Using structure locations as a basis for mapping the wildland urban interface

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ABSTRACT

The wildland urban interface (WUI) delineates the areas where wildland fire hazard most directly impacts human communities and threatens lives and property, and where houses exert the strongest influence on the natural environment. Housing data are a major problem for WUI mapping. When housing data are zonal, the concept of a WUI neighborhood can be captured easily in a density measure, but variations in zone (census block) size and shape introduce bias. Other housing data are points, so zonal issues are avoided, but the neighborhood character of the WUI is lost if houses are evaluated individually. Our goal was to develop a consistent method to map the WUI that is able to determine where neighborhoods (or clusters of houses) exist, using just housing location and wildland fuel data. We used structure and vegetation maps and a moving window analysis, with various window sizes representing neighborhood sizes, to calculate the neighborhood density of both houses and wildland vegetation. Mapping four distinct areas (in WI, MI, CA and CO) the method resulted in amounts of WUI comparable to those of zonal mapping, but with greater precision. We conclude that this hybrid method is a useful alternative to zonal mapping from the neighborhood to the landscape scale, and results in maps that are better suited to operational fire management (e.g., fuels reduction) needs, while maintaining consistency with conceptual and U.S. policy-specific WUI definitions.

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1. Background

The wildland urban interface (WUI), i.e., the zone where houses and other human structures are near or overlap with wildland vegetation, is a major focus of wildland fire policy and management. The WUI is widespread, covering about 9% of the land area of the conterminous U.S. and 39% of its housing units (Radeloff et al., 2005), and has grown rapidly in recent decades (Hammer et al., 2009; Theobald and Romme, 2007).

The WUI highlights wildland fire as a social problem. In the WUI residential areas are exposed to wildland fire risk because neighborhoods are built in or near wildland fuels. When fires occur in or near the WUI, they threaten lives, homes, and communities. At the same time, the WUI is also where human fire ignitions are most common (Syphard et al., 2009). When a fire occurs, the likelihood

of a home in the WUI being destroyed is influenced by many factors operating at different spatial scales including characteristics of the individual property (building materials, adjacent vegetation), of the neighborhood (proximity of other houses and vegetation, ease of road access, level of fire protection), and of the landscape (terrain, ecological characteristics, vegetation density, weather) (Syphard et al., 2012). Human perceptions of fire risk, decisions and behavior also operate at a range of scales, and effective wildland fire management and structural fire protection require both individual and collective action. Hence the wildland fire problem in the U.S. spans a range of scales, requiring methods for mapping the WUI that are robust and consistent across scales.

Fire policy reflects the multi-scale character of the fire problem. Under the National Fire Plan of 2001, the Federal government assumed a more central role in fire management, particularly for coordinating activities and bringing consistency to fire policy. The Healthy Forest Restoration Act of 2003 realigned fire management responsibilities, emphasizing the role of local communities in managing wildland fire. Both federal and state agencies and local

communities continue to shape current U.S. fire policy, and the Federally-mandated Cohesive Strategy of 2009 brings together fire management agencies at all levels of government. Thus as fire policy has broadened to address local, state, regional, and national fire issues, WUI mapping and analysis methods must also expand and provide suitable WUI maps from local to national scales.

Existing mapping methods reflect limited housing data availability in the United States, as well as broad policy language, and do not facilitate fine-scale WUI mapping. Conceptually, the WUI is comprised of more than a single house; it is a neighborhood, a characteristic termed its "settlement definition" (Platt, 2010). The settlement definition in the U.S. is conveyed as areal housing density, and the U.S. Federal Register defined the WUI as an area that consists of more than one structure per 40 acres (i.e. 6.17 housing units/km^2) (USDA and USDI, 2001). Using this density threshold and a second criterion of 50% or more wildland vegetation, Radeloff et al. (2005) mapped the WUI in the conterminous U.S. based on census blocks, the smallest unit for which housing information is available in the U.S. Census. This is a zonal approach that assesses the number of homes per zone (i.e., census block), hereafter referred to as WUI-Z. A density threshold, as provided by the Federal Register, works well with the zonal WUI definition, where census blocks are the zones in which housing and vegetation densities are evaluated.

However, the zonal approach suffers from the modifiable areal unit problem (MAUP), the bias that can result when point-based measured are aggregated into areas and summary statistics are calculated (Openshaw, 1984). U.S. census blocks are bounded on all sides by visible features, such as streets, roads, and streams, and by invisible boundaries, such as city and county boundaries,, which means they vary in size, and tend to be larger where housing is less dense. As a result, the precision of mapping based on census blocks varies systematically across space, and is lower in areas with lower housing density.

Alternatives to zonal methods of WUI mapping utilize actual locations of homes or structures. Such structure- or point-based methods use the spatial coordinates for each individual structure and non-zonal settlement characterizations (i.e., a settlement is characterized by a collection of points and not by a zone), which are typically context-specific. Such WUI maps have been developed in several European countries where wildland fire management and policy vary over smaller spatial scales (Silva et al., 2010; Lampin-Maillet et al., 2009, 2010). The European Wildland Urban Area Fire Risk Management Project (Caballero, 2008) characterized the WUI according to housing and vegetation characteristics, classifying areas into five WUI categories (intermix, sparse or clustered intermix, urban interface, clustered, or occluded urban interface), without quantifying areal housing and vegetation densities. Similarly, Lampin-Maillet et al. (2010) mapped the wildland—urban interface, again without reference to housing or vegetation density thresholds, by categorizing vegetation (none, sparse, continuous) and housing (isolated, scattered, dense, and very dense), and then characterizing the housing and vegetation combinations — the WUI — according to fire behavior.

