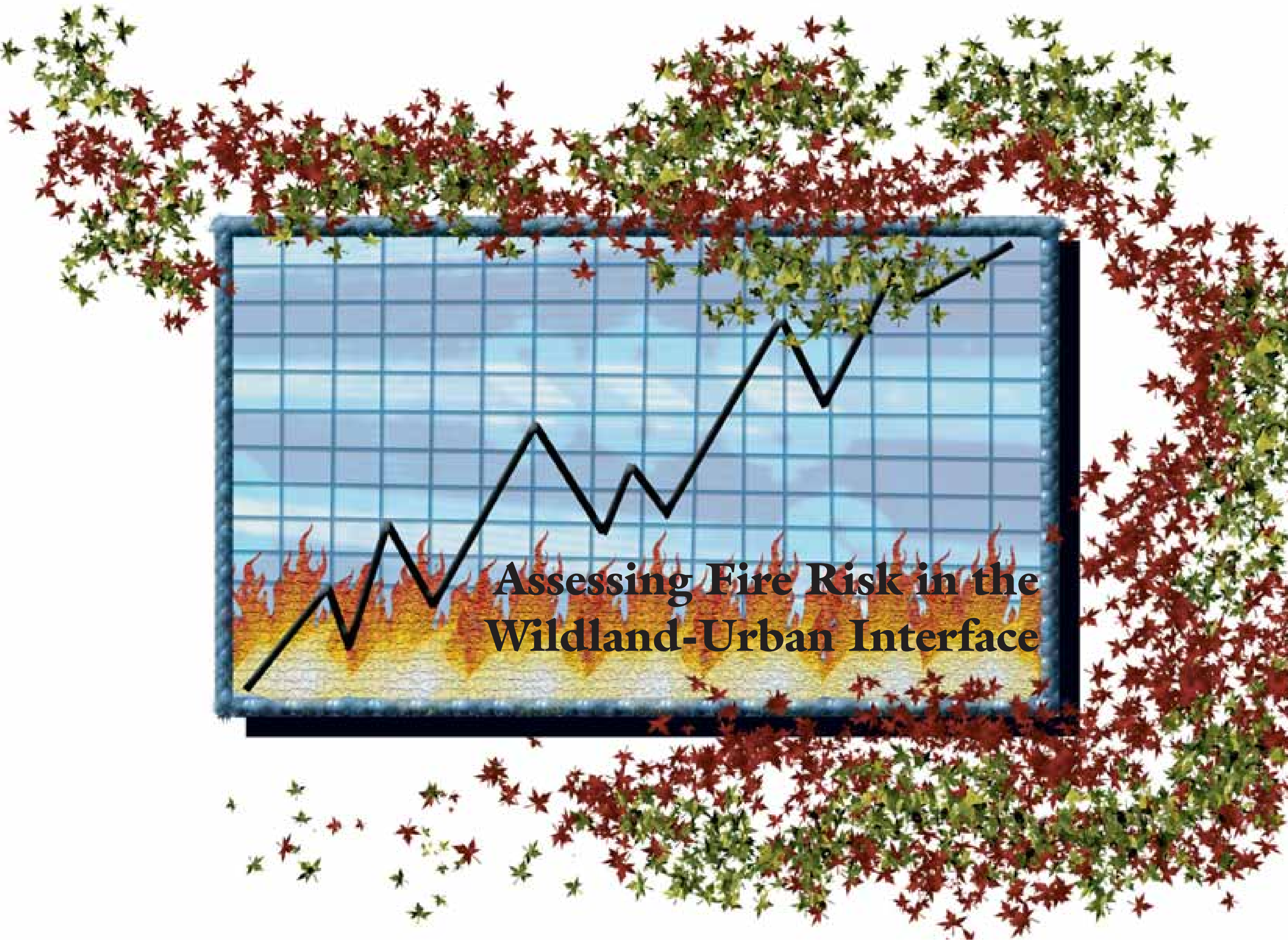

Assessing Fire Risk in the Wildland-Urban Interface

Robert G. Haight, David T. Cleland, Roger B. Hammer, Volker C. Radeloff, and T. Scott Rupp

