/old/Library/WUILibrary.php, accessed 5 January 2011) are appropriate for regional planning applications but insufficient for strategic estimates of values at risk during wildfire events (Radeloff *et al.* 2005).

Point-specific methods to identify structure locations are more accurate than area-density methods. Fig. 9 displays the intersection of a hypothetical fire perimeter at a location in Gallatin County. For this example, a fire perimeter is surrounded by a 1.6-km buffer as a hypothetical fire threat zone. Census block and parcel boundaries are mapped along with building point clusters and GPS structure points. The fire-threat zone contains 91 building cluster and 104 GPS structure points. Ten parcels have one-to-many relationships between building clusters and GPS structure point where multiple structures are located on a single parcel. In this case, 25 census blocks are intersected. Summarising the SILVIS data results in 1240.95 ha of uninhabited, 5208.88 ha of very low structure density, 284.54 ha of low density and 7.73 ha of moderate density (see Table 7), yet little information is available to suggest the actual location of threatened structures. Weighting the housing density estimates by the portion of the census block intersected results in an estimated housing unit count of 64, an undercount compared with either point-specific method.

Limitations of this approach

The availability of digital GIS-based cadastral data in usable form fundamentally controls the ability to derive building cluster points. The availability of these data is generally high owing to convergence of technology and recognised value of GIS parcel systems to manage real estate property tax or cadastral systems. Many counties treat these as public data with no restrictions. Counties with restrictions have typically responded well when data has been requested for emergency response to wildfires.

Identification and collection of available data have been very successful to date. The authors continue to work with the FDGC CSC in these efforts. The Subcommittee works with states to assist them in building sustainable cadastral data systems with a set of core attributes that meet service needs for emergency support applications. Additionally, they identify means to assist counties with resources to convert paper tax records to digital, GIS-based cadastral systems. The committee's goal is to build sustainable statewide cadastral data systems from which all federal and other government users of these data may draw through secured access to meet public-service needs. The accuracy of the cadastral data will remain the purview of the data stewards, the county and state personnel ultimately responsible for the integrity of these systems.

The completeness and accuracy of building clusters in developing WUI areas is most limited by the rate of WUI development. New WUI parcels are commonly small, so a building cluster will likely be very close to a structure. Rapid WUI development may outpace update of tax-assessment and associated cadastral records. New development may not be accounted for each fire season. This reinforces the need to update cadastral data and building clusters on at least an annual basis as well as the essential caveat of the critical importance of local knowledge to verify structure locations.

Three issues are inherent limits to this method: reduced spatial precision with increased parcel size, undercount of potentially valuable structures, and overcount of low-value assets where the improvement is not an inhabitable structure. Ultimately, the preferred solution will be to work directly with spatial data of precise structure inventories from GPS and other sources. Many counties appear to be going in this direction. Exact location of addressable structures to support emergency response dispatching is one of the driving forces for counties developing structure-point locations. Development of more accurate structure locations within parcels will likely follow a pattern similar to development of digital GIS-based cadastral systems. Forward thinking locales with sufficient resources, such as Gallatin County, will lead the way. Some of these