Australia's WUI fire problems are also severe due to widespread exurban settlement and highly volatile fire regimes. There, researchers created a point-based WUI map by digitizing structure locations in burned areas from orthophotos (Lowell et al., 2009), and assuming that all houses in previously burned areas were in the WUI, which avoids the need for a housing density definition. The fire perimeter becomes the de facto measure of where fuels and houses intermix.

A second alternative combines features of zonal and point-based methods. It is based on digital cadastral data and assumes that each parcel's centroid represents the location of a structure or

building cluster (Platt, 2010; Calkin et al., 2005, 2011). The strength of the parcel centroid method is its simplicity, and that it avoids the need to digitize structure locations. However, its major weakness is that the parcel's centroid may not be the actual structure location, since the structure's location may also depend on landscape characteristics (lakes, hills), infrastructure (roads, power lines), and parcel size. Multivariate modeling with ancillary data can be used to refine the structure location estimate, but is costly and involved. Furthermore, parcel sizes, like Census blocks, are typically larger in more sparsely settled areas, so precision varies across the U.S. and is typically lower in rural, Western areas.

While alternative WUI mapping methods have used structure location data, none addresses all three aspects of the WUI definition consistently (vegetation density, housing density and proximity to a large vegetated area) and housing density has been most problematic. With structure location, data analysis is required to determine where houses constitute a neighborhood (i.e., a cluster of houses). Without a Census block, pixel, or other areal unit for which to assess housing density, alternative methods either assume that each structure defines its own WUI zone, approximate the location of the structure, or use ad-hoc information to determine the location of neighborhoods. Our goal was to develop a consistent point-based method to map the WUI, hereafter referred to as WUI-P, which determines the location of neighborhoods using housing location point data.

2. Methods

2.1. Algorithm for mapping fine scale WUI using structure locations

Our mapping process applies the parameters of the standard WUI-Z definition: housing density exceeds 6.17 houses/km^2, and [1] at least 50% wildland vegetation (intermix WUI); or [2] less than 50% wildland vegetation, but within a distance of 2.4 km of an area larger than 5 km^2 with at least 75% wildland vegetation (interface WUI).

In contrast to WUI-Z, the WUI-P method (Fig. 1) calculates the density of housing units and wildland vegetation around each pixel in a landscape by using a circular moving window analysis. We varied the window in size to represent smaller or larger neighborhoods (i.e., areas on which to base the density calculations), according to the needs of WUI map users. The process requires only two types of data: [1] a structure location map (ideally in the form of a GIS point layer); and [2] a map of vegetation cover which distinguishes wildland vegetation from non-wildland land covers (typically a GIS raster land cover map, here the National Land Cover Dataset (NLCD; Homer et al., 2007)). We calculated housing density for each pixel to create a raster map with a spatial resolution of 30 m, the resolution of the NLCD. The value of each 30-m pixel is the housing density d per km^2 for a given neighborhood (moving window) size. Density is calculated by designating a circular neighborhood with a radius of r meters and counting the number of structures in that neighborhood. The radius r may take any value, but if it is defined in meters, d must be converted to density per km^2 as follows:

