The wildland–urban interface dynamics in the southeastern U.S. from 1990 to 2000

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Abstract

Resolving environmental impacts caused by the wildland–urban interface (WUI) expansion such as wildlife habitat fragmentation, or increased fire risk entails an accurate delineating of WUI boundary and its dynamics prediction. This study identified WUIs throughout the 11 states of southeastern U.S. in 1990 and 2000 and observed their change during this period utilizing census surveyed housing density and remotely sensed land-cover data. In 1990 and 2000, states of North Carolina and Virginia had the highest, while the state of Arkansas had the lowest proportion of WUI coverage. From 1990 to 2000, states of South Carolina, Florida and Mississippi have seen a radical WUI expansion, while North Carolina has experienced no noticeable WUI transformation. Total WUI area increased from 241,983 km² in 1990 to 285,415 km² in 2000. Wildland–urban interface patch number decreased from 1362 to 1282 and mean WUI patch size enlarged from 178 km² to 233 km². Total WUI area in each single year and new added WUI from 1990 to 2000 have high sensitivity to threshold adjustment of low housing density, vegetation density, while subtle sensitivity to threshold modification of high housing density. Vegetation density is a more significant factor than housing density in determining WUI coverage in both 1990 and 2000 and WUI dynamics from 1990 to 2000 in each state. Urban aggregation index is a significant factor related with WUI coverage in each state as well.

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1. Introduction

The wildland–urban interface (WUI) is the area where housing structures meet or intermingle with wildland vegetation (U.S. Departments of Agriculture and Interior, 2001). A WUI typically lies between a developed urban area and an undeveloped wildland area. The Federal Register classifies the WUI into “intermix” where housing is mixed with heavy wildland vegetation and “interface” where housing structures are developed in sparse vegetation area close to dense wildland vegetation. The closeness is generally set as 2.4 km (California Fire Alliance, 2001).

Recently, the Southeastern U.S. has witnessed a rapid WUI expansion prompted by fast population growth and urban sprawl. The total population of the 11 southeastern states grew from 57,465,822 in 1990 to 64,937,077 in 2000 (U.S. Census Bureau, 2000). Residence of new-arriving population around the fringe of urban area (suburban sprawl) or in rural areas (rural sprawl) creates two urbanization patterns and they lead to distinct environmental impacts (Theobald, 2001). Rural sprawl occupies a much larger area than suburban sprawl for the same total added population. In terms of environmental impacts, rural sprawl can affect a much larger area and suburban sprawl can lead to much more intense effect because rural sprawl occurs at a lower density than suburban sprawl (Hansen et al., 2002). Since the 1970s, rural sprawl has been more pronounced than suburban sprawl in the United States (Fuguitt, 1985; Johnson and Fuguitt, 2000). This migration pattern has tripled the land consumed by urbanization since 1950 (Ball, 1997).

Wildland–urban interface expansion can induce a series of biological and environmental impacts such as wildlife habitat loss or fragmentation, and deteriorating air and water quality (Liu et al., 2003; McKinney, 2002; Monroe et al., 2003). Population degradation of half of all federally listed threatened species in the United States is primarily caused by urbanization...
to 2000 (Barnard, 2001). To decrease the loss caused by wildfire, development near wildlands creates dangers from quite complex wildfires. The dynamics of forest fuels, changing wind conditions, humidity, fuel type, and other factors in the WUI present unique problems to firefighters. Larger and more frequent wildfire around the country in recent years and fears that such fires will continue causes significant concern regarding the safety of people as well as private and public property located in or near WUI areas (Cortner, 1991; Miller et al., 2000). Rapid population growth in the WUI has become the chief cause of growing catastrophic fire loss and expenditures for combating wildfires (Cohen, 2000). In 2000, over three million hectares were burned and 861 structures and 16 lives were lost across the U.S. (National Interagency Fire Center, 2001). In addition to burned forest, wildfire has caused at least $3.2 billion in damage to homes and other improved property between 1991 and 2000 (Barnard, 2001). To decrease the loss caused by wildfire and to protect public safety in the WUI, the federal government has spent huge amounts of money to combat wildfire each year. In 2001, this funding reached $2.8 billion (ECONorthwest, 2001). However, the enormous government effort is still less than what conditions require as developed areas encroach upon wildland areas at an unprecedented rate. Constraints on the amount of government funding for combating wildfire underscore the importance of mapping priority areas for wildfire risk control. Federal, state, and local governments have established the WUI as a priority fire prevention area and as a natural hazard and public policy problem (Glickman and Babbitt, 2001; Keeley et al., 1999; Radeloff et al., 2005a; Steelman and Kunkel, 2004).

