RESOURCE LAND LOSS AND FOREST VULNERABILITY IN THE CHESAPEAKE BAY WATERSHED[1]

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ABSTRACT

The contemporary pattern of urban development in industrialized countries is increasingly taking the form of low density, decentralized residential and commercial development. In the Chesapeake Bay watershed, which is located within the mid-Atlantic region of the United States, dispersed development patterns have been linked to habitat fragmentation and declining water quality. Our objectives were to document how this urbanization process has expanded throughout the watershed and to explore how lands comprising the natural resource base, particularly forests, have been replaced by a matrix of the built environment. We accomplished this by mapping impervious surface cover (houses, roads, etc.) across the ~168,000 km^2 area using a time series of satellite imagery. We calculated metrics of land use change and used these to estimate the loss of resource lands across the region. We conservatively estimate that 334 km^2 of forest, 888 km^2 of agriculture and 2 km^2 of wetlands have been converted to impervious surfaces between 1990 and 2000. We also used the time series to calibrate a spatial model of urban land use change, and forecasted future development patterns in Maryland out to 2030 under different policy scenarios. Using Maryland Department of Natural Resources' (DNR) Strategic Forest Lands Assessment (SFLA), which evaluates forest resources in terms of their economic and ecologic value, and Maryland's Green Infrastructure, which identifies ecologically valuable patches of contiguous forests and wetlands, we evaluated the vulnerability of natural resources in Maryland. Threats, associated with loss and fragmentation, were identified.

KEYWORDS. urban sprawl, forest vulnerability, forest fragmentation, resource land loss, Chesapeake Bay, mid-Atlantic, Maryland

INTRODUCTION

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[1] In Bettinger, P. C. Hyldahl, S. D. Danskin, J. Zhu, Y. Zhang, W. G. Hubbard, T. Lowe, M. Wimberly, and B. Jackson, eds. 2005. Proceedings of the 4th Southern Forestry and Natural Resources GIS Conference, December 16-17, 2004, Athens, GA, pp. 84-95. Warnell School of Forest Resources, University of Georgia, Athens, GA.

The Chesapeake Bay estuary is a unique and complex ecosystem. An ephemeral feature over geologic time scales, the estuary began to fill roughly 10,000 years ago when rising sea level reached the current mouth of the Bay. The present day extent of the shallow estuary was reached roughly 3,000 years ago, when the lower Susquehanna and James rivers were submerged. While the Bay maintains an open connection with the Atlantic Ocean at its mouth, it is continually flushed with fresh water and sediments from the discharge of over one hundred rivers and thousands of tributary streams (Schubel, 1986). The resulting nutrient-rich environment has created a biological ecosystem that is highly productive. The primary productivity of estuaries is roughly five times greater than the average for the oceans; the fish production in the Chesapeake Bay is one hundred times greater than the oceans. In economic terms, the seafood-landings are valued in the tens of millions of dollars. When all bay-related economic activity is considered, including seafood landings, tourism and recreation, the Bay's total economic worth is in the hundreds of billions (Horton, 2003). The biological richness and ecosystem services provided by the estuary are invaluable.

The watershed of the Bay is large (Figure 1), encompassing 168,000 km^2 and including parts of the states of New York, Pennsylvania, West Virginia, Maryland, Delaware and Virginia and all of the District of Columbia. It is therefore greatly influenced by human activity on the land. Water quality in the Bay has suffered due to increases in the discharges of sewage, agricultural fertilizers, and animal wastes, and through deforestation and land development (Horton, 2003). The coastal watersheds in the mid-Atlantic are among the most highly developed in the United States (Beach, 2002) and the declines in the water quality and aquatic ecosystems of the Chesapeake Bay estuary are related to the high levels of impervious surfaces within its watershed. Impervious surfaces, including asphalt, concrete and other hard surfaces that water cannot permeate, can have deleterious effects on the hydrological functioning of a watershed and contribute to increasing levels of nitrogen, phosphorous, sediments and other pollutants (Arnold et al., 1996; Goetz et al., 2003).