$$d(x, y, z) = \frac{N}{\pi \cdot r^2} \cdot 1,000,000 \qquad (1)$$

Where N is the number of houses in the circular neighborhood of radius r (in meters), and the correction factor is 1,000,000 m^2. The housing density raster is then coded "1" for each pixel where housing density is more than 6.17 houses per km^2 and "0" otherwise. Pixels that fall inside water bodies are assigned a "0" as well, to avoid mapping WUI there.
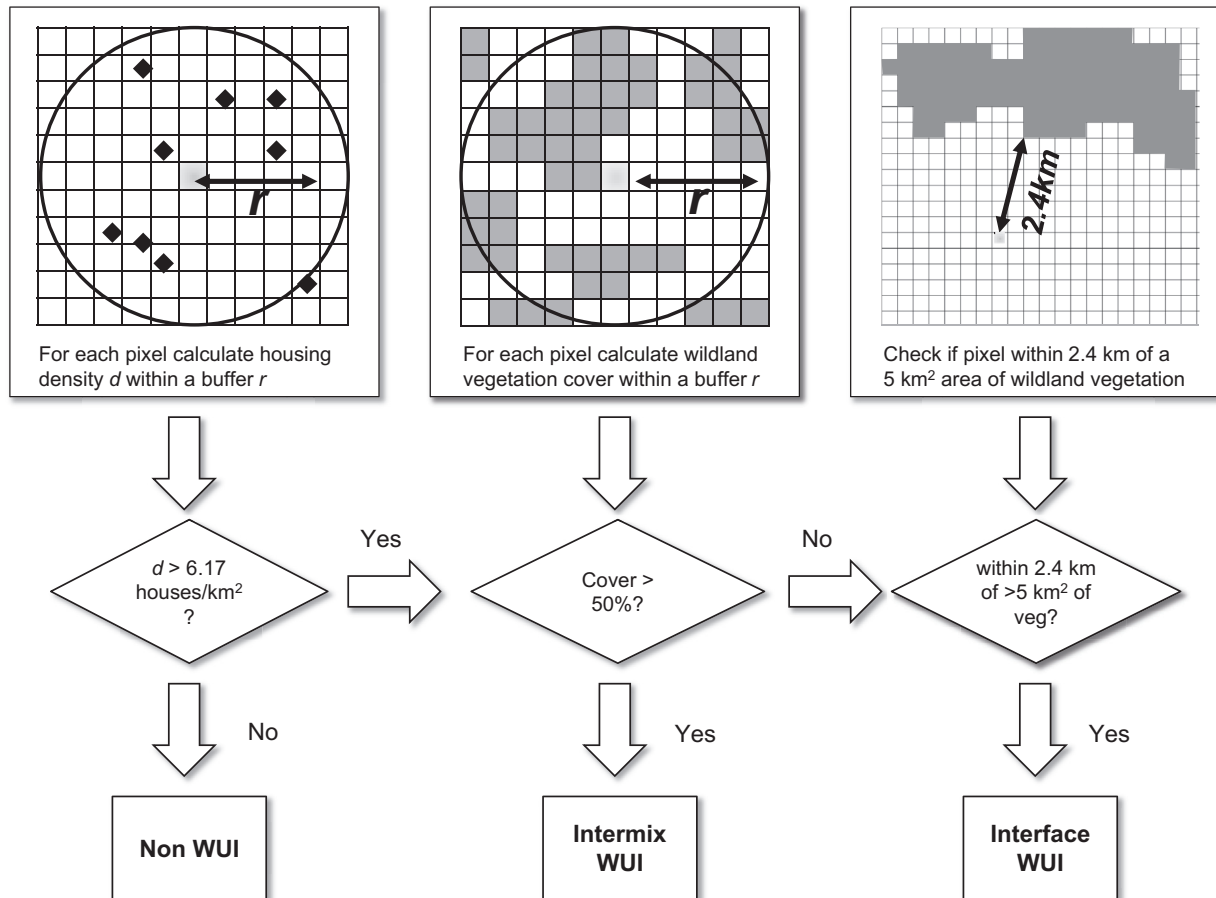
Fig. 1. A flowchart of the WUI-P algorithm.

The wildland vegetation cover raster has the same resolution as the housing density raster, uses the same neighborhood definition (circle with radius r (m)), and has pixel values representing the proportion of wildland vegetation in the pixel and its surrounding neighborhood. This vegetation raster is coded "1" where there is more than 50% wildland vegetation cover and "0" otherwise.

A second wildland vegetation cover raster is generated to distinguish between interface and intermix WUI. This follows the same approach as for the WUI-Z: identifying places within 2.4 km of contiguous wildland vegetation larger than 5 km². First, the wildland vegetation raster is converted to GIS polygons and contiguous patches of wildland vegetation are identified. Then the area of each wildland polygon is calculated and only those larger than 5 km² are retained. A 2.4 km buffer is applied around each of these polygons, and the outcome is converted back to raster form, coded "1" where pixels are within 2.4 km of wildland patches larger than 5 km², and "0" otherwise.

The housing density and two wildland vegetation rasters are then combined to form the WUI map for a given neighborhood radius r. Pixels are designated as intermix if housing density exceeds 6.17 housing units per km², ("1" in the housing density raster) and vegetation density in their vicinity exceeds 50% wildland vegetation ("1" in the first wildland vegetation raster). Pixels that exceed the housing density threshold but have less than 50% wildland vegetation in their neighborhood are designated as interface WUI if they are within 2.4 km of contiguous wildland vegetation patches that are larger than 5 km² ("1" in the second wildland vegetation raster).

To assess the sensitivity of WUI designation to the neighborhood size, we created ten WUI maps using radius (r) values from 100 to 1000 m, increasing in 100-m intervals, for four study areas. For each study area, we calculated the percentage of interface, intermix, and total WUI, and the percentage of structures outside WUI areas. For validation, we compared these results with corresponding values from WUI-Z.

We assessed the spatial congruence between WUI areas in both mapping approaches by generating a confusion matrix between WUI-Z and each WUI-P map (i.e., at different buffer distance) separately. A confusion matrix for thematic maps denotes the number of pixels within each class combination in both maps (e.g., the number of pixels that are defined as WUI in the WUI-Z map but as non-WUI in the WUI-P map). The agreement between two maps can be calculated by summing the number of pixels that belong to the same class in both maps (i.e., the main diagonal of the confusion matrix), and dividing it by the total number of pixels. However, since our focus was on the precision of WUI mapping, not of non-WUI mapping, our agreement calculations excluded pixels that neither method assigned to a WUI class to minimize the bias that would be caused by extensive map agreement in regions where there is little WUI.