To date WUI delineation has been explored from a variety of aspects using residential density including population density and housing density data, or a combination of housing and vegetation density data (ECONorthwest, 2001; Greenberg and Bradley, 1997; Radeloff et al., 2005a; Sampson et al., 2000; Theobald, 2001). However, the role of vegetation in composing the WUI has never been accurately incorporated in previous efforts. Approaches utilizing vegetation and residential data that were not created for the same period were built on the underlying assumption that land use change had not caused significant WUI change in the study period (Radeloff et al., 2005a). Besides not thoroughly considering the role of vegetation in constituting the WUI, prior WUI location efforts were limited to map the WUI for one year. Wildland–urban interface dynamics in a multi-temporal regime incorporating both housing and vegetation density at a regional scale have rarely been documented. Policy-makers and land managers need to understand spatial and temporal patterns of urban and rural sprawls and design appropriate strategies to minimize their impacts. To meet these needs, this study incorporated National Land-Cover Data (NLCD) for 1992 and 2001, and census surveyed housing data from 1990 to 2000 to study WUI dynamics from 1990 to 2000. The objectives are to (1) map the WUI in 1990 and 2000 in the southeastern United States; (2) analyze WUI dynamics from 1990 to 2000; (3) compare the sensitivity of WUI dynamics to wildland vegetation and residential housing density change. The results will provide insight for fire managers, conservation planners, and land use planners into the trends and patterns of WUI expansion.

2. Methods

2.1. Data retrieving and processing

Housing density is summarized at a series of census units such as state, county, tract, census block group (CBG), and census block (Zhang and Wimberly, 2007). This study employed data at the CBG level, the second finest census unit. The finer level of census block has inconsistent spatial boundaries in various survey periods, precluding its usability in the multi-temporal analysis conducted in this study. Although census data at the CBG level has the same problem in that boundaries may change from one survey to the next, techniques are available to overcome this problem. To make data from 1990 to 2000 comparable at the CBG scale level, Geolytics reorganized 1990 census data based on boundaries from 2000 (Geolytics, 2004). The present study utilized housing data at CBG scale in 2000 and CBG data in 1990 that has been reorganized based on 2000 boundaries (U.S. Census Bureau, 2000). Housing density at the CBG level was calculated for the states of Florida, Georgia, South Carolina, North Carolina, Virginia, Kentucky, Tennessee, Alabama, Louisiana, Arkansas, and Mississippi.

Thirty-meter resolution land-cover data in 1992 and 2001 was obtained from the NLCD (Homer et al., 2004; Vogelmann et al., 2001). These two land-cover data sets are based on the Landsat Thematic Mapper satellite from the early to mid-1990s and 2001, respectively. Accuracy assessment for NLCD 1992 revealed that land-cover classification accuracy can reach 81% for the study area (the Southeastern U.S.) at the three-cell moving window patch level (Stehman et al., 2003). This study employed proportion of vegetation in each CBG, not compared cell by cell from 1990 to 2000. Each CBG is large enough to contain plenty of cells to ensure the comparison unit is larger than the three-cell patch. Accuracy of cross-validation for assessing classification and prediction reliability for NLCD 2001 can reach 82% for the southeastern U.S. (Homer et al., 2004).