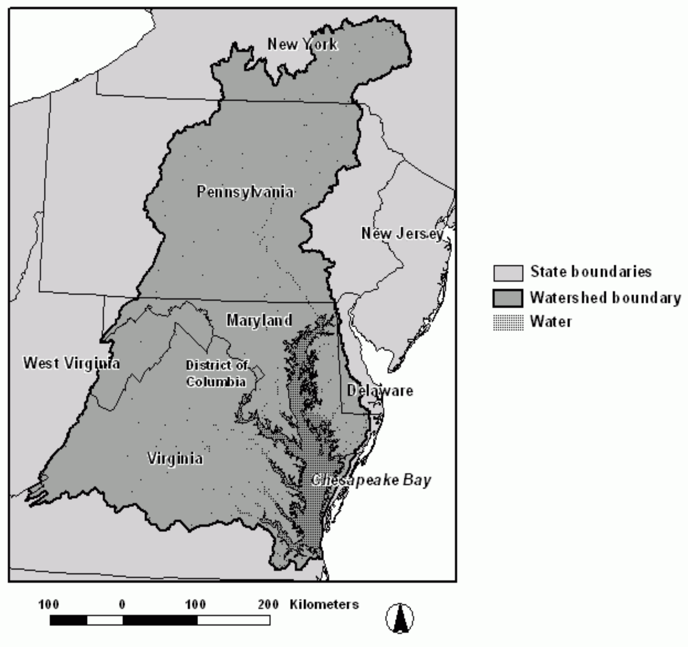

Figure 1. The Chesapeake Bay watershed

Regional restoration activities in the watershed have been coordinated by the Chesapeake Bay Program, a multi-jurisdictional partnership that was formalized in the early 1980s when the first Chesapeake Bay Agreement was signed by the governors of Maryland, Virginia and Pennsylvania, the mayor of the District of Columbia, the administrator of the Environmental Protection Agency, and the chair of the Chesapeake Bay Commission, a legislative advisory group made up of policy makers representing the signatory states (Ernst, 2003). The original Bay agreement outlined goals to restore the Bay's water quality and living resources, and also laid the institutional framework for Bay restoration. The most recent agreement, Chesapeake 2000, addresses water quality, habitat restoration, fisheries management, sound land use, and community engagement (Chesapeake Bay Program, 2000). The Bay Program efforts have become increasingly sophisticated, utilizing tools to monitor and model atmospheric deposition, land use change, and water quality.

One of the principal successes of the Bay Program has been the reduction of point sources of pollution by initially targeting municipal wastewater sources and with a more recent focus on industrial agriculture and animal farming activities. Another primary input of nutrient pollution comes from non-point sources that are closely linked to human activities distributed across the landscape. The gains that have been made through pollution reduction efforts to date have largely been offset by changes in land use. Much of our work has focused on providing the land use and land cover data sets that are necessary to better address these issues, and to research their utility for land use and land cover change analyses and vulnerability assessments.

We have recently completed a Bay-wide analysis to estimate the loss of resource lands (forests, agriculture and wetlands) due to development that occurred between 1990 and 2000 (Jantz et al., forthcoming). We have also worked extensively with an urban land use change model, SLEUTH (Clarke et al., 1997, U.S. Geological Survey, 2004), and have created forecasts of development out to 2030 in the Washington, DC-Baltimore metropolitan area (Jantz et al., 2004) and for the state of Maryland. For Maryland, we developed GIS-based methods to use the forecast data for vulnerability analyses of forest resources.