2.2. Study areas

The effects of alternative mapping methods can vary with the characteristics of the study area (Stewart et al., 2007, 2009). Consequently, we choose four very different areas to test the WUI-P mapping procedure (Fig. 2, Table 1):

Fig. 2. Locations of the study sites in the conterminous United States.

a) a portion of the Pine Barrens in northwestern Wisconsin;
b) a portion of the Huron-Manistee National Forest in northern Lower Peninsula Michigan;
c) Grand County, Colorado, including the western portion of Rocky Mountain National Park, near Wyoming; and
d) a portion of the Santa Monica Mountains in southern California, near the outskirts of Los Angeles.

Wildland fire is a major problem in all four study areas, and exurban or rural housing is widespread. However, the four areas vary greatly in topography, housing type and spatial pattern, vegetation and fire regime, as well as in housing density (Table 1).

In Wisconsin, we analyzed a 60,000 ha area west of Minong, in northwestern Wisconsin, bordered by US Highway 53 on the East, and the Namekagon and Saint Croix Rivers on the West. The area is part of the northwestern Wisconsin Pine Barrens, a glacial outwash plain with flat to gently rolling topography, with elevation ranging from 270 to 400 m. The northwestern Wisconsin Pine Barrens are more fire prone than any other area in the state (Radeloff et al., 2000). The landscape is a mosaic of forests, clear cuts, and to a lesser extent, agricultural fields. The dominant tree species is Jack Pine (*Pinus banksiana* Lamb), along with Red and White Pine (*Pinus resinosa* Ait. and *Pinus strobus* L.); Burr, Red, and Pin Oak (*Quercus macrocarpa* Michx., *Quercus rubra* L., and *Quercus ellipsoidalis* E.J. Hill); and Trembling Aspen (*Populus tremuloides* Michx.) (Radeloff et al., 1999). Housing growth has been steady since the 1970s and particularly strong through the 1980s and 1990s, mainly due to second and recreational home development, with the majority of houses (new and old) clustered near lakes or dispersed throughout forests (Gonzalez-Abraham et al., 2007a, 2007b). The study area is largely rural.

Our second study area covered 273,398 ha in two administrative units of the Huron National Forest (Mio and Huron Shores Ranger Districts) in northern Lower Michigan, bordered by US Highway 75 on the West, and the shore of Lake Huron on the East. Terrain is flat to rolling, with elevation ranging from 180 to 420 m. Similar to Minong, this is a sandy glacial outwash plain, mostly forested, and the dominant species are Jack, Red, and White Pine. The fire-adapted Jack Pine support the spread of severe, stand-replacing fires (S. Goldman, personal communication; Cleland et al., 2004). As in the Minong area, homes are clustered around lakes, in small (e.g., 5–10 home) forested subdivisions, or in the towns of Mio, Oscoda, and Roscommon. Infrastructure is limited and road quality is poor. Housing growth rates are low, and there are fewer seasonal homes than the Wisconsin study site, which has similar biophysical but different social characteristics.

In Southern California, our study region in the Santa Monica Mountains encompasses 43,088 ha of Mediterranean habitat, characterized by steep, coastal mountains. Elevation ranges from 0 to 938 m. The primary vegetation types are chaparral (e.g. *Ceanothus* spp. or *Adenostoma fasciculatum*) and coastal sage scrub vegetation (e.g. *Salvia* spp. or *Artemisia californica*), with small pockets of exotic grass; oak woodland; and riparian vegetation. Slightly more than half of the land in the mountains is in public ownership (primarily National Park Service), and much of the privately owned land remains undeveloped; however, housing growth in the Santa Monica Mountains has increased in recent decades as intense development pressure from the nearby Los Angeles metropolitan region extends outward (Syphard et al., 2007). While fire is a natural process here, recent housing and population growth have increased ignitions to the point that fire frequency exceeds its natural range of variability in many areas (Keeley et al., 1999). Chaparral-dominated shrublands are typified by high intensity, stand-replacing fires that are difficult or impossible to suppress under severe, high-wind weather conditions (Keeley and Zedler, 2009).

Grand County in north-central Colorado is our fourth study area, and covers 478,285 ha along the border with Wyoming. The Continental Divide borders the county's Middle Park Valley on the north and east, the Gore Range on the West. Elevation ranges from 2200 to over 3900 m. Vegetation consists of grasses and shrubs on valley floors, conifer forests dominated by Lodgepole Pine (*Pinus contorta*) on mountain slopes across the entire county, spruce − fir forests (Engelmann Spruce, *Picea engelmannii*; and subalpine fir, *Abies lasiocarpa*) mostly in the eastern part of the county, Aspen (*Populus tremuloides*) in the western part of the county, and subalpine grasslands and meadows above the tree line. Seventy-four percent of the county is in public ownership (mostly Forest Service).

2.3. Data

Point-based structure location data were obtained from the USDA Forest Service for the Huron NF; from the U.S. Geological Survey for Grand County; and we digitized structures ourselves for Minong and the Santa Monica Mountains. The images used to digitize the Santa Monica Mountains' structures were free Google maps (with images from 2007 to 2009, depending on the exact

Table 1
Characteristics of the four study areas.