The NLCD 2001 and NLCD 1992 land-cover classifications are compatible, and support change detection, because (1) 1992 land-cover data and 2001 land-cover data have almost the same classification scheme. Water, forest, shrub, herbaceous, and wetland classes in NLCD 2001 are nearly identical to NLCD 1992 definitions. Wildland vegetation defined in this study included only these identical vegetation classes in NLCD 1992 and NLCD 2001; (2) this study compared only coarse types of vegetation. Comparison of NLCD 1992 and NLCD 2001 can be used to estimate land-cover change at a simple classification detail (e.g., water, urban, agriculture, forest, barren, wetland, grass/shrub) (O’Briant, 2006); (3) the comparison conducted in this study was at the CBG level which is much larger than a pixel, not cell by cell.
The wildland vegetation in the 1990s included coniferous, deciduous, and mixed forest; shrubland; grassland/herbaceous; transition; and woody and emergent herbaceous wetlands. For 2001 data, deciduous, evergreen, and mixed forest; shrub/scrub; grassland/herbaceous; woody wetlands, and emergent herbaceous wetlands were defined as wildland vegetation. Wildland vegetation and non-vegetation areas were assigned a grid value of 1 and 0, respectively. Vegetation density was calculated as mean grid value in each CBG.

2.2. Wildland–urban interface location

This research did not attempt to differentiate the intermix WUI and interface WUI. The WUI located in this study includes all intermix WUI and a large portion of interface WUI. The whole WUI location process was conducted at the CBG level. The CBG size increases along the gradient from urban, suburban, WUI to wildland area (Zhang, 2004). In an area adjacent to wildland where the Interface WUI (not the Intermix WUI) occurs, each CBG is large enough to incorporate those areas within 2.4 km in most cases. In addition, Intermix WUI has more ecological and environmental meaning with respect to wildlife habitat loss or wildfire fighting and it is the focus of this study.

Housing and wildland vegetation density were combined to locate the WUI. Thresholds of housing and vegetation density were empirically set based on previous work that specified urban housing density as higher than 1.55 housing units/ha; wildland housing density as lower than 0.06 units/ha; and WUI housing density as between these values (Theobald, 2001). A vegetation density threshold was determined empirically from the relationship between vegetation density and landscape connectivity. Generally disturbance propagation depends on landscape connectivity. A large and catastrophic fire cannot spread in a highly fragmented vegetation landscape. Percolation theory predicts that a landscape’s connectivity undergoes an abrupt transition from connected to unconnected at critical thresholds (Turner et al., 2001). A landscape covered by over 60% of vegetation is most ideal for such disturbance as fire to percolate. When the cover is below 30%, vegetation patches are highly fragmented. The average patch size tends to be small and landscape connectivity is lost; flow of a disturbance will be interrupted (Butry et al., 2002). This study conservatively took 60% of wildland vegetation density as the low threshold of the WUI. Areas reaching the combination of housing and vegetation density thresholds were defined as the WUI.

2.3. Spatial pattern of the WUI in 1990 and newly added WUI between 1990 and 2000

The resultant WUI in vector format was converted into a grid file and the total WUI patch and mean patch size were calculated in Fragstats (McGarigal et al., 2002). Vegetation density and housing density are the main factors determining WUI pattern and dynamics based on common WUI definition. To determine the relative importance of vegetation density and housing density in driving WUI pattern and dynamics, WUI coverage was regressed on vegetation and housing density in each state and their corresponding contribution to WUI pattern was calculated as variance explained by each factor. Statistical analysis was conducted using SPSS (Statistical Package for the Social Sciences, 2006).

Besides vegetation and housing density, the spatial pattern of urban land use can be another significant factor deciding WUI creation and spatial pattern since WUI area typically lies outside the fringe of an urban area (Syphard et al., 2007). Highly clustered urban land use that concentrates a majority of developed land in one location is hypothesized to cause a smaller area of the WUI. To determine the relationship between the WUI and vegetation density, housing density, and urban land pattern, the relationship among them was explored state by state. The WUI coverage for each state was regressed on vegetation density, housing density, and an urban cluster index in SPSS. Cluster index is highly correlated with aggregation of focal urban land patch. When focal patches are randomly distributed, its value will be zero. A maximum aggregated landscape will have cluster index of one. Urban land-cover cells were retrieved from NLCD data in 1992 and 2001 state by state. To fit the maximum running capability of Fragstats, urban grid files were resampled from 30 m to 90 m resolution and the urban cluster index was calculated state by state.

2.4. Sensitivity analysis

The spatial transition from urban areas to the WUI areas and then to wildland areas is a gradual process. Arbitrary WUI boundaries based on thresholds inferred from expert opinion and federally mandated definitions involve a large portion of subjective judgment. Understanding the sensitivity of WUI change to the two determining factors (housing and vegetation density) can assist in predicting future WUI trends based on the dynamics of the determining factors. Thresholds of housing and vegetation density were adjusted plus and minus 20% from their initial values to test the response of WUI areas.