ABSTRACT

Identifying areas of the wildland-urban interface (WUI) that are prone to severe wildfire is an important step in prioritizing fire prevention and preparedness projects. Our objective is to determine at a regional scale the relative risk of severe wildfire in WUI areas and the numbers of people and houses in high-risk areas. For a study area in northern lower Michigan, we first develop a spatial database of WUI areas (both intermix and interface) using housing data from the 2000 US Census and 1994 vegetation data from the Gap Analysis Project of the Michigan Department of Natural Resources. Then, we develop a spatial database of historic (pre-1900) fire regimes and current (1994) fuels to identify areas with high risk of stand-replacing fires. High-risk areas historically supported jack pine (*P. banksiana* Lamb.) and mixed pine forests with stand-replacing fire rotations less than 100 years and currently support upland conifer and hardwood forests. Analysis of the databases shows that 26% of the study area is WUI. About 25% of the WUI has relatively high fire risk. Over 88% of the WUI with high fire risk has low housing density (<1 house per 2 ha) and is classified as intermix where fuels and structures intermingle. The predominance of high-risk intermix areas with low-density housing has implications for planning effective fuel treatments and evacuation plans.

Keywords: fire risk; fire regime; fuel distribution; housing density; Michigan; population density; wildland-urban interface; US Census

Government agencies, businesses, and communities are concerned about the likelihood of severe wildfire and its threat to people, houses, and natural resources in the wildland-urban interface (WUI). In general terms, the WUI is where houses and fairly dense vegetation are both present. A fine-scale map shows that WUI areas are widely distributed across the United States and cover almost 10% of the coterminous 48 states (Stewart et al. 2003). Recent wildland fire policy targets the WUI as the area where resources will be dedicated to fire prevention and preparedness projects (USDA et al. 2002) including fuel reduction in forests (Conard et al. 2001), fuel removal in the immediate vicinity of homes (Cohen 2000), and emergency evacuation planning (Church and Cova 2000). With limited resources for fire prevention and preparedness, planners set priorities by choosing the type and location of projects to maximize the expected reduction in damage to people,

Figure 1. **Study area in northern lower Michigan.**

houses, or natural resources. The process of setting priorities typically includes a risk analysis involving the determination of the probabilities of severe wildfire in WUI areas and the values at risk of damage or loss.

The purpose of this article is to determine the relative risk of severe wildfire in WUI areas and the numbers of people and houses in high-risk areas in northern lower Michigan. Throughout the article, we use the term fire risk to mean the likelihood that a particular place on the landscape will experience a stand-replacing fire within a discrete period of time. There are at least two ways to quantify fire risk. One approach involves processing site-specific information on weather, terrain, and fuels through mathematical models of fire ignition, intensity, and spread to classify land units by fire risk (e.g., Burgan and Shasby 1984, Sanchez-Guisandez et al. 2002). A second approach involves estimating empirical models of fire occurrence based on biotic, abiotic, and human variables to classify land units by fire risk (e.g., Cardille et al. 2001, Prestemon et al. 2002). When models to quantify fire risk are unavailable, spatial layers of biophysical data related to historical fire regimes and current ecological conditions are used to classify land into condition classes, which may include qualitative estimates of fire risk (e.g., Hardy et al. 2001).

We take the latter approach and determine the relative risk of fire in WUI areas using qualitative risk classes based on historical fire regimes and current fuels in northern lower Michigan. A fire regime refers to the long-term nature of fire in an ecosystem and is typically described by fire frequency and severity (Brown 2000). We classify land units by historical fire regime based on information on the frequency and size of pre-1900 stand-replacing fires in relation to biophysical characteristics of the land. Then, we overlay current vegetation types classified by flammability. We assume that areas with histories of frequent stand-replacing fires and with currently flammable fuels have the highest fire risk. Combining the map of fire risk with a WUI map allows us to identify portions of the WUI with high fire risk and determine the amounts and densities of houses and people in the high-risk areas. The results suggest the type and location of fire prevention and preparedness projects that will maximize damage reduction.

