MAPPING THE BUILT ENVIRONMENT – FIRE INTERFACE ACROSS THE MID-ATLANTIC REGION, USA

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ABSTRACT

As the extent and density of the built environment, particularly residential areas, has increased around urban areas, it has been widely recognized that more structures and lives are at risk of wild fire. In the eastern United States this has not received as much attention as in the more fire-prone west, but a number of recent drought years and fire events in the East have brought the issue into the public and policy arena. We have developed maps of the built environment across the entire 168,000 km^2 Chesapeake Bay watershed using Landsat Thematic Mapper (TM) imagery and decision tree algorithms. This approach provides highly accurate maps of impervious cover, our surrogate for the built environment, but also permits estimation of the proportion of each cell occupied by impervious cover (between 0-100%). While the above maps allow for the assessment of current and past conditions, we have also developed forecasts of urbanization for the Washington, DC-Baltimore region and for the state of Maryland. Under some future scenarios, expansion of developed land into rural, predominantly forested areas is significant. Using these maps, it is a straightforward matter to calculate and map the areas where the built environment is adjacent to forested areas and to identify areas of urban expansion into forested areas. A distance buffer around forested areas can identify the developed areas at risk for possible wildfire events. We are currently expanding the modeling work to produce forecasts of future urbanization across the Chesapeake Bay watershed, which will allow for vulnerability assessments over a much broader region. We will report on these recently developed maps in this region of rapid land use change, with an emphasis on the current and future potential for fire damage to residential areas in Maryland.

1. MAPPING THE BUILT ENVIRONMENT

Satellite mapping focused specifically on urban areas has progressed rapidly (see review by Tatem and Hay 2004). Maps of the built environment are required for a variety of resource management applications, and have relevance to fire threat and vulnerability assessments at the urban-forestland interface. We created built environment maps for 1990 and 2000, using over 100 multi-temporal Landsat-5 TM and Landsat-7 ETM+ scenes. Extensive pre-processing of the Landsat scenes was conducted to address radiometric variation, as well as removal of clouds, cloud shadows, topographic distortion and illumination variations. Geometric orthorectification was performed to achieve the locational precision necessary for change detection work (Goetz et al. 2004). A vector planimetric database of Montgomery County, MD, which consisted of hand delineated polygons of impervious surfaces (roofs, streets, sidewalks, etc.) as interpreted from aerial photographs, provided training data used to develop the regression tree algorithms to map the built environment at subpixel resolution using the satellite imagery. By rasterizing or "gridding" the vector planimetric data, a 3-meter resolution coverage was derived. The number of 3-meter cells within each overlying Landsat 30-meter cell was then enumerated to produce a 30-meter image of continuous subpixel impervious surface, or built environment, values ranging from 0 to 100%. Using this subpixel impervious surface training data set, regression tree algorithms were developed and cross-validated, incorporating combinations of image variables as input, until robust trees were developed that would accurately classify the Landsat images according to the development intensity within each pixel. A diverse set of rules was employed to constrain the tree size and complexity. The resulting maps represent a continuum of developed areas derived from the Landsat imagery, where each cell provides subpixel information on the proportion of the 900 m^2 that is occupied by human built land cover features.

The built environment maps were validated using two sets of high-resolution digital orthophoto quarter quadrangles (DOQQs). The 1990 impervious surface reference data consisted of sixty-four 0.3 km^2 DOQQs with a cumulative area of 19.2 km^2 distributed over 6,030 km^2 of the Piedmont physiographic province near Washington, DC. The extent of impervious surfaces in the DOQQs was visually identified and manually digitized, and the type of impervious cover was also noted (e.g. roof, street, sidewalk, parking lot, etc.). The resulting vector file was then converted to a three-meter raster. In order to make a direct comparison between these high-resolution maps of impervious surfaces and the estimates of subpixel built environment cover derived from Landsat imagery, the 3-meter cells were summed within overlying 30-meter cells to create a 30-meter continuous image of the percentage of built environment. The 2000 map validation data consisted of twelve 5.9 km^2 interpreted DOQQs with a cumulative area of 70.8 km^2 spread across 54,264 km^2 of the central and northern portions of the watershed, provided by the NLCD (Yang and others 2003b). While the 1990 reference data set provided additional information regarding the type of surfaces, the 2000 data set represents only the extent of built environment features (Jantz et al. 2005).