METHODS

Resource Land Loss 1990-2000

In order to estimate forest, agricultural and wetland loss, we used a combination of map products. The extent of forest, agriculture and wetlands in 1990 was estimated using areas of agreement between the U.S. Geological Survey's Multi-resolution Land Characterization (MRLC) (Vogelmann et al., 1998) and a land cover map produced by the Mid-Atlantic Regional Earth Science Application Center (MA-RESAC) (Varlyguin et al., 2001). Both maps represent circa 1990 land cover at an intermediate scale (30 meter resolution) and both were derived from Landsat satellite imagery, although different classification methods were used in each case. The MRLC map was produced using an unsupervised maximum likelihood clustering algorithm, while the MA-RESAC map was derived using a supervised decision tree classifier. Using two independently produced maps ensured a robust, albeit conservative, estimate of the extent of forest, agriculture, and wetlands in 1990.

Impervious surface extent for 1990 and 2000 were derived from impervious surface maps produced by the MA-RESAC (Goetz et al., 2004). These maps were also derived from Landsat satellite imagery using a regression tree classifier and represent the percentage of impervious surface within each 30 x 30 meter pixel. Using these two impervious surface maps, we identified areas that had undergone development between 1990 and 2000. These areas of change were then compared to the 1990 map of resource lands to identify what lands had been converted to impervious surfaces. For a complete description of this analysis, including accuracy assessments of the land cover and impervious surface maps (Jantz et al., forthcoming).

Forest Vulnerability in Maryland

Central Maryland contains a highly urbanized corridor that stretches from Washington, DC to Baltimore, MD. Residential development for these urban centers is sprawling into rural counties in western and eastern portions of the state, and second home development is also becoming more prevalent in rural areas with natural amenities (Weber, 2001). We applied the SLEUTH urban growth model to the state of Maryland assuming three different policy scenarios and evaluated the impact of development on forest resources.

SLEUTH is a cellular automata (CA) model, so space is represented as a regular grid of cells that can change state (i.e. become urbanized) as the model iterates. A state change can be initiated when a set of neighborhood conditions are met, the conditions of which are defined by conceptually simple transition rules, or growth rules. SLEUTH has four growth rules, each of which represents an aspect of the urban development process, that are calibrated to match the urban growth patterns in the study area. The spontaneous new growth rule randomly selects single cells across the landscape for potential urbanization and can simulate dispersed development patterns. New spreading center growth occurs when a cluster of cells becomes urbanized, which can then spawn urban growth into adjacent areas. Edge growth creates new urbanized cells adjacent to existing urban clusters, and road influenced growth simulates the attraction of roads for development. Resistance to development is modeled through a slope layer, which accounts for the influence of topography on development patterns, and a user-defined excluded layer, which delineates areas that are wholly excluded (i.e. water and protected parks) or partially excluded (i.e. zoning) from development.

Previously, we calibrated SLEUTH to simulate patterns of urban development in the Washington, DC-Baltimore region. Using the calibration coefficients we derived for this area, we created forecasts of urban development for the state of Maryland out to 2030 assuming three different policy scenarios:

1. A business as usual, or current trends, scenario that took into account current zoning, smart growth policies, land use regulations, and protected lands.
2. A managed growth scenario that incorporates stricter smart growth policies and stronger protections on natural resource lands at a level that could be realistically achieved with strong political commitment.
3. A best-case scenario for natural resource protection, with strong restrictions on development in areas that are outside of designated growth centers.

Forecasts were initialized with the extent of urban development in 2000 as represented in the impervious surface area maps, although these 30 meter resolution maps were resampled to 45 meters due to computational limitations. Because SLEUTH has a random component, one hundred Monte Carlo simulations were run, producing map products that represent the probability of any cell in the landscape becoming developed.

The Maryland Department of Natural Resources (DNR) has developed several GIS-based tools to facilitate forest management and preservation. The strategic forest lands assessment (SFLA) (Maryland Department of Natural Resources, 2003) scores all forested land cover in the state from 0-100 to indicate its ecologic or economic value. The green infrastructure (GI) assessment (Weber, 2003) identifies "hubs," or large unfragmented natural areas that provide critical ecosystem functions, and "corridors," which are linear remnants of natural lands that connect the hubs. These two data sets represent key forest and natural resource areas in the state.