Study Area

The study area is 4,282,600 ha (1 ha = 2.471 ac) in 33 counties of northern lower Michigan (Figure 1). Approximately 65% of the study area is forested with a rich variety of decidu-

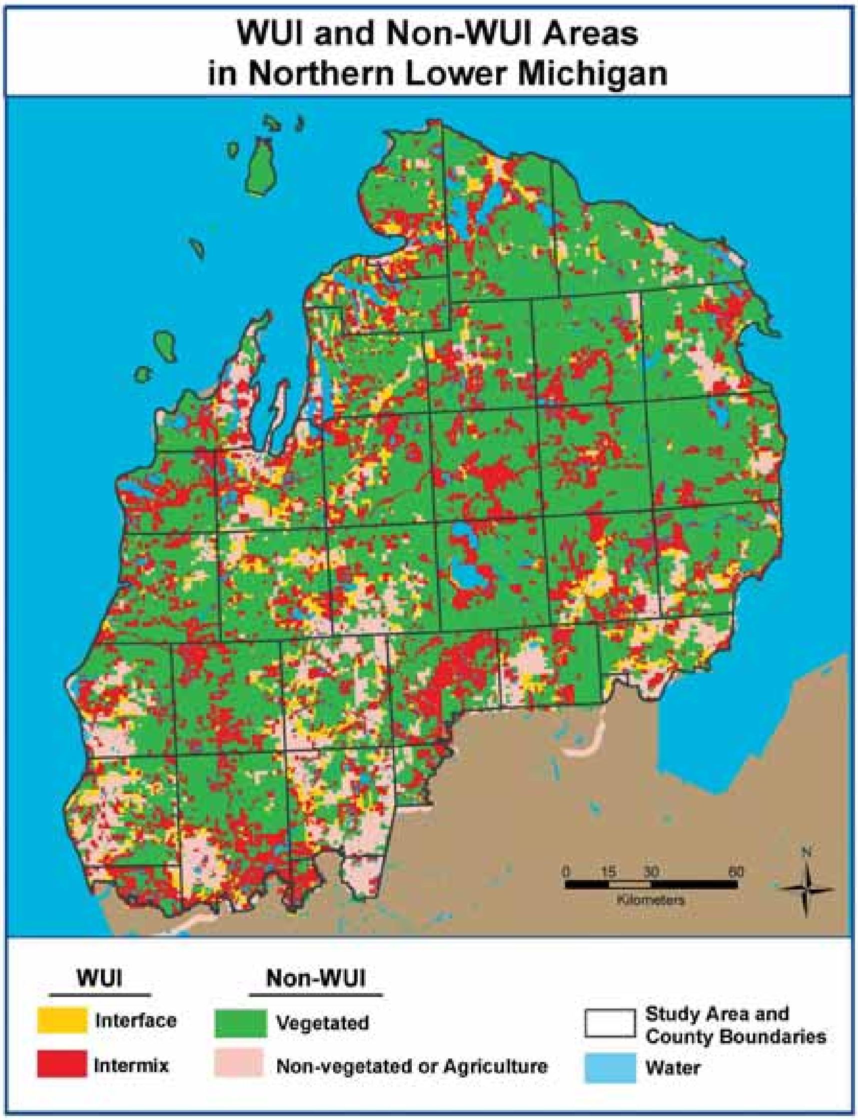

Figure 2. **Wildland-urban interface and intermix areas in northern lower Michigan.**

ous and coniferous forest types (Leatherberry 1994). Hardwood forest types including maple (*Acer* spp.)-birch (*Betula* spp.), aspen (*Populus* spp.), oak (*Quercus* spp.)-hickory (*Carya* spp.), and elm (*Ulmus* spp.)-ash (*Fraxinus* spp.)-soft maple cover 75% of the forest land, while conifer types including red pine (*P. resinosa* Ait.), white pine (*P. Strobus* L.), and jack pine (*P. banksiana* Lamb.) cover 25%. Private individuals own more than half the forestland. Approximately 40% of forest is in public ownership, including the Huron-Manistee National Forest.

