Defining and Predicting Urban-Wildland Interface Zones Using a GIS-Based Model

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Abstract.—Resource managers are beginning to experience a deluge of management conflicts as urban population centers expand into formerly wildland settings. Fire suppression, recreational, watershed management, and traditional forest management practices are activities that have become contentious in many locales. A better understanding of the interface zone between these two types of land is important if managers are to successfully maintain the values of such lands. A pragmatic model for defining the urban-wildland interface for LeFlore County, Oklahoma, was developed, allowing identification of these transitional zones. Census data were used to obtain information on housing densities, population densities, and other social and cultural activities. LandSat MSS images provided a description of the current land cover and land use of the study area. Additional data (such as digital soil maps) were processed and added to the GIS structure. On-site ground truthing was also conducted.

THE URBAN-WILDLAND INTERFACE

Since the beginning of colonization of North America in the 17th century, communities have been created by clearing and developing wildlands. Every farm, town, and metropolitan area was originally carved from forested areas or other wild landscapes. Early settlers considered these undeveloped lands as either a barrier to be conquered or as a major source of raw materials for commodity production. Today, people often view these areas with different attitudes and motivations. The attraction of rural landscapes and the appeal of a home on a large lot often influence people to move beyond established cities. This has resulted in conflicts involving urban development and preservation or use of pre-existing wildlands.

The urban-wildland interface of today differs from earlier urban encroachment into wildland settings. In the early part of this century, great numbers of people left their farms and moved to cities as industrial jobs became available. After World War II, people in urban areas began to migrate back toward rural areas, creating vast suburbs around cities. By the late 1950's an "urban/rural fringe" surrounded many cities, with manufacturing enterprises and suburban development merging with rural communities. It has become increasingly important to properly manage the natural resources in the transitional zones between urban areas and areas traditionally considered wildlands; these zones are often referred to as urban-wildland interfaces.

These interfaces may be better understood by discussing the competing uses for urban fringe lands and the principal motivations of landowners. This also provides insight into the complexity of the problem and why the management of these areas is of interest to natural resource managers. Lee (1984) suggests that the interface can be characterized as an ecological condition in which human activities and artifacts interact with natural objects in a wildland ecosystem. This is illustrated by the urban-wildland interface fire hazard problem: the interface is characterized by the rapid transfer of heat from wildland fuels to fuels found in residential structures, or vice versa. Another adverse and significant problem involves the use of these areas for recreation: for example, the impact of all-terrain vehicles on the vegetation within these sensitive areas. Other potential problems occur when people move to these areas and bring along domestic animals that may impact the existing natural wildlife population.

The interface may be accurately delineated by distinguishing between its geographic, social, and ecological components. From the aesthetic perspective, the interface is a wide and sometimes nebulous boundary distinguished, for the most part, by the presence or absence of trees. From a jurisdictional perspective, the interface is sometimes thought of as either the boundary between public and private land or the point where parcel size begins to change from relatively small to relatively large lots. Where structures appear on the landscape, the interface

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may be defined by a line drawn between the built and non-built environment. Finally, using physical and biological growth criteria, the interface may resemble a soil map, where highly productive lands are distinguished from less productive lands. The union of all three components represents a situation in which values are assigned to particular linkages between human activities and natural ecosystems in an area where residential development is located within or near a forest (Chun 1996).

The interface between urban and rural settings represents a paradox with the urban and rural perspectives having some characteristics in common as well as points of conflict. Many city dwellers depend heavily on rural landscapes for recreational activities. Suburbanites or people living in the interfaces may argue that the presence of agricultural operations negatively influences their living space. For example, prescribed burning, a recognized forest and wildlife habitat management tool, has a strong negative connotation for many city dwellers. Urban noise,wildlife, domestic and farm odors, dust control, and concerns about non-point-source pollution and waste disposal are other issues. Thus, a tension zone is created between urban and rural settings. Resource managers are now beginning to experience a deluge of conflicts involving such practices as fire suppression, recreational overuse, watershed management, and traditional forest management. A better understanding of this urban-wildland interface is of utmost importance if managers are to successfully understand and maintain the values of these lands.