We conducted a vulnerability assessment of the strategic forest lands by combining the maps of development probability with the maps showing the economic or ecologic value. We first applied an equal interval classification to the economic and ecologic value maps to create three categories (low, medium, and high value). These classified maps were then combined with the maps of development probability, allowing for a visualization and quantification of development risk across value classes.

We performed a similar assessment with the GI hubs, although in this case we considered two kinds of risk associated with development: 1) the wholesale loss of hub area, and 2) the risk of hub fragmentation. These types of risk are related, but the risk associated with fragmentation becomes important in areas where development pressure is relatively low, yet development patterns are highly dispersed. To calculate the risk associated with the loss of hub area, we calculated the average number of pixels that were forecasted to be developed within a GI hub. To estimate the risk of fragmentation, we also considered the potential area over which the forecasted development could occur (i.e. clustered or dispersed throughout the patch). Figure 2 provides an example of this approach for a single hub.

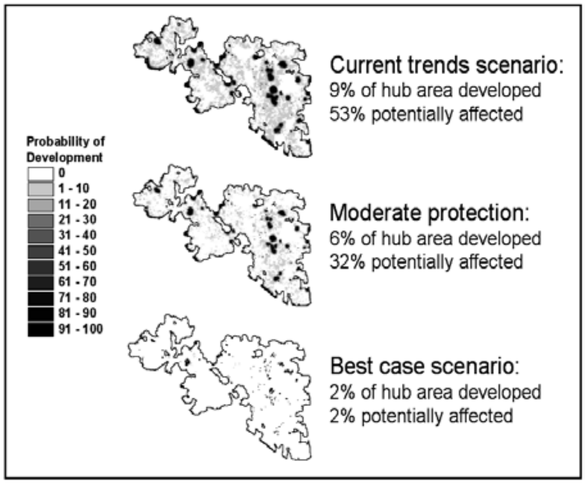

Figure 2. Illustration of the risk associated with wholesale loss of a forest hub and the potential risk of fragmentation within the hub.

RESULTS AND DISCUSSION

Resource Land Loss 1990-2000

The analysis of resource land conversion across the watershed (Jantz et al., forthcoming) shows that agriculture suffered the most loss (888 km^2, or 1.97 %), while a total of 334 km^2, or 0.37 %, of forested lands were converted to development. Some smaller municipalities lost as much as 17% of their forest lands and 36% of their agricultural lands to development, although in the outlying counties losses ranged from 0 – 1.4% for forests and 0 – 2.6% for agriculture (Figure 3). Fast growing urban areas surrounded by forested land experienced the most loss of forest to impervious surfaces. This can be observed in the northern Virginia area and around Richmond, VA at the southern part of the watershed. Agricultural land loss in Delaware, central Pennsylvania and central Maryland is associated with population growth and residential sprawl from Washington, DC and Philadelphia, PA. Much of the wetland loss detected was minimal (<1%) and highly dispersed, possibly due to the conservative methods used to detect change in wetland areas and the accuracy of the land cover maps.