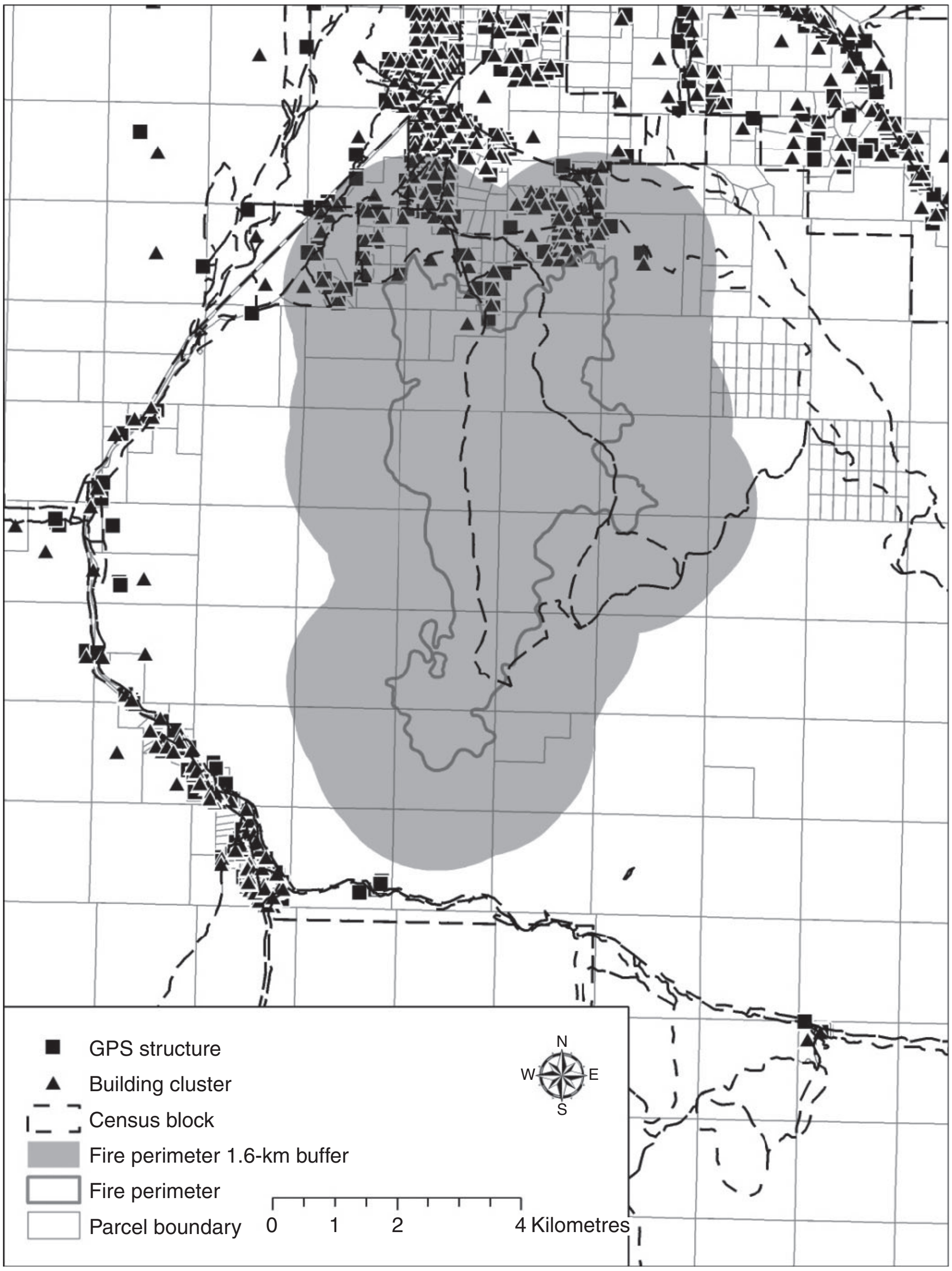

Fig. 9. Hypothetical fire area SW of Bozeman.

counties will be located in fire-prone areas with significant WUI exposure. Other counties at high risk from wildfire may be rural and economically disadvantaged, with limited resources to complete their digital cadastral system.

Those responsible for local development of comprehensive structure-point databases may find it efficient to start with building clusters. This base layer may be improved by refining locations using air photos and targeted GPS survey. This approach was taken with the Montana structure-point project (M. Fashoway, pers. comm., 13 October 2009). GIS technicians moved building cluster points to match visible structures and added points where multiple structures were visible on a parcel.

Limitations of this study

Several non-quantified uncertainties are acknowledged in this study. We obtained the most current data for each step of the analysis, including aerial photography, GPS structure points and cadastral data. It is possible that these datasets have changed. We expect any changes to be relatively minor. We cannot account for possible data-entry errors or errors during the GPS survey. Given the source and intended uses of these data, we expect reasonable data accuracy. This study presents the outcome for one county in one state. The GPS structure-point data used in this study are not commonly found elsewhere in the state or other states at the time of this study. The outcomes are consistent with the authors'

Table 7. SILVIS data results for wildland–urban interface fire example

Type	Area (ha)	%
Low-density, interface	53.15	0.79
Low-density, intermix	231.39	3.43
Medium-density, interface	3.86	0.06
Medium-density, intermix	3.87	0.06
Uninhabited, no vegetation	85.28	1.26
Uninhabited, vegetation	1155.70	17.14
Very low density, no vegetation	222.55	3.30
Very low density, vegetation	4986.33	73.94
Water	1.42	0.02

experience over the past 4 years applying building clusters in wildfire decision support where the clusters could be informally compared with aerial imagery.

Conclusion

Advanced decision support with WFDSS rapidly delivers spatially explicit identification of approximate structure locations relative to predicted fire spread, to support development of risk-informed wildfire management strategies. WFDSS-RAVAR structure maps are built off building cluster data derived from GIS cadastral data, which as demonstrated in this study, are accurate and precise approximations of structure locations. Building cluster techniques map a building cluster to parcels with identified GPS structure points on 90% of the parcels within Gallatin County, Montana. Similar results are expected in other counties throughout the western US. Building clusters provide superior information for wildfire decision support compared with area density techniques.

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