Since 1970, rural, forested counties in the upper Midwest experienced rapid increases in population and housing so that few forests are more than 25 km from dense human settlements (Radeloff et al. 2004). The region of northern lower Michigan is a good example of this trend where the population grew from approximately 400,000 people in 1970 to 750,000 people in 2000. Recreational and aesthetic amenities associated with forests together with low property values make the study area an attractive place for retirees and recreational home ownership.

Humans cause the vast majority of modern wildfires in the upper Midwest. Since 1985, approximately 350 forest fires were reported per year in northern lower Michigan, and more than 95% of those fires were human caused (Cardille et al. 2001). During this period, fire occurrence was strongly related to human access: fires occurred more often in areas with higher road and population densities. Fire suppression limited average fire size to about 3.5 ha (9 ac), and, as a result, an average of 1,225 ha (3,027 ac) burned per year, or 0.03% of the study area. While rare, large fires do occur, such as the 1980 Mack Lake fire, which burned about 9,700 ha (24,000 ac). Since 1860, six other large fires burned in the Mack Lake area with an average return interval of 30 years (Simard and Blank 1982).

Wildland-Urban Interface

We base our WUI classification on definitions of interface and intermix communities that are published in a report to the Council of Western State Foresters (Teie and Weatherford 2000). An interface community exists where structures such as homes or business facilities directly abut wildland fuels with a clear line of demarcation between them. Wildland fuels do not generally continue into the developed area. An intermix community exists where structures are scattered throughout a wildland area and wildland fuels are continuous outside of and within the developed area. Similar definitions in the Federal Register (66 FR 751) establish a minimum density of one structure per 16 ha (40 ac) for both interface and intermix communities.

We map interface and intermix areas using a combination of housing density and vegetation cover criteria developed for a nationwide assessment (Stewart et al. 2003). The housing information is block-level housing data from the 2000 US Census. A Census block is the smallest reporting unit of the US Census and is an area of land bounded on all sides by visible features such as roads, streams, or railroad tracks and invisible features such as county lines or property lines. Census blocks can be very small (a city block) or very large (several hundred hectares in sparsely settled areas) and average 78 ha in the study area. Within each Census block, all housing units are counted whether they are occupied or vacant.

In addition to structures, definitions of interface and intermix communities include wildland fuels. To identify wildland fuels, we use a vegetation

Table 1. Land area, houses, and people in wildland-urban intermix and interface areas in northern Lower Michigan.

Land class	Land area (ha)		Houses		People	
	Total	%	Total	%	Total	%
Intermix						
High density[a]	800	0	8,065	4	7,006	2
Medium density	73,100	8	94,392	43	114,004	36
Low density	846,100	92	118,637	53	195,231	62
Total intermix	920,000	100	221,094	100	316,241	100
Interface						
High density	2,100	1	23,216	21	38,663	20
Medium density	31,300	16	65,085	59	104,877	55
Low density	162,000	83	21,830	20	48,522	25
Total interface	195,400	100	110,131	100	192,062	100
Total WUI[b]	1,115,400	26	331,225	72	508,303	67
Total non-WUI	3,167,200	74	130,068	28	249,286	33
Total study area	4,282,600	100	461,293	100	757,589	100

[a] *Housing density classes (houses/ha): low (0.06-0.49), medium (0.49-7.41), high (>7.41).*
[b] *WUI is composed of intermix and interface areas.*

cover map from a classification of 1994 LandSat Thematic Mapper satellite imagery obtained from the GAP Analysis Project of the Michigan Department of Natural Resources. Vegetation cover is classified into 32 types and mapped at a 30-m resolution. We divide the 32 cover types into two sets. The first set is used to identify vegetated wildlands and includes forest, shrubland, and grassland types. The second set is used to identify areas that are not wildlands and includes barren lands, urban areas, and vegetation associated with agriculture (e.g., orchard, vineyard, pasture, cropland).