If natural resource managers are to be able to effectively manage urban-wildland interfaces, they must first need to be able to identify these zones. Numerous attributes such as vegetative cover, land use, housing density, housing location, population density, land ownership status, surface water features, topography, and other characteristics that could potentially affect the resources or the resource users must be considered. To accomplish such an undertaking, attributes must be referenced by a common denominator. One factor that each of these attributes has in common is a specific spatial location; therefore, they can all be referenced by their geographic location.

STRATEGY FOR DEVELOPING THE MODEL

A common and reasonable understanding of what is meant by the urban-wildland interface must include the development of a set of pertinent criteria that suggests an implicit and usable definition of the urban-wildland interface. However, the actual criteria may differ. A criterion is a category of conditions or processes by which the urban-wildland interface may be assessed. It is characterized by a set of related indicators that are monitored periodically to assess change. A factor is a measure of an aspect of the criterion. It is a quantitative or qualitative variable that can be measured or described and that, when observed periodically, demonstrates trends. No single criterion or factor defines the urban-wildland interface; they must be looked at as a set of interrelated characteristics within a social and environmental context. For this project it was proposed that urban-wildland interface be defined or characterized by a set of criteria and related factors. The criteria selected for this study were:

1. Physical and biological criteria define the interfaces in terms of what actually constitutes the zone. This refers not only to flora and fauna but also to physical factors such as soil types. Vegetation, taken as the composite of the whole assemblage of plants growing in an area, responds to physical environmental factors such as climate, soils, hydrology, and elevation. Therefore, natural vegetation provides a good summary of the physical properties of any location.

2. Jurisdictional criteria can view the interface as either the boundary between different land ownerships or whether the areas lie within the boundaries of minor civil divisions (such as town boundary limits). This includes both private and public ownership.

3. Economic criteria can be measured by looking at median income levels per household. Increased population and real personal income have been linked to urbanization of forested areas (Alig and Healy 1987).

4. Development criteria can be measured by the presence or absence of humanmade structures on the landscape. People often make use of wildland environments for their second homes and for cultural development. The importance and validity of this criterion is increasing as fire and recreation-related management problems arise because of this activity.

THE STUDY

The purpose of this project was to develop a pragmatic model for defining the urban-wildland interface through an identification and evaluation of potential data sources and variables representing land-use/land-cover, economic, and social factors. Several limitations concerning the overall scope of this project and specific data analyses were necessary. These required that the development and implementation of the model be restricted to one county in Oklahoma and that data would be obtained from information derived from census studies, satellite imagery, other digital data sources, and field work (Chun 1996).

The study area for this work was LeFlore County, located in the southeastern part of Oklahoma. The county includes 4,097 km^2 (1,582 square miles), mainly in the Arkansas River Valley and the Ouachita Mountains physiographic sections. Topography differences range from the nearly level floodplains of the Arkansas, Poteau, and Kiamichi Rivers to the steep mountainous areas in the southern part of the county. Many low ridges are adjacent to the rolling and undulating areas of the northern part of the county. The total population is 46,300 residents, and urban areas include Poteau (8,200 residents), Pocola (4,600), Heavener (2,800), Spiro (2,500) and Arkoma (2,300). Fort Smith, Arkansas (55,000) lies east just across the Oklahoma/Arkansas state line and has a significant economic and social impact on LeFlore County (Oklahoma Department of Commerce 1993). Historically, the region consisted of small subsistence farms with cotton and corn as the major crops. Recently, the trend in farming has moved towards livestock farming. Many of the upland areas are now pasture with cultivation limited to bottomland areas.

LeFlore County was chosen because it has a substantial economy based on natural resources. Many of the residents are part-time ranchers. Woodland industries use hardwood and pine timber, and several sawmills and charcoal plants operate in the southern part of the county. The county also includes part of the Ouachita National Forest and the Winding Stairs Mountain National Recreation and Wilderness Area.

DATA

The primary sources of data for this project were remotely sensed land-cover data combined with data from the US Census Bureau's TIGER/Line files. For the land-cover/land-use data layer, recent (March 1992) LandSat Multispectral Scanner images were obtained; use of MSS data was a constraint based on the available budget for the project. The images were registered to ground coordinates and classified to produce land-use/land-cover classes. Eight categories were created: urban, cropland, rangeland, pasture, pine, hardwood, wetlands, and water. Ground truthing was conducted, and the classification accuracy was considered satisfactory. Additional data included a file containing digitized soil maps, which was obtained from the Oklahoma State University Department of Geography.

Land-cover variables cannot reveal economic and social information. However, these data sets can be obtained using TIGER/line files. TIGER is an acronym for Topologically Integrated Geographic Encoding and Referencing system. It allows for the creation and maintenance of a digital GIS database using data from the 1990 Census. It provides complete coverage of the United States including line features such as roads and railroads, landmark features such as schools and churches, and polygon features such as census statistical data locations. Useful data included the median household income expressed as dollars per year per household and housing density measured in dwelling units per unit square kilometer (DU/km^2).

To express housing density (dwelling units per area), the simple computation of dividing the number of dwelling units per census group block by the area of the census group block was done. Housing density is used to measure urban development encroachment into the wildland areas. As one moves from an urban center, the number of dwelling units per acre decreases and one expects that in ideal wildland areas no dwellings would be present. For this project a conservative figure of 1 to 20 dwelling units per square kilometer was initially used to identify the urban-wildland interface zone. This range is appropriate and reflects the low population of the county.

Median household income was used to measure the economic activity of landowners. It has been hypothesized that with higher income, one's interest in the environment becomes more varied. In certain cases this can be focused on the value of the land as a means of making a livelihood, while in others it may be focused on the concerns for the environment (Smith 1994).

PC ARC/INFO, a popular GIS development package, was used to overlay the data layers and create the database using polygon and line topology. PC ARC/INFO stores its data files in dBase format; this is useful for complete integration of data from other sources such as the TIGER/Line files. Additionally, this package allows for easy updating of both spatial and attribute information.

RESULTS

LeFlore County

The data coverages were imported into ArcView, a powerful GIS end-user package. This software provided the means to visualize, explore, and analyze the database spatially. ArcView also allowed the building of very sophisticated queries to identify specific data combinations. Boolean operators such as "and," "or," "less than," "greater than," and "equal to" were used in the design of queries.

The query tool in ArcView allows an analyst to select features and records in a table that relates to the attributes values. Using this tool, the following query was built. An area is considered to be an urban-wildland interface if the following set of criteria is met: areas are outside town boundary limits; land cover is "rangeland" or "pasture" or "pine" or "hardwood"; housing density is greater than or equal to 1 but less than or equal to 15 DU/km^2; median household income is greater than or equal to $6,000 but less than or equal to $12,000 per household per annum. This is Criteria #1 and can be expressed by the following:

((([Leftowns] = 16) or ([Leftowns] = 0) and
(([class] = "rangeland") or ([class] = "pasture") or
([class] = "pine") or ([class] = "hardwood")) and
(([Housing density] >= 1) and ([Housing density] <= 15) and
([Median household income] >= $6,000) and ([Median household income] <= $12,000))).

Different sets of attributes or numerical values that lie within the range of the values found in the database were used in the construction of other queries. This feature of ArcView made it useful in exploring the outcome of other predictions by altering the values. It is one of a large number of possible combinations resulting from changing the values of the attributes. For this study, six sets of criteria or scenarios were chosen (table 1).

Criteria #1, previously outlined, results in a potential urban-wildland interface area totaling 38,498 ha (95,129 acres). Criteria #2 modifies the first criteria to show a range of the housing density of 1-20 DU/km^2 and a median household income of $10,000-$20,000. The resulting interface has an area of 35,327 ha (87,291 acres).

The predicted interface zones can be illustrated with graphic output. The interface zone predicted by Criteria #1 is concentrated on the western border of the county (fig. 1). Criteria #2 is similar to the first criteria except that additional interface zones now extend from the concentration on the western border in a northeasterly direction, following a major highway (fig. 2). Graphic output was generated for each of the other four criteria. This allowed comparisons of predicted interface locations.

Criteria #3 explores the effect of median household income in the high range values (for LeFlore County) of $20,000 to $32,000 along with a low housing density range of 1-15 DU/km^2. The predicted interface is found to be concentrated around the edges of the major towns in the northern section of the county. The area of the interface defined by this prediction is 63,813 ha (157,681 acres). Mechanized agriculture is the dominant activity in this region, and this is reflected in the high median household income values. Potential conflicts are likely to occur when such activities are present. Wildland encroachment for farm expansion and effects of farming activities (poultry and hog production) can have undesirable impacts on water quality in the surrounding areas.

In an attempt to evaluate the prediction capability of the housing density, the median household income variable was left out of the query used in the construction of Criteria #4. The result shows a large predicted interface with an area of 89,443 ha (221,011 acres), concentrated in the northern and western sections of the county. Not surprisingly, the areas follow major roads and occur adjacent to towns in areas of high agricultural activities. The predicted area is similar to that predicted by Criteria #3. This is expected as the numerical values of the variables in Criteria #4 are captured in Criteria #3.

Table 1.—*Summary of six different combinations of attribute values used to define potential urban-wildland interface zones*

Criteria number	Outside of town limits	Land cover class	Housing density	Median household income
			#/km²	
1	yes	pine, hardwood, pasture, rangeland	1 - 15	$6000 - $12,000
2	yes	pine, hardwood, pasture, rangeland	1 - 20	$10,000 - $20,000
3	yes	pine, hardwood, pasture, rangeland	1 - 15	$20,000 - $32,000
4	yes	pine, hardwood, pasture, rangeland	1 - 10	not used
5	yes	pine, hardwood, pasture, rangeland	not used	$6000 - $18,000
6	yes	pine, hardwood, pasture, rangeland	1 - 10	$6000 - $18,000

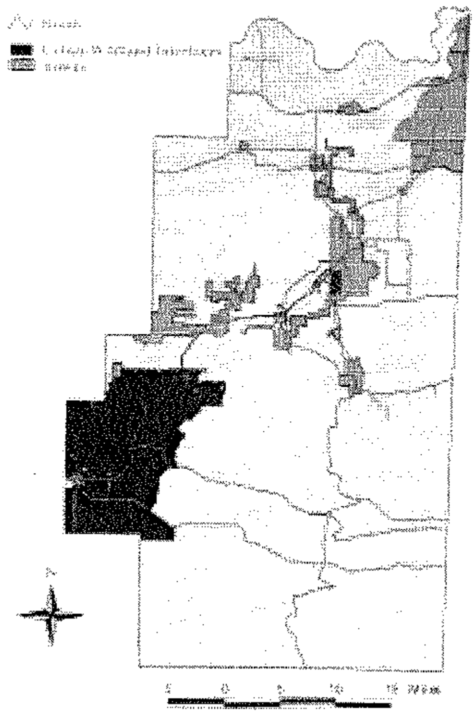

Figure 1.—*Map of LeFlore County, Oklahoma, showing the urban-wildland interface locations, as predicted by Criteria #1, overlaid with thematic map of town boundaries.*

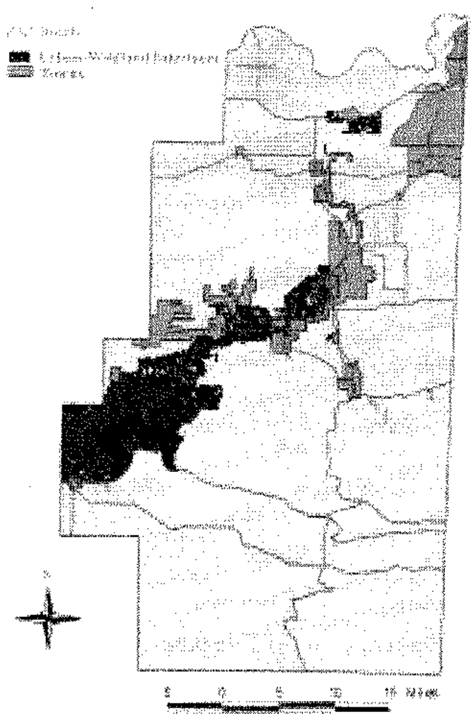

Figure 2.—*Map of LeFlore County, Oklahoma, showing the urban-wildland interface locations, as predicted by Criteria #2, overlaid with thematic map of town boundaries.*

A similar query (Criteria #5) was built for the median household income, leaving out the housing density variable. The result shows the predicted interface to be concentrated in the middle part of the county. The area predicted by Criteria #5 is 91,495 ha (226,083 acres).

Finally, Criteria #6 was built to include lower range values for both the housing density and the median household income; the values are 1-10 DU/km^2 and \$6,000 to \$18,000, respectively. The predicted interface has a total area of 37,595 ha (92,896 acres), closely matching that predicted by Criteria #1 and #2. However, the area defined by Criteria #6 is much more highly fragmented.

For all six criteria used, the southern portion of the county showed no area as potential urban-wildland interface. This region has a very low human population and very low economic activity, and a large percentage of the area is part of the Ouachita National Forest. The consistency of five of the six criteria in predicting the area in the vicinity of the town of Talihina was also noteworthy. Perhaps, there are merits in looking more closely at this location in a future study.

Procedure for Defining the Urban-Wildland Interface

The purpose of this study was to develop a model for defining the urban-wildland interface. The model resulted in a step-by-step procedure that is simple, concise, and iterative. This procedure includes steps involving data acquisition, preparation, analysis, and output:

Data Acquisition

1. Remotely sensed digital data are important sources of land-use/land-cover information. These data are available in several formats such as LandSat MSS, LandSat TM, and SPOT. Data from this source must be registered to a predetermined coordinate system such as the Universal Transverse Mercator (UTM). Registration allows for spatial analysis of real world geography. Extraction of useful information is done by analysis of the properties of the raster or vector values using computer algorithms available in GIS software packages.

2. The Housing and Population files found in the US Census Bureau's TIGER/Line files can provide data for the median household income and the housing density. These files also contain digital data depicting town boundaries and roads.

Data Preparation

1. Remotely sensed data can be classified into land-cover types using supervised and unsupervised

techniques. Results should be ground truthed to ensure classification accuracy is acceptable.

2. The data in the TIGER/Line files are stored in digital format and, using Arc and Arc Plot software, can be transformed into lines and polygons. Using Arc/Info, topology can be created from the lines and polygons, simultaneously building Arc Attribute Table and Polygon Attribute Tables. These tables can then be later joined with the polygons for the land cover-types within Arc/Info. This results in the required database.

Data Analyses

1. The database can then be imported into ArcView, where data manipulation, construction of queries, and visual display of the result of the queries may be performed. Query construction is facilitated using several query building tools available in ArcView. Building queries is constrained only by the numerical values of the fields within the database and the number of records contained in it. For example, the following query can be constructed:

((([Leftowns] = 16) or ([Leftowns] = 0) and
(([class] = "rangeland") or ([class] = "pasture") or
([class] = "pine") or ([class] = "hardwood")) and
(([Housing density] >= 1) and ([Housing density] <= 15) and
([Median household income] >= $6,000) and ([Median household income] <= $12,000))).

2. The versatility of ArcView enables an analyst to alter the numerical values within the range provided for selected variables or to eliminate certain variables when building the queries. The example below illustrates several altered values (shown in bold):

((([Leftowns] = 16) or ([Leftowns] = 0) and
(([class] = "rangeland") or ([class] = "pasture") or
([class] = "pine") or ([class] = "hardwood")) and
(([Housing density] >= 1) and ([Housing density] <= **20**) and
([Median household income] >= **$12,000**) and ([Median household income] <= **$24,000**))).

Data Output

1. The visual display on the computer monitor can be used to make high quality maps by using the Layout feature of ArcView. Layout allows one to control the appearance of the finished product. Hard copies in the form of transparencies and maps can be obtained by using a color printer such as Hewlett Packard XL300 PaintJet printer.

2. Results pertaining to the areas of the urban-wildland interface can also be presented in tabular format and statistical parameters such as means, standard deviations, summations, and ranges are easily obtained using the Statistical function in ArcView. The selected records for each query determine the predicted area, which can be converted to a shape file and added as a separate theme in another View or exported as a theme to another vector-based GIS package.

CONCLUSIONS

The model developed in this study has the potential to provide valuable information to forest managers, county officials responsible for land-use policies, and city planners in LeFlore County. Relevant data were acquired and created from existing sources, sorted and evaluated, and entered as coverages (layers of information) into a computer format. The database was designed using a popular and easily accessible GIS package: PC ARC/INFO. This package allows the input, manipulation, and easy display of data. Using ArcView, an end-user GIS display software that is compatible with PC ARC/INFO, queries were built and likely interface zones visually displayed. A number of queries relating to these coverages were designed which would identify an area as being an urban-wildland interface. This proved the versatility and usefulness of the model.

One of the objectives of this study was to evaluate the variables that can be used in developing the set of procedures. This resulted in using four layers: housing density, median household income, town boundary limits, and land-cover types. Areas are considered as potential interface zones if they occur outside of town boundaries and satisfy required values for land cover, household income, and housing density.

Another objective was to evaluate the potential application of the model to other counties or regions in the southeastern United States. For areas near LeFlore County, application of this process would seem to be feasible and permissible. For other regions, however, physical land-cover differences and different patterns of socioeconomic activities may dictate that a different set of variables needs to be used. This may be a different number of variables or different types of variables.

Problems associated with the urban-wildland interface zones are major issues in natural resources management. The interfaces are zones where social, economic, and political factors interact in complex ways. Problems are often social and institutional rather than technical. The need for better tools to handle ever more critical natural resource problems is obvious, and the rapidly developing field of information technology provides the necessary machinery. GIS is a very powerful tool for analyzing vast amounts of spatial data that can aid in developing an understanding of the importance of the variables that define the interface zone. However, the limitations of GIS must be carefully considered when using the results produced from this approach for decisionmaking. More elaboration and analysis of the social aspects as related to the inhabitants of these zones needs to carried out. As they begin to understand the values, preferences, and attitudes of new residents, resource managers will be better able to demonstrate their role and responsibilities in issues relating to the interface zones.

ACKNOWLEDGMENTS

The following people reviewed this manuscript: Roger Williams, Assistant Professor of Forestry, The Ohio State University; Columbus, OH, USA, and Tom Hennessey, Professor of Forestry, Oklahoma State University, Stillwater, OK, USA.

LITERATURE CITED

Alig, R.J.; Healy, R.G. 1987. Urban and built-up land area changes in the United States: an empirical investigation of determinants. Land Economics. 63(3): 215-226.

Chun, A.V. 1996. Development of a model for defining and predicting the urban-wildland interface for LeFlore County, Oklahoma. Stillwater, OK: Oklahoma State University. 93 p. M.S. thesis.

Lee, R. 1984. Implication of contemporary community organization and social values for forest management on the residential/wildland interface. In: Bradley, ed. Landuse and forest resources in a changing environment: the urban/forest interface. Seattle, WA: University of Washington Press. 222 p.

Oklahoma Department of Commerce. 1993. Statistical abstracts of Oklahoma. Oklahoma City, OK. 278 p.

Smith, Z.A. 1994. The environmental policy paradox. Englewood Cliffs, NJ: Prentice Hall. 255 p.