3. Results

The state of Florida had the highest housing density in 1990, followed by Virginia, then North Carolina; Arkansas had the lowest housing density in 1990 (Table 1). Areas with housing density over 0.06 unit/ha saw the most extensive distribution in Florida (Fig. 1). By 2000, all states experienced housing development and the rank ordering of housing density remained the same as in 1990. Alabama had the highest vegetation density in 1990, followed by North Carolina and Virginia; Arkansas had the lowest vegetation density (Table 1 and Fig. 1). By 2000, most states had seen decreased vegetation density except Georgia, South Carolina, Mississippi, and Louisiana where vegetation density increased.

The largest WUI patch in 1990 started from northern Georgia and went along the northwest tip of South Carolina, eastern Tennessee and western North Carolina, ending at the borders between North Carolina and Virginia. Several additional large patches with circular shape were distributed in eastern Kentucky and central Alabama (Fig. 2). Typically each WUI cluster...
exhibited a circular pattern around a city. The WUI was relatively spread out in Florida, Arkansas, and Louisiana. North Carolina and Virginia had the highest and Arkansas had the lowest WUI coverage in 1990 (Table 1). By 2000, North Carolina was still covered by the highest WUI and Virginia was replaced by South Carolina in the second place. In 2000, large WUI patches occurred largely in the same region as in 1990 (Fig. 2). Changes were characterized as expanding out from the original WUI or shrinking in the inner WUI ring around metropolitan areas such as Atlanta, Georgia. The WUI expansion was evident in South Carolina and Mississippi, especially around mid-sized cities such as Augusta, Georgia, and Columbia, SC (Fig. 2, Table 1). Among the 11 states, Mississippi and South Carolina have seen the fastest growth. The WUI in states which had high WUI presence in 1990 remained relatively stable between 1990 and 2000 regardless of increased total housing units from 1990 to 2000.

Table 1

<table>
<thead>
<tr>
<th>State</th>
<th>State land (km²)</th>
<th>WUI cover 1990 (%)</th>
<th>WUI cover 2000 (%)</th>
<th>Vegetation density 1990 (%)</th>
<th>Vegetation density 2000 (%)</th>
<th>Housing density 1990 (/km²)</th>
<th>Housing density 2000 (/km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Carolina</td>
<td>79,948</td>
<td>23.2</td>
<td>33.8</td>
<td>67.4</td>
<td>71.2</td>
<td>17.008</td>
<td>21.008</td>
</tr>
<tr>
<td>Virginia</td>
<td>103,135</td>
<td>25.3</td>
<td>29.8</td>
<td>69.3</td>
<td>66.2</td>
<td>23.471</td>
<td>27.358</td>
</tr>
<tr>
<td>Kentucky</td>
<td>104,430</td>
<td>17.3</td>
<td>20.2</td>
<td>61.4</td>
<td>57.8</td>
<td>14.351</td>
<td>16.689</td>
</tr>
<tr>
<td>Tennessee</td>
<td>109,020</td>
<td>18.9</td>
<td>19.6</td>
<td>63.5</td>
<td>58.9</td>
<td>18.559</td>
<td>22.342</td>
</tr>
<tr>
<td>Louisiana</td>
<td>118,718</td>
<td>10.1</td>
<td>12.8</td>
<td>60.2</td>
<td>62.5</td>
<td>14.21</td>
<td>15.292</td>
</tr>
<tr>
<td>Mississippi</td>
<td>123,336</td>
<td>9.5</td>
<td>14.4</td>
<td>61.1</td>
<td>64.5</td>
<td>8.055</td>
<td>9.283</td>
</tr>
<tr>
<td>North Carolina</td>
<td>127,037</td>
<td>36.2</td>
<td>36.7</td>
<td>69.4</td>
<td>65.2</td>
<td>21.545</td>
<td>26.958</td>
</tr>
<tr>
<td>Alabama</td>
<td>133,947</td>
<td>19.8</td>
<td>20.6</td>
<td>73.9</td>
<td>72.1</td>
<td>12.357</td>
<td>14.495</td>
</tr>
<tr>
<td>Arkansas</td>
<td>137,048</td>
<td>5.6</td>
<td>7.4</td>
<td>58.8</td>
<td>58.4</td>
<td>7.287</td>
<td>8.544</td>
</tr>
<tr>
<td>Florida</td>
<td>144,565</td>
<td>14.9</td>
<td>19.2</td>
<td>65.8</td>
<td>64.6</td>
<td>36.408</td>
<td>44.019</td>
</tr>
<tr>
<td>Georgia</td>
<td>151,854</td>
<td>21.5</td>
<td>26.2</td>
<td>67</td>
<td>70.3</td>
<td>17.322</td>
<td>21.549</td>
</tr>
</tbody>
</table>