Finally, we assume that areas within 2.4 km (1.5 miles) of wildland vegetation are in the vicinity of wildland fuels. This is roughly the distance that firebrands can be carried from a wildland fire to the roof of a house. We use this buffer distance to identify interface areas.

Using Census blocks and the vegetation cover map, we obtain an operation definition of WUI, which includes both interface and intermix areas. Interface areas are Census blocks with greater than one house per 16 ha, less than 50% vegetation cover, and within 2.4 km of an area (made up of one or more contiguous Census blocks) over 500 ha with greater than 75% vegetation cover. Intermix areas are Census blocks with greater than one house per 16 ha and greater than 50% vegetation cover.

Mapping the interface and intermix areas (Figure 2), we find that 26% (1,115,400 ha) of the study area is classified as WUI (Table 1). The WUI contains 72% (331,225) of the houses and 67% (508,303) of the people. Intermix areas compose 82% of the WUI area and contain over 60% of the houses and people in the WUI.

Because interface and intermix areas can include a wide range of housing densities, we define three housing density classes (houses/ha): low (0.06–0.49), medium (0.49–7.41), and high (>7.41). In the intermix, areas with low-density housing cover most of the land area (92%) and contain over half the houses and people (Table 1). In the interface, areas with low-density housing cover most of the land area (83%) but contain only 20% of the houses and 25% of the people.

Historical Fire Regimes

We use a map of historical fire regimes in northern lower Michigan (Cleland et al. 2004) to provide spatially explicit information about the relative risk of severe wildfire. Four fire regime classes are defined based on the rotation of stand-replacing fires. The classification focuses on stand-replacing fires because documentation of the historical frequency and size of less severe fire types is not available. Fire rotation, which is the length of time necessary for an area equal in size to the study area to burn (McPherson et al. 1990), is used to classify stand-replacing fires because it incorporates information on fire size in addition to fire frequency. The classification is based on literature describing historical fires in forest types of Michigan as interpreted from fire scars, charcoal and pollen analyses, stand age distributions, and US General Land Office original Public Land Survey records. The fire rotation lengths and associated class names are <150 years (FR1), 150–350 years (FR2), 350–550 years (FR3), and >550 years (FR4).

The fire regime classes are keyed to biophysical characteristics including historical vegetation, elevation, landform, and soil texture and drainage (Table 2). For example, the short-rotation class FR1 occurs in very dry, flat outwash plains underlain by coarse-textured sandy soils supporting short-lived, fire-prone jack pine and mixed pine forests. In contrast, the very-long-rotation class FR4 occurs in mesic moraines and glacial lakebeds underlain by fine-textured loamy soils supporting long-lived, fire-resistant northern hardwood forests. Based on an analysis of these biophysical characteristics, two additional fire regime classes are defined for wetland conifer forests with fire rotations <150 years (FR3W) and wetland conifer-hardwood forests with fire rotations >550 years (FR4W).