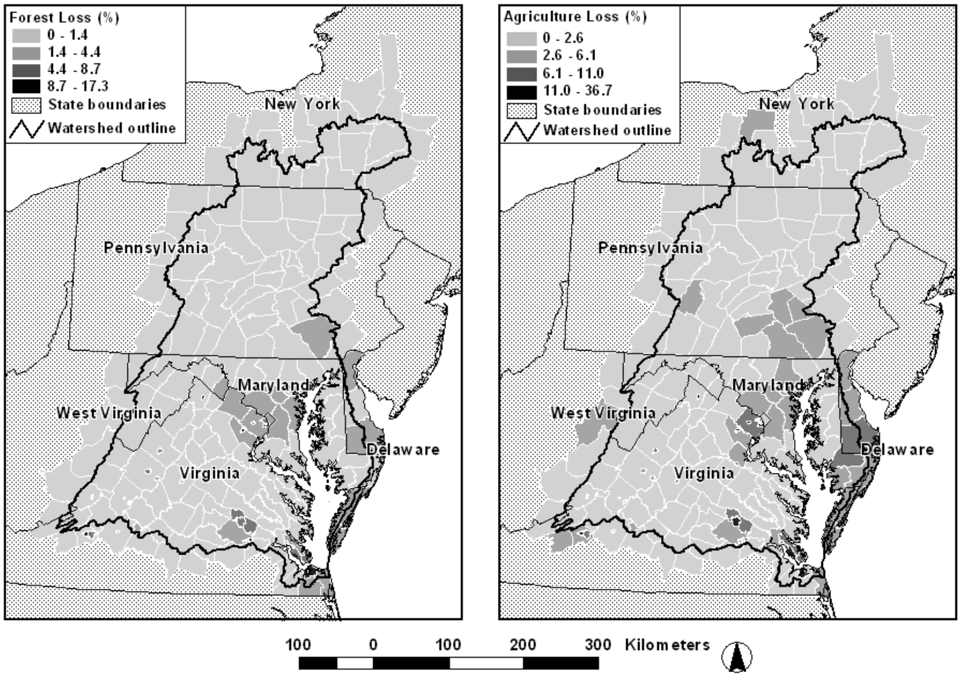

Figure 3. Forest and agricultural land loss across the Chesapeake Bay watershed, showing the proportion of forests or agriculture lost within each county.

When considering the contribution that each county makes to the total resource land loss across the watershed, hotspots of regional significance are apparent (Figure 4). Some of the counties surrounding Richmond, VA are responsible for 2.0 – 3.8% of the total forest loss in the watershed. Similar levels of deforestation can be observed in northern Virginia and central Maryland. The effects of development pressure from Washington, DC and Philadelphia, PA are even more apparent in the map of agriculture loss, where some counties in eastern Maryland, Delaware and southern Pennsylvania each account for 2.3 – 6.3% of the total regional loss.

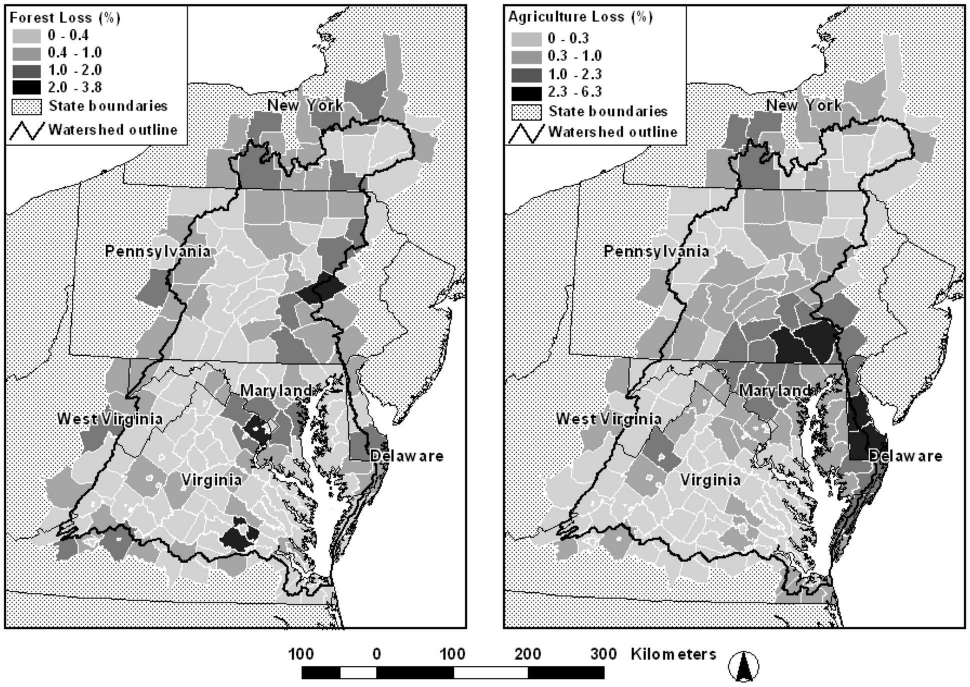

Figure 4. The contribution of each county to the total amount of forest or agricultural land loss in the watershed.