Fig. 1. The general pattern of housing and vegetation density for the 11 southeastern U.S. states in 1990. The vegetation density is the percentage of a Census Block Group that is classified as wildland vegetation.

Fig. 2. The spatial pattern of the WUI in 1990 (WUI 1990) and 2000 (WUI 2000), and showing the spatial relationship of the new added WUI over the decade with WUI 1990 and WUI 2000.
Table 2
Statistical relationship between WUI coverage and density of vegetation and housing (as in Table 1 and an urban cluster index in 1990 and 2000, where a cluster index value of one indicates a highly aggregated urban area)

<table>
<thead>
<tr>
<th>Year and model type</th>
<th>P value</th>
<th>% Variance explained</th>
<th>Coefficient sign</th>
<th>R square</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1990</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model composed of no cluster index</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Housing density</td>
<td>0.513</td>
<td>2.8%</td>
<td>+</td>
<td>0.548</td>
<td>0.042</td>
</tr>
<tr>
<td>Vegetation density</td>
<td>0.032</td>
<td>37.2%</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model including cluster index</td>
<td></td>
<td></td>
<td></td>
<td>0.724</td>
<td>0.023</td>
</tr>
<tr>
<td>Housing density</td>
<td>0.123</td>
<td>12.5%</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetation density</td>
<td>0.366</td>
<td>4.2%</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cluster index</td>
<td>0.072</td>
<td>18.1%</td>
<td>−</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2000</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model composed of no cluster index</td>
<td></td>
<td></td>
<td></td>
<td>0.441</td>
<td>0.098</td>
</tr>
<tr>
<td>Housing density</td>
<td>0.193</td>
<td>13.6%</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetation density</td>
<td>0.107</td>
<td>23.5%</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model including cluster index</td>
<td></td>
<td></td>
<td></td>
<td>0.631</td>
<td>0.06</td>
</tr>
<tr>
<td>Housing density</td>
<td>0.041</td>
<td>33%</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetation density</td>
<td>0.074</td>
<td>23.5%</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cluster index</td>
<td>0.099</td>
<td>18.5%</td>
<td>−</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Table 1). For example, North Carolina and Alabama saw large housing developments, while WUI expansion in these two states was minor. Total WUI area increased from 241,983 km² in 1990 to 285,416 km² in 2000. Total WUI patch number decreased from 1362 to 1282 and mean WUI patch size enlarged from 178 km² to 233 km².

The WUI coverage in each state has significant relationship with combination of vegetation density and housing density in each state in 1990 at the 95% confidence level ($P = 0.042$) (Table 2). The addition of an urban cluster index in each state can improve prediction of WUI coverage. The $R^2$ square increased from 0.548 to 0.724 in 1990 and from 0.441 to 0.631 in 2000 with the inclusion of the urban cluster index. Between 1990 and 2000, WUI dynamics was significantly related to the combination of vegetation density and housing density at the 95% confidence level (Table 2). Relatively, vegetation density is a stronger driver of WUI coverage in each single year and of WUI dynamics from 1990 to 2000 than housing density, which is shown by the higher proportion of variance explained by vegetation density than housing density in each model (Tables 2 and 3). For the WUI in 1990, vegetation density contributed 37.2% of variance in comparison with 2.8% explained by housing density. In 2000, 23.5% of variance explained by vegetation density was still higher than the 12.6% explained by housing density. In terms of WUI dynamics from 1990 to 2000, the variance explained by vegetation density change accounted for 50%, while variance explained by housing density change accounted for 12.5%.