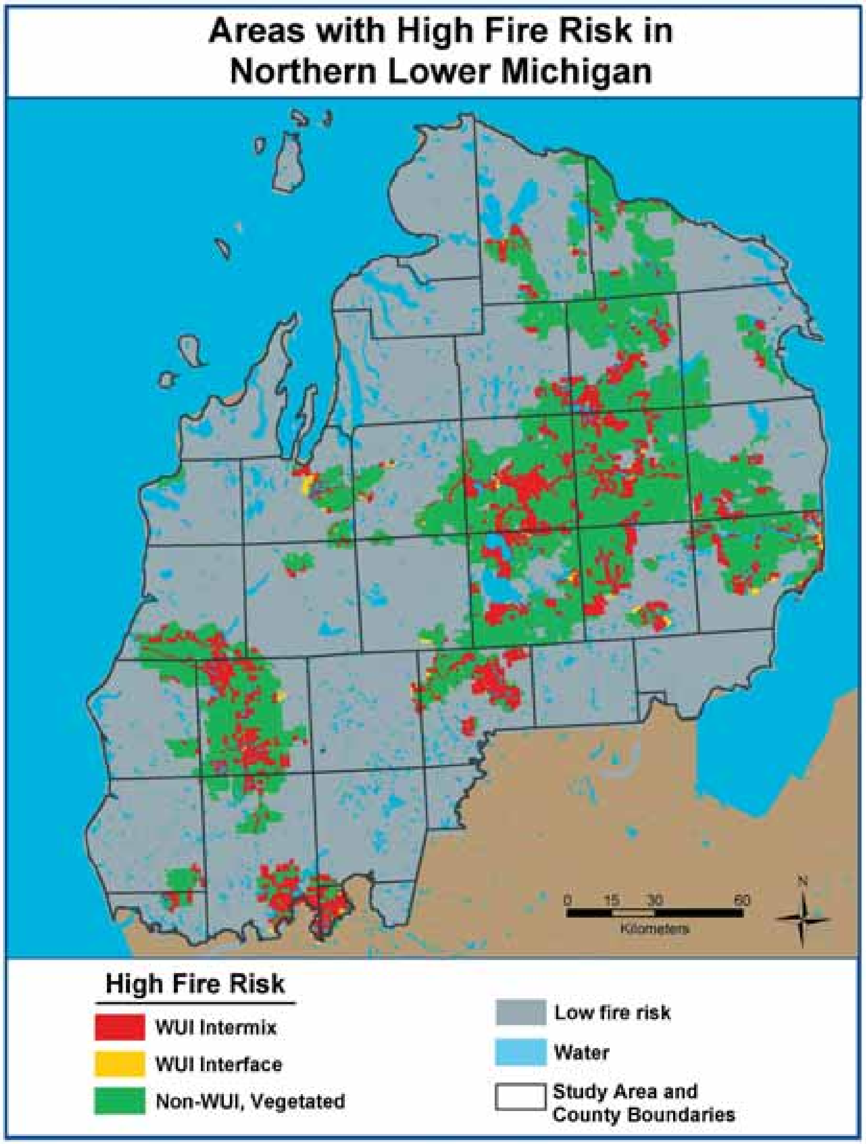

Figure 3. **Areas with relatively high risk of severe wildfires in northern lower Michigan.**

The short-rotation wetland class (FR3W) occurs within or adjacent to fire-prone landscapes, while the long-rotation wetland class occurs within fire-resistant hardwood forests.

The fire regimes are mapped using a spatial database of ecological units, called Landtype Associations, which are landscape-level mapping units in the National Hierarchy of Ecological Units (Cleland et al. 1997). Landtype Associations were originally mapped by the Michigan Natural Features Inventory based on differences in local landform, lake density, soil drainage, and soil texture (Corner et al. 1999). The map of Landtype Associations has approximately 850 polygons with median and maximum sizes of 2,023 and 148,000 ha, respectively. Each polygon is assigned a fire regime class based on elevation, landform, soil characteristics, and knowledge of historical vegetation (Cleland et al. 2004). Xeric classes (FR1 and FR2) dominated by jack pine and mixed pine types cover 22% of the study area, while the mesic class (FR4) dominated by northern hardwoods covers 42% of the study area (Table 2).

Cleland et al. (2004) calculated the historical fire rotation of each mapped fire regime class using locations and sizes of stand-replacing fires in northern lower Michigan in the early 1800s estimated from Public Land Survey records. The fire rotations of the two most fire prone classes (FR1 and FR2, jack pine and mixed pine forests) are 59 and 107 years, respectively (Table 2). The rotation of the most fire-resistant class (FR4, northern hardwood forests) is more than 10 times longer (1,385 years).