Study area	Area (ha)	Housing density (km^{-1})	Census block median (ha)	County median home value (state median)	Topography
Santa Monica, CA	43,088	41.3	3.6	$985,500 ($421,600)	Mountainous
Grand County, CO	484,003	3	6.6	$269,100 ($236,700)	Flat to Mountainous
Huron NF, MI	273,398	4.8	13.7	$93,100–$119,300 ($137,300)	Flat
Minong, WI	60,000	6.3	13.3	$130,000–$156,000 ($169,700)	Flat

location), digitized using a customized OpenLayers-based interface (http://openlayers.org/, last accessed January 31st 2013). This open source software tool allowed rapid digitizing of structure locations. In Wisconsin, aerial photos from the National Agriculture Imagery Program (NAIP; images from 2008) were used to establish housing locations (available at http://nationalmap.gov/viewer.html, last accessed January 31st 2013). The 2001 National Land Cover Database (NLCD, Homer et al., 2007) was used to determine land (vegetative) cover at 30-m resolution in all four study areas.

3. Results

3.1. Structure location in relation to WUI-Z maps

We used structure data to visually examine WUI-Z maps. In all four study areas, some structures that met WUI criteria conceptually (i.e., houses located in or near wildland fuels) were left outside WUI-Z areas. These exclusions resulted from the relatively large size of the census blocks in all four study areas which reduced zonal housing density, a result of the modifiable area unit problem. Since most of the census blocks were covered by wildland vegetation dense enough to reach or exceed the WUI threshold, these exclusions were due to variations in settlement characteristics (spatial clustering of homes), among the study areas. For example in Grand County, many structures were dispersed at low densities across the landscape, making them less likely to reach WUI housing density thresholds within a census block, while on the Huron, most structures were clustered, making them more likely to be classified as WUI. The overall percentage of structures inside the WUI-Z was lowest in Grand County (67.9%) and Minong (70%), followed by Santa Monica (82.5%). The highest percentage of structures inside the WUI-Z occurred on the Huron (88.4%).
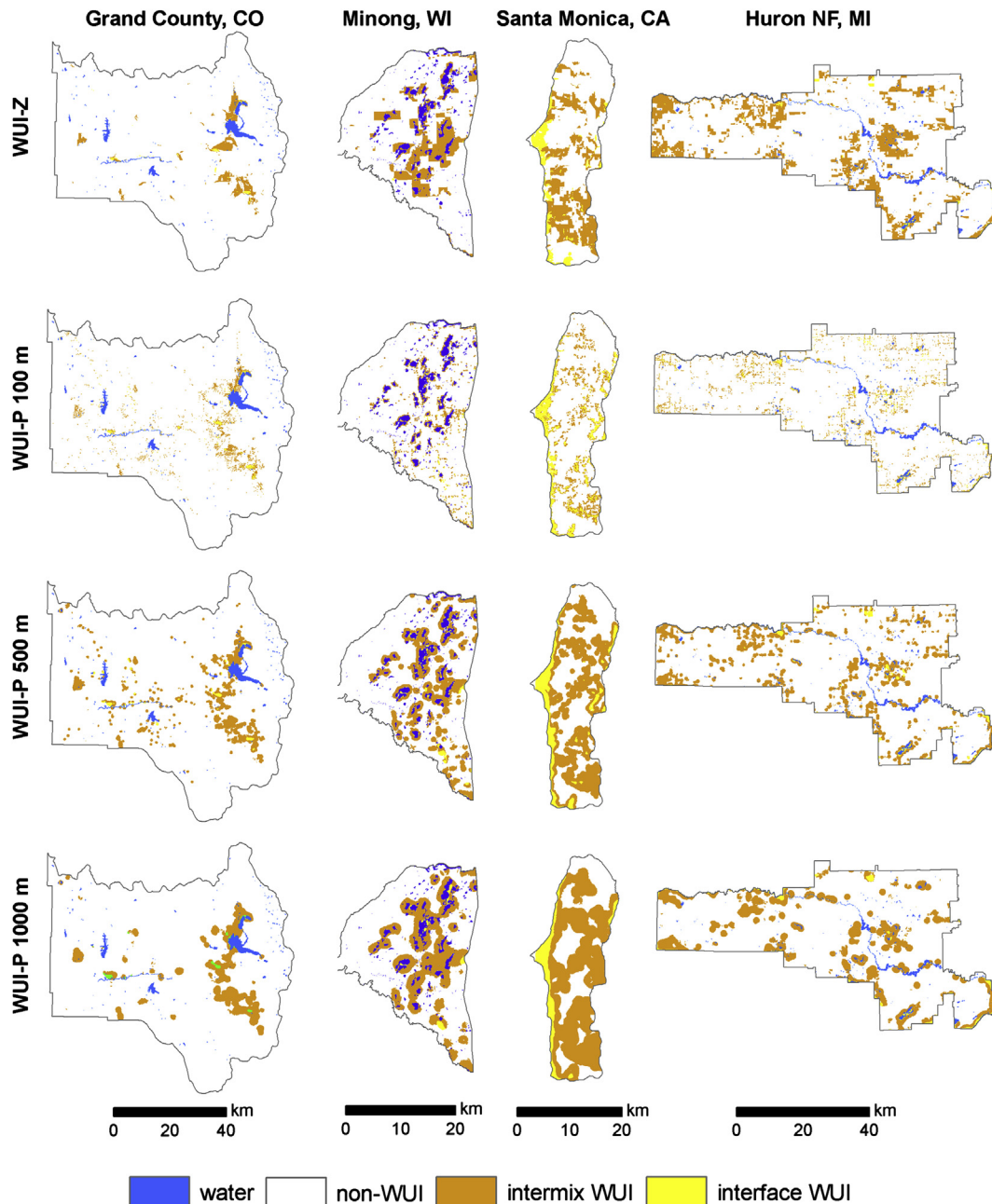

Fig. 3. WUI-Z maps (top row) and WUI-P maps (bottom three rows) at three different buffer distances for the four study areas.