Total WUI area responded differentially to the adjustments of low and high housing or vegetation thresholds. In 1990, a 20% lower vegetation threshold added 31% new WUI area and a 20% higher vegetation threshold diminished the WUI over 60%. For low housing density threshold, 20% increment shrank the WUI by 24% and a 20% decrease in housing density resulted in additional 29% of WUI. Modification of the high housing density threshold failed to result in significant WUI area change (Table 4). Likewise, a 20% decrease or increase of the vegetation threshold led to 35% more and 42% less of WUI area, respectively, in 2000. Minus or plus 20% of low housing threshold caused 30% more and 19% less of WUI area, respectively (Table 4). In terms of the development of non-WUI into the WUI from 1990 to 2000, 20% decrease of the vegetation threshold added 19% WUI, while increasing the threshold 20% caused slight WUI change. Plus or minus 20% of low housing density threshold resulted in 16% less or added 23% of converted WUI, respectively (Table 4). Neither the WUI in each year nor the dynamics from 1990 to 2000 were sensitive to modification of high housing threshold.

4. Discussion

Relative to detecting urban land use that can be extracted directly using a remote sensed image or residential density, mapping of WUI area is more complex since it entails incorporating the coexistence of both developed land and wildland vegetation. Utilization of merely housing density will misclassify as the WUI those areas reaching housing density criteria while without suitable vegetation density. Wildland vegetation density change was a more significant factor than housing density in determining formation of the WUI in 1990 and 2000 and its dynamics during this period in the Southeastern U.S. Previous research that...
combined housing density in 2000 and wildland vegetation density in 1992 to locate the WUI in 2000 under the assumption that vegetation density had not been a significant factor causing WUI dynamics in the past decade (Radeloff et al., 2005a) is not applicable in the Southeastern U.S. Between housing and vegetation density, a low value of either factor or both simultaneously will lead to low WUI coverage. For example, WUI coverage is low in Arkansas with low vegetation density and Mississippi with both low housing and low vegetation density. Extremely high housing density will bring on relatively low WUI coverage in a state such as Florida, because a lot of area is already urbanized. A combination of intermediate housing and vegetation density, such as in North Carolina, will generate the highest WUI coverage, similar to the phenomenon in southern California (Syphard et al., 2007).

The sensitivity of WUI area to each threshold is determined by proportion of area under each determining factor within certain value range. The Southeastern U.S. has an average 60% of vegetation coverage and 0.25 unit/ha of housing density. Extensive areas with vegetation and housing density approximating their corresponding WUI criteria in the Southeastern U.S. set the stage for a WUI that responds promptly to vegetation density and low housing density thresholds. Linger reaction of WUI area to high housing density threshold reveals that a relatively low proportion of the area is dense with housing. In addition, CBG size in urban areas is much smaller than the CBG in exurban and wildland area. Addition of several CBG around urban area caused by threshold modifications will not induce substantial total WUI change.

The WUI occupies a much larger area than urban or suburban area and impacts caused by WUI expansion can be more extensive than those occurring in the urban area. Wildland–urban interface covers approximately 22% of the 11 southeastern states, which is comparable to WUI coverage identified in another research conducted in Northern Michigan (Haight et al., 2004), but much higher than the average 10% for the 48 conterminous states (Stewart et al., 2003). Only Arkansas has a lower value than the national average. The continual WUI expansion is resulting in increased total WUI area, enlarged WUI patch size, and higher connectivity among each WUI patch in the Southeastern U.S., which will degrade natural wildlife habitat through removing or fragmenting existing wildlife habitat (Radeloff et al., 2005b; Theobald et al., 1997). Decreased biodiversity has been widely reported under negative effect of habitat fragmentation (Joly and Myers, 2001; McKinney, 2002).