To see if the frequency and size of modern fires are related to the historical fire regime classes, we tabulate the number of small (<40 ha), medium (40–200 ha), and large (>200 ha) fires in each fire regime class using the Lake States Fire Database compiled by the USDA Forest Service and Departments of Natural Resources in Minnesota, Wisconsin, and Michigan (Table 2). The Lake States Fire Database includes the location, size, and cause of each fire occurring between 1985 and 2000. The total number of ignitions in all fire-size classes is disproportionately higher in the FR1 and FR2 categories, which have 37% of the ignitions but cover only 22% of the study area. Furthermore, FR1 and FR2 classes have disproportionately more medium and large fires. On average, 1.7 fires greater than 40 ha burns per year in the FR1 and FR2 classes, whereas only one fire greater than 40 ha burns per year in the other fire regime classes, which cover 78% of the study area. About 1.5% of ignitions in FR1 and FR2 classes are fires greater than 40 ha compared with 0.5% of the ignitions in the other categories. The modern fire frequency data suggest that FR1 and FR2 fire regime classes not only have the highest risk of ignition but also the highest risk of fires greater than 40 ha.

Current Vegetation

The map of historical fire regimes is based on elevation, landform, soils, and historical vegetation and represents our estimate of the location of different stand-replacing fire regimes across the landscape prior to European settlement. In addition to historical fire regime, another variable used to estimate fire risk is current composition and density of vegetative fuels. Mapping current fuels is important because areas within a given historical fire regime class may not be equally flammable due to conversion from forest to agricultural and urban uses.

We create a fuels map using the 32

Table 2. Attributes of stand-replacing fire regimes in northern lower Michigan.

Stand-replacing fire regime	Proportion of study area	Historical fire rotation (years)	Number of modern fires 1985-2000		
			<40 ha	40-200 ha	>200 ha
FR1 Extremely xeric ecosystems dominated by jack pine	0.10	59	943	4	5
FR2 Xeric ecosystems dominated by white and red pine	0.12	107	884	13	4
FR3 WWetland ecosystems adjacent to FR1 and FR2 areas	0.06	120	551	5	0
FR3 Dry-mesic ecosystems dominated by white pine and hemlock	0.19	473	1,155	8	0
FR4 Mesic ecosystems dominated by northern hardwoods	0.42	1,385	1,174	1	0
FR4 WWetland ecosystems adjacent to FR4 areas	0.11	684	326	1	0

Table 3. Land area, houses, and people in land classes with high and low levels of risk of stand-replacing fire in northern Lower Michigan.

Land class	Land area (ha)		Houses		People	
	Total	%	Total	%	Total	%
WUI[a]						
High fire risk[b]	277,200	25	79,303	24	94,895	19
Low fire risk	838,200	75	251,922	76	413,408	81
Total WUI	1,115,400	100	331,225	100	508,303	100
High-risk WUI						
Intermix						
High density[c]	300	0	2,702	3	1,921	2
Medium density	22,400	8	29,222	37	30,859	33
Low density	243,700	88	35,994	46	46,850	49
Interface						
High density	100	0	986	1	1,066	1
Medium density	4,000	2	9,313	12	11,708	12
Low density	6,700	2	1,086	1	2,491	3
Total high risk WUI	277,200	100	79,303	100	94,895	100

[a] *The WUI class includes all intermix or interface areas.*

[b] *Areas with high fire risk are the intersection of the two historical fire regime classes with the shortest rotations (FR1 and FR2) and current cover types with moderate and high flammability.*

[c] *Housing density classes (houses/ha): low (0.06-0.49), medium (0.49-7.41), high (>7.41).*

cover types obtained from the 1994 LandSat Thematic Mapper satellite imagery. We group the cover types into three classes based on flammability. The upland conifer type is the most flammable and includes jack pine, red pine, and white pine forests. The dry upland hardwood type is moderately flammable and includes oaks and northern hardwood forests growing in upland areas. The least flammable type includes lowland and moist hardwood forests, shrubland, wetland, and agricultural areas. Overlaying the map of fuel types with the map of historical fire regimes, we find that 80% of the area of the two fire regime classes with the shortest rotations (FR1 and FR2) is covered by forest types in the high or moderate flammability classes. In contrast, only 16% of the area of the very-long-rotation class (FR4) is covered by forest types with moderate or high flammability.