3.2. WUI-P maps and patterns

The WUI-P maps were heavily affected by the choice of neighborhood size (radius). At smaller sizes, WUI-P tended to resemble the fine-scale spatial pattern of structures (Fig. 3, second row) and only a small proportion of the area was classified as WUI-P (Fig. 4). Nonetheless, the majority of structures were mapped as either intermix or interface WUI-P (Fig. 5). With larger neighborhood sizes, larger areas of WUI-P emerged (Fig. 3, third and fourth rows), increasing the relative percentage of the landscape defined as WUI-P (Fig. 4). At the same time, the number of structures assigned to WUI-P classes decreased with neighborhood size as isolated structures fell below the housing density threshold and were classified as non-WUI, which occurred in all study areas except the Santa Monica Mountains (Fig. 5), probably because structures there are more clustered due to the rugged topography.

Neighborhood size (buffer radius) had an almost asymptotic relationship with the percentage of landscape defined as WUI-P in Grand County, Huron, and Minong study areas, while in the Santa Monica Mountains, the relationship was more linear (Fig. 4). In all four study areas, interface WUI-P was relatively rare at the smallest radius (100 m), peaked at 200 m, and declined at larger radii (Fig. 4), though its absolute percentages were very low compared to intermix WUI-P. In the Santa Monica Mountains, the percentage of the landscape defined as interface WUI-P was highest at the smallest radius, and decreased at greater distances. In all study areas, the relationship between WUI-P intermix (which makes up the majority of total WUI-P) and buffer size was similar to that of total WUI-P (described above).
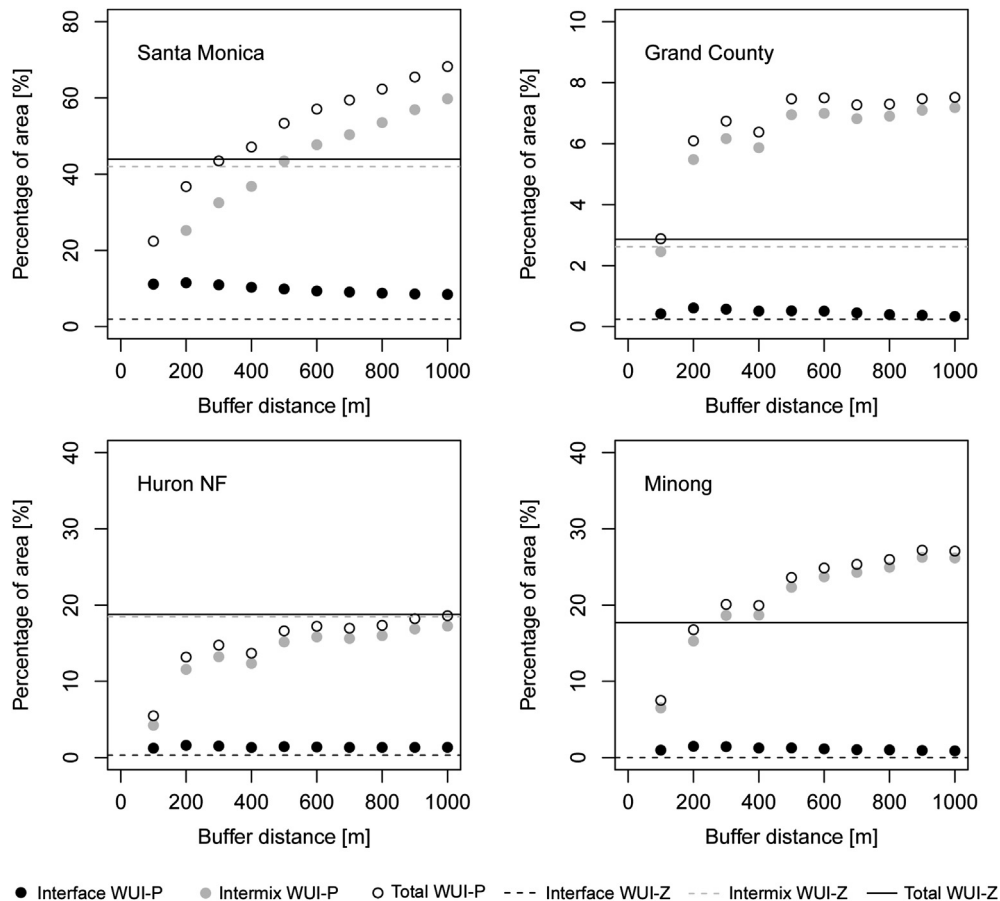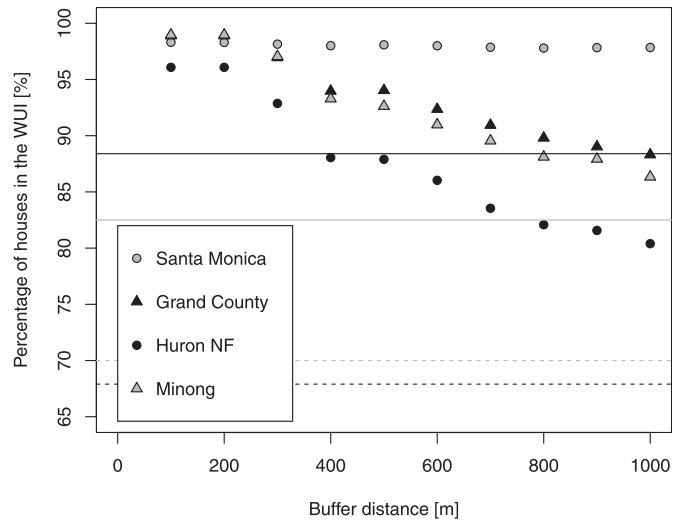