Increased WUI area from 1990 to 2000 implies that humans are increasingly intermingled with wildland vegetation, which increases the likelihood of anthropogenic fire ignitions into wildland, thereby exposing more wildland vegetation, private or public properties, or even human lives to potential fire risk. The complex wildfire situation in the WUI makes management planning and fire fighting more challenging in the WUI. Successful management will consider not only technical issues, but social impact and perceptions of local residents. Land managers must possess the new skills such as the effective way to communicate about the wildlife-people conflicts, and the acceptance of prescribed fire (Duryea and Hermansen, 2002). The growing number of residents in the WUI set the stage that fire fighting becomes everyone’s responsibility, not just of land managers or government. Acquainting local residents about the potential fire risk and avenues of fighting fire becomes increasingly important. Designing and construction of housing in the WUI should involve more concern and planning for fire safety. These advance planning actions such as fire-safe landscaping, building property with fire-proof material can lessen the devastation of a wildland fire.

The WUI consumes a much higher proportion of land than an urban area when accommodating the same amount of population. Other facilities accompanying arrivals of residents, such as a road network consumes additional land by WUI expansion and reduce open spaces. The large areas of land lost to WUI expansion revealed in this study underscores the necessity of effective land use planning in the Southeastern U.S. The WUI expansion should be a main component of land development.
programs and be carefully considered in regional research or planning related to land development and conservation. The development plan is also required to visualize future landscapes resulting from human activities. Increased population growth and parallel development, land use planning and policy issues, and economic and taxation are key driving forces on rapid WUI expansion (Monroe et al., 2003). It is time for decision-makers to consider curbing the rapid WUI growth through encouraging concentrated development. This study provides some operational information for planning purposes, a WUI map and summaries of WUI spatial pattern. Mapped WUI in this study can also be used in assisting priority-setting of the national fuels management program across the Southeastern U.S. With limited resources for fire prevention and preparedness, planners need to set priorities for treatment by choosing the location of projects to maximize the expected reduction in damage to people, houses, or natural resources. Significance comparison of each factor in causing WUI dynamics can contribute to predicting future WUI creation and allow federal agencies to take proactive measures in addressing the WUI issues.

Issues arising from rapid WUI sprawl differ by state. Some states such as North Carolina and Virginia have high WUI coverage and some state such as South Carolina is experiencing fast WUI expansion. Allocation of government effort in setting priority order should consider local condition in each state and implement corresponding fire prevention or WUI sprawl limiting planning. Government effort in preventing potential wildfire should set priority to those states covered by high proportion of WUI area. Policies limiting WUI sprawling should be stricter in states experiencing fast WUI expansion. In addition to housing density, vegetation density and urban aggregation patterns are two other important factors determining WUI formation. A highly aggregated urban pattern will generate low WUI development, which was also validated in California where a clustered spatial pattern of urban development resulted in no net WUI growth (Syphard et al., 2007). In planning development, clustered urbanization or development in low vegetated area can decrease WUI formation. Encouraging people to live in relatively developed urban centers, or suburban sprawl, rather than in newly developed land or rural sprawl might assist in slowing down the pace WUI expansion (Theobald et al., 1997). In highly developed area, securing existing protected area can be an efficient measure to preserve wildlife habitat. Adjacent cities or even counties need to coordinate on planning to achieve “smart-growth” (Burby and May, 1997) and avoid conflict among adjacent cities and discourage sprawl growth (Gale, 1992). In fast developing regions, land use planning should integrate ecological principles to preserve critical habitats and corridors (Broberg, 2003).

There are several limitations on this study. First, it is inappropriate to equate the WUI map to a fire risk map. The main purpose of mapping WUI area is to provide assistance for wildfire management. The WUI integrates wildland vegetation and permanent human activity, and reflects the area where potential fire risk is high, because fire ignition source, fuel load and potential loss of property or even human lives are all located in the WUI. However, other factors not considered in this study, such as historic fire frequency, local weather, vegetation structure and topography can determine fire frequency and intensity to a large extent (Heinselman, 1981). Second, remote sensed vegetation data and census surveyed residential data are not from identical years. Ideally, vegetation data in 1990 should be combined with housing data in 1990 in locating the WUI in 1990. Likewise, the WUI in 2000 should be located from vegetation data in 2000 and housing data in 2000. Constrained by data availability, this study used vegetation data in 1992 and vegetation data in 2001 as surrogates of vegetation data in 1990 and 2001, respectively. Then vegetation density has to be assumed to be stable during the period between 1990 and 1992 and between 2000 and 2001.

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