As a result of the attention to consistency across the image data sets, as well as the quality of the training data and the classification methodology used to create the built environment maps, they were in good agreement with the validation data sets. Overall spatial agreement between the 1990 built environment map and the DOQQs was 79%. Spatial agreement for the 2000 map with the relevant DOQQs was higher, at 83%. Comparisons between mapped and DOQQ estimates of subpixel (continuous) values produced a correlation of 0.61 for 1990 and 0.68 for 2000. Large omission errors in the 1990 built environment map, where the aerial photo measured 70-100% impervious cover and the Landsat-based map measured 0%, made up 12% of total omission errors. Sixty-nine percent of those 12% occurred in areas defined as transitional (recently cleared or disturbed areas) in the DOQQs, suggesting they may have been developed by the time the satellite imagery was acquired.

These built environment surface maps provide unique information relevant to a range of applications, including assessments of vulnerability to fire. Using these map data products, a number of assessments were conducted, including quantifying the rate of changes in the built environment, calibrating a model of future urbanization, and assessing developed areas at risk of fire.

2. CHANGES IN THE BUILT ENVIRONMENT 1990 – 2000

The built environment maps have utility for tracking land use change associated with urbanization, including low density residential development. We have used the circa 1990 and 2000 built environment maps to provide metrics of the location and amount of change that has occurred across the entire 168,000 km^2 Chesapeake Bay watershed. The change map for the study area consisted of impervious surface pixels representing previously undeveloped areas that had experienced a 20% or more increase in impervious surface area between 1990 and 2000 (Figure 1). Within the watershed, development increased 62%, from 5,177 km^2 in 1990 to 8,363 km^2 in 2000.

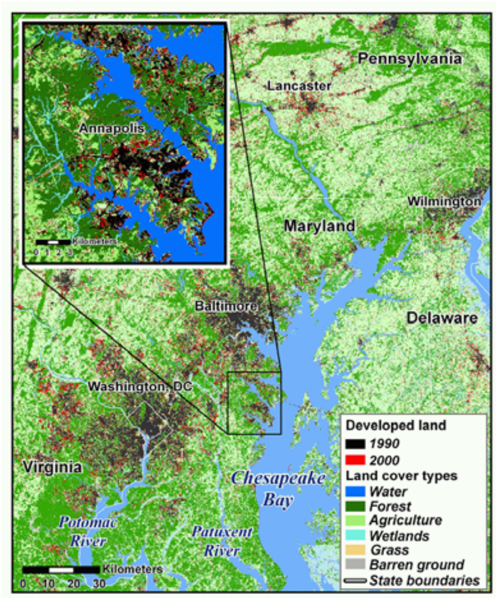

Figure 1: Changes in the built environment between 1990 and 2000 in the Washington, DC – Baltimore, MD region.

3. PREDICTIVE MODELING OF FUTURE URBANIZATION

Predictions of future land use are important for a number of applications, including the vulnerability of developed lands to fire. Cellular automaton models (e.g., O'Sullivan, 2001) are pattern-based mechanistic models that offer some insight into the constraints (e.g., topography) and 'drivers' (e.g., road building) of the development process. We have explored the applicability of the SLEUTH (slope, land use, exclusion, urban extent, transportation, hillshade) model (Clark et al., 1997) to simulate patterns of urban change in an area comprising about 15% of the

Chesapeake Bay Watershed, although we are currently working towards Bay-wide modeling. SLEUTH simulates urban dynamics through the application of four growth types: spontaneous new growth, which simulates the random urbanization of land; new spreading center growth, or the establishment of new urban centers; edge growth; and road influenced growth.

The model was calibrated to simulate urban development patterns using the time series of built environment maps described above. During calibration, a set of growth parameters were derived that maximized the model's ability to match the rate of growth, but which also performed well in terms of spatial fit. Calibrated model predictions of spatial patterns across the time period 1986 to 2000 were able to nearly exactly match the observed patterns (93% overall accuracy) and successfully simulate the historic rate of development (Jantz et al. 2003, 2005). Future urban extent maps for the state of Maryland, predicted out to 2030 under various land protection scenarios, were useful for visualizing and exploring potential development, as well as for assessing vulnerability to fire.