Fig. 5. Percentage of structures inside WUI-P zones at different buffer distances. Lines depict the corresponding values in WUI-Z maps (Santa Monica — solid gray, Grand County — dashed black, Huron NF — solid black, Minong — dashed gray).

3.3. WUI-Z and WUI-P comparison

In all study areas except Huron, WUI-Z and WUI-P classified the same proportion of the landscape as WUI at one of the three smallest radii (Fig. 4). These distances differed among study areas (300, 200, and 100 m respectively in Santa Monica, Minong, and

Fig. 4. Percentage of intermix, interface, and total WUI-P and WUI-Z in the four study areas.

Grand County), and the resulting spatial patterns of WUI-P they portrayed were different, too (Fig. 3). In contrast, on the Huron, WUI-Z always covered a larger percentage of the landscape than the WUI-P, although the difference at the largest radius (1000-m) was small.

The spatial similarity of WUI areas, as measured by the number of pixels classified as WUI in both WUI-Z and WUI-P (excluding all pixels classified as non-WUI in both) was generally low (less than 45%) across study areas and neighborhood sizes (Fig. 6). For the smallest neighborhoods (100 m), similarity was lowest (ranging from 15% on the Huron to 30% in Santa Monica). For Grand County and Minong, similarity increased nearly asymptotically to ∼32% and 36%, respectively. In contrast, Santa Monica and Huron had the most agreement between WUI-P and WUI-Z at intermediate neighborhood sizes (500 m [45%] and 600 m [36%], respectively).

The congruence in terms of the numbers of houses inside the WUI (i.e., the proportion of houses classified as WUI in both WUI-Z and WUI-P, out of all houses) was moderate to high in all study areas (Fig. 7). In Santa Monica and Huron the congruence was slightly above 80%, and not affected by neighborhood size. In contrast, congruence in Minong and Grand County increased from 65% at the smallest radius to 74% and 75% at the largest radius, respectively.

4. Discussion

We developed a new approach to derive WUI maps from housing location data, which is based on the calculation of housing and vegetation densities around each pixel in the landscape by using circular buffers to create 'neighborhoods', and applying these buffers with a moving window approach across the area to be mapped. While buffers have been used for various purposes in previous WUI mapping studies (Wilmer and Aplet, 2005; Lampin-Maillet et al., 2010; Platt, 2010) our approach differs in two important ways: a) the buffer that we used is fully scalable, and b) because we examined housing and vegetation densities within the 'neighborhood' we use the same zonal densities for housing and vegetation as set out in the U.S. definition of WUI. The scalability of the method allows it to bridge the gap between community-specific and nationally consistent mapping methods wherever housing location data are available.
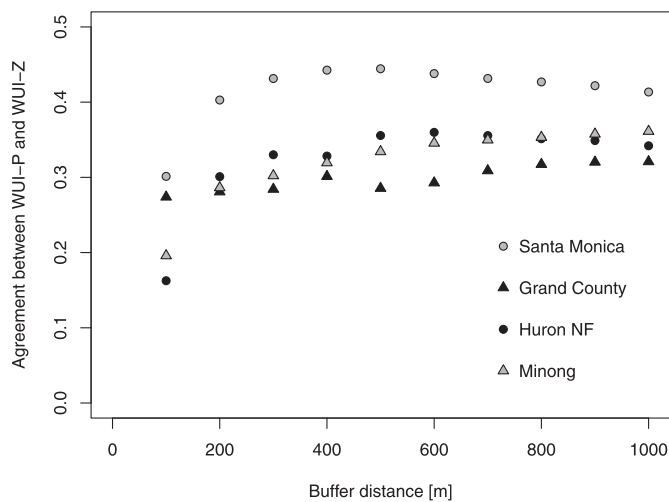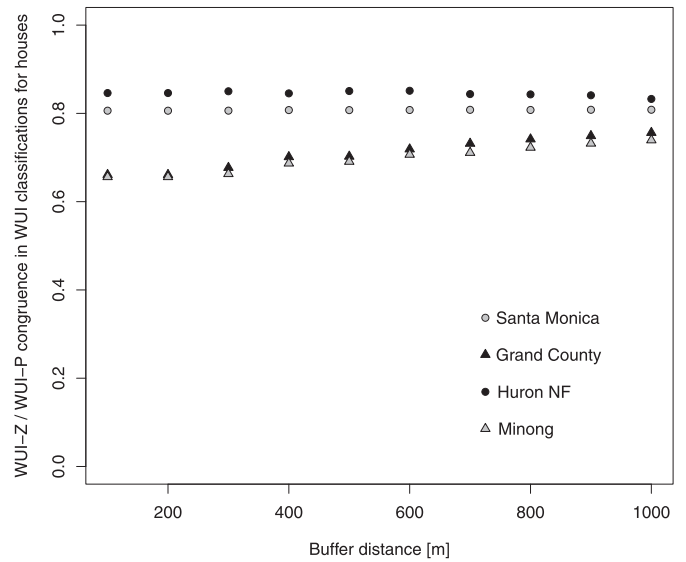
Fig. 7. Congruence in numbers of houses inside the WUI between WUI-P and WUI-Z at different buffer distances. Congruence is defined as the proportion of structures that are located inside the WUI by both WUI-Z and WUI-P approaches, divided by the total number of houses (inside and outside the WUI).

In terms of the area and the number of homes included by each method, differences between methods depend largely on the configuration of both vegetation and housing, and on their joint distribution. The errors any WUI maps try to avoid include: (a) classifying as WUI those neighborhoods that are not intermixed with or adjacent to wildland vegetation; (b) classifying as non-WUI homes that are intermixed or in close proximity to wildland vegetation and that are near other homes (and the vegetated areas associated with them); and (c) including wildlands that are distant (≥2.4 km) from homes. These three cases have different significance. Including too many homes (a), makes the WUI classification less useful for targeting appropriate neighborhoods for Firewise or similar preparedness programs, and selects non-WUI areas where fuel reduction treatments may not be necessary. Excluding homes that fit the WUI concept (b) is problematic because it could result in overlooking neighborhoods where preparedness and mitigation resources are needed.

Including distant wildlands as WUI (c), feeds concern that fuels reduction and other hazard mitigation work will be undertaken far from houses and communities (Schoennagel et al., 2009). To avoid these pitfalls, our WUI-P method focuses the WUI (and thus any management tied to the WUI) closely around communities and not in more remote areas. It essentially follows the fine scale patterns of settlements and houses. WUI-Z may facilitate "WUI" fuel treatments much further away from actual structures, since it may include low housing density areas in census blocks. Fire policy and politics complicate fire management, but costs in relation to budget constraints are an equally serious concern for fire managers. The improved precision of the point-based WUI maps we developed here ensures that fuel management, homeowner outreach programs and other resource meant to be WUI-specific are applied only within the WUI.

The WUI-P method offers a flexible way of creating a WUI map at multiple scales, so that organizations can choose to map the WUI using structure location data and neighborhoods (buffers) according to their management needs and concerns. Even WUI analysis and mapping done with a very small or very large neighborhood size can later be revisited and reanalyzed, because the method is unambiguous in its treatment of any conditions. A community can create multiple maps with a different buffer size for comparison

Fig. 6. Areal agreement between WUI-Z and WUI-P maps based on confusion matrices (0 – no agreement, 1 – perfect agreement). Pixels that were non-WUI in either map were excluded from the analysis to eliminate overestimation of agreement in regions with little WUI cover.

with neighboring communities, or to reflect a new management concern. No unique information or operations need to be reconstructed to determine how the WUI map was generated. Similarly, new vegetation data and updated structure location information can be substituted and the analysis easily re-run.

This structure-specific WUI-P approach thus creates a product that is complimentary to the WUI-Z, currently the only feasible approach for creating a consistent national product for strategic planning. However, as long as no nationwide data on housing locations is available, the WUI-Z method remains essential and relevant, since digitizing airphotos or satellite images to create such a dataset would be very costly. Similarly, all-hazards or emergency preparedness information (e.g., 911 data) which include structure locations are not publicly available nor are cadastral data. Until the WUI concept (or other structure location-specific management) gains wider use for issues beyond fire – such as managing wildlife habitat, and open space planning – there will be limited support for comprehensive structure location mapping, and the WUI-P will remain most practical for use at local to regional scales.

5. Conclusions

The WUI is a tension zone where human activity and natural processes interact to create a novel and complex set of issues. Wildland fire managers have been aware of WUI issues and problems for decades (Bradley, 1984), but the formal WUI definitions, and the maps and policies tied directly to it are relatively new (Radeloff et al., 2005) and still evolving (Stewart et al., 2007). Advances in remote sensing and spatial analysis have increased the rate of change in WUI mapping and analysis by expanding the data and methods available to analysts. One notable tension throughout this evolution has been the need for both national and local WUI maps, and hence different WUI definition and mapping approaches. The availability of these options requires scientists, managers and policy makers to choose between using local, particular, detailed and unique data and methods or general, consistent, and all-inclusive data and methods. Much depends on the intended application (Stewart et al., 2009; Platt, 2010). Arguments for each are compelling, but some degree of consistency and comparability is necessary to support policy making. Transparency and replicability are also desirable for any policy decision that affects the distribution of resources. Given these realities, improving the quality of maps and methods that can maintain consistency and replicability is a high priority. The method presented here expands the types of data that are useable in mapping the WUI, and introduce a means of scaling WUI mapping to suit the analysts' purpose, without sacrificing consistency and replicability.

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