Forest Vulnerability in Maryland

Patterns of economic and ecologic value ascribed to forest lands are similar across the state, with many of the high value forests concentrated in the western and eastern counties (Figure 5). Lower value forests are found in the central part of the state. Forecasts of development for the current trends scenario show development concentrated along the Baltimore-Washington, DC corridor, but with dispersed patterns occurring across the state (Figure 6). In the managed growth and best case scenarios, new growth is clustered and these dispersed patterns are much less pronounced.

In terms of vulnerability, forests with low economic and ecologic value are projected to experience the highest risk for development in all three scenarios (Figure 7). The low value category for the ecologic strategic forests is at a particularly high risk, with more than 25% of its total area being forecasted for development. Moderately and highly valued ecologic strategic forest lands tend to be more protected in all three scenarios when compared to the economic strategic forest lands. Total projected forest losses for the ecologic and economic strategic forests are summarized in Table 1.

Table 1. Total projected forest loss for Maryland's strategic forest lands. Note that these numbers represent the totals for each category of strategic forest lands and do not account for the overlap.

	Current trends	Managed growth	Best case
Ecologic strategic forests	1427 km^2 (12%)	1170 km^2 (10%)	804 km^2 (7%)
Economic strategic forests	1456 km^2 (12%)	1197 km^2 (10%)	829 km^2 (7%)

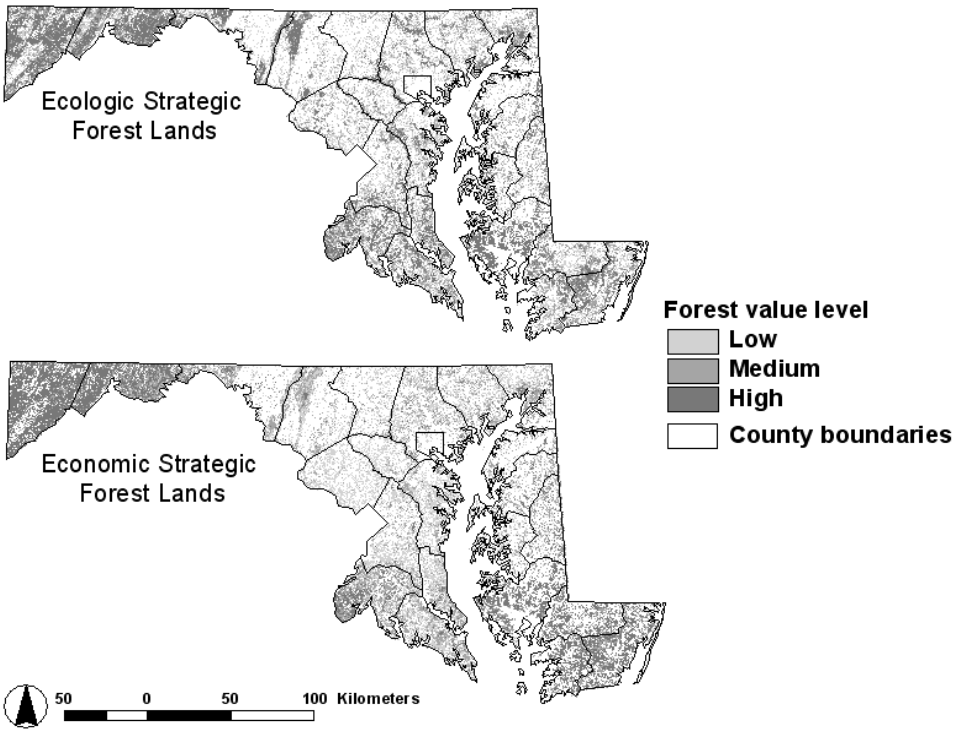

Figure 5. Economic and ecologic strategic forest lands for Maryland. Source: Maryland Department of Natural Resources (2003).