Fire Risk in the Wildland-Urban Interface

Land units with relatively high fire risk are identified by overlaying the maps of historical fire regimes and fuels. We assume that the intersection of areas of the two fire regime classes with the shortest rotations (FR1 and FR2) and cover types with moderate and high flammability have higher probabilities of stand-replacing fire relative to other land units.

Overlaying the map of land units with high fire risk with the map of the WUI, we identify areas inside and outside the WUI with high risk of stand-replacing fire (Figure 3). Within the WUI, 25% of the area has high fire risk (Table 3). The high-risk WUI includes 24% of the houses and 19% of the people. Because areas in the high-risk WUI have higher probabilities of experiencing stand-replacing wildfires, focusing finite resources for fire prevention and preparedness in high-risk WUI areas should result in greater damage reduction than spreading those resources across the entire WUI without regard to fire risk.

Almost all (88%) of the area of WUI with high fire risk is intermixed with low-housing density (less than 1 house per 2 ha) (Table 3). This low-density intermix area includes almost half the houses and people in the high-risk WUI. The dominance of intermix in the high-risk WUI suggests that fuel treatment around homes to reduce the likelihood of home ignition in the event of a wildfire will maximize expected damage reduction. Compared with communities with higher housing densities, low-density intermix areas include scattered houses without a clear line of demarcation between wildland fuels and houses, making it difficult for fire suppression crews to safely reach and protect every house during a fire. Intermix areas may also have fewer regulations aimed to reduce fire ignitions, such as restrictions on outdoor burning, resulting in a higher ignition potential. Finally, intermix areas may have fewer fire suppression resources. As a result, it is especially important in these low-density intermix areas to promote home structural characteristics and fuel conditions that reduce home ignition (Cohen 2000).

About half the houses and people in the high-risk WUI occur in medium and high housing-density classes (greater than 1 house per 2 ha) (Table 3). Some of these areas may require special planning for evacuation in the event of a wildfire. A measure of the safety of an evacuation is the length of time needed to clear a neighborhood, and two primary factors influencing this measure are the number of people requiring evacuation and the capacity of lanes leading out of a neighborhood in vehicles per minute (Church and Cova 2000). Areas of WUI with high fire risk combined with information about the transportation network and housing density can help identify neighborhoods that have potentially risky combinations of high population and low exit road capacity.

Conclusions

The WUI can be identified in a straightforward and consistent way with a classification of block-level housing density information from the 2000 US Census and vegetation cover types. Using definitions of interface and intermix areas that are consistent with a national WUI assessment, we find that the WUI covers 26% of our northern lower Michigan study area and contains about 70% of the houses and people.

Areas of WUI with relatively high risk of stand-replacing fire can be identified using knowledge of historical fire regimes and flammability of current vegetation. In northern lower Michigan, high-risk areas are xeric ecosystems that historically supported jack pine and mixed pine forests with stand-replacing fire rotations less than 100 years and currently support upland conifer and hardwood forests. We find that 25% of the area of WUI has high fire risk. Almost all of the high-risk WUI has low housing density (less than 1 house per 2 ha) and is classified as intermix where fuels and structures intermingle.

Determining the relative risk of severe wildfire and the houses and people at risk is the first step in an economic analysis of fire prevention and preparedness projects. The economic analysis requires the assignment of quantitative estimates of fire risk to historical fire regime classes. These estimates could be based on the frequency and size of fires observed in recent decades or models of fire behavior or occurrence. The analysis also requires quantitative estimates of the benefits and costs of different kinds of fire prevention and preparedness projects that are defined for intermix and interface areas with different housing densities. Information on fire risk together with project benefits and costs can then be used in an economic model to determine the locations and types of projects that maximize expected damage reduction under a limited budget. As researchers develop such models, a source of inspiration is the extensive literature on optimal siting of emergency service facilities and fire prevention projects in cities (e.g., ReVelle 1991).

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