4. FIRE VULNERABILITY ASSESSMENT

We provide a straightforward example of how the above map products can be used to assess current and future fire vulnerability at the urban-forestland interface in the state of Maryland. A Landsat-derived sub-pixel tree cover map was used to identify forested areas in 2000 (Goetz et al. 2004). In this case, we defined pixels as forest if the subpixel tree cover value was at least 50%. To create a map of the potential forested extent in 2030, we used a SLEUTH forecast of urbanization to identify areas that would be deforested due to development. We were not able to consider forest regeneration between 2000 and 2030. We then generated a 60-meter buffer around both current and predicted forested areas of Maryland, and identified urban land that occurred within this buffer (Figure 2).

We found that in 2000 a total of 30% (7,508 km^2) of the land in the state of Maryland was within 60 meters of forested areas. Of this land within the buffer, 11% (818 km^2) was developed in 2000. This indicates that 17% of the 4871 km^2 of developed land in the state is potentially vulnerable to wildfires that could occur in the adjacent forest patches. Developed areas at an even higher risk, those with in 30 meters of forested areas, made up 8% (370 km^2) of the total developed land in Maryland.

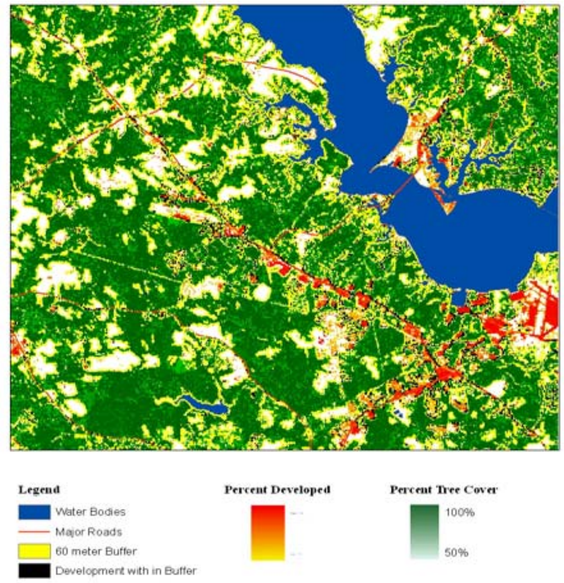

Figure 2. West Bank of the Patuxent River (St. Marys County, MD) in 2000 displaying 60 meter buffers around forested areas and urban areas within and adjacent to buffers.

In 2030, 15% (937 km^2) of the area within 60 meters of forested areas would be developed. The total increase of developed land potentially vulnerable to wildfires was 119 km^2. However it is important to note that the area of the buffers actually decreased by 17% due to the loss of forestland to development. Because we were not able to consider forest regeneration, this is likely an underestimation of the urban-forestland interface of 2030.

In future work we hope to incorporate forest cover types and forest fire probability maps in order to further refine our assessment of developed areas' vulnerability to wildfire. In addition, it would be useful to quantify a method of determining fire threat as a function of forest density and type as well as distance from forested areas. Incorporating these additional methods into our fire vulnerability assessment would produce an even more refined picture of those areas likely to be threatened by wildfires today and in the future.

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6. BIOGRAPHIES

Dr. Scott Goetz works on the application of satellite imagery to analyses of environmental change, including monitoring and modeling links between land use change of various types (e.g., urbanization, fire disturbance), the loss of resource lands, impacts on biodiversity, and changes in forest productivity. Before joining the Woods Hole Research Center in 2003 he was on the Faculty at the University of Maryland College Park for 7 years, where he maintains an adjunct associate professor appointment. He was a research scientist at the NASA Goddard Space Flight Center from 1985 to 1995. He has authored, to date, approximately 50 refereed journal publications and book chapters, and recently edited a special issue on advances in biophysical remote sensing. He serves on the editorial board of *Remote Sensing of Environment*. He graduated from the Pennsylvania State University (BS), the University of California (MS), and the University of Maryland (PhD).

Dr. Claire Jantz is a geographer who uses geographic information systems (GIS) to study land-use change, particularly patterns of urbanization and deforestation in the mid-Atlantic region. She is also interested in the process of land-use policy development and uses modeling techniques to link policies to patterns of land-use change. She has received degrees from the University of Tennessee (BA) and the University of Maryland (MA, PhD).

Jules Opton-Himmel

Mr. Opton-Himmel is an intern studying land use change issues at the Woods Hole Research Center. Prior to joining the Center he worked for the New England Forestry Foundation and as a Biological Field Technician for The University of Washington. He earned his Bachelors degree in Earth and Environmental Science from Wesleyan University and will begin a master's program at The Yale School of Forestry and Environmental Studies in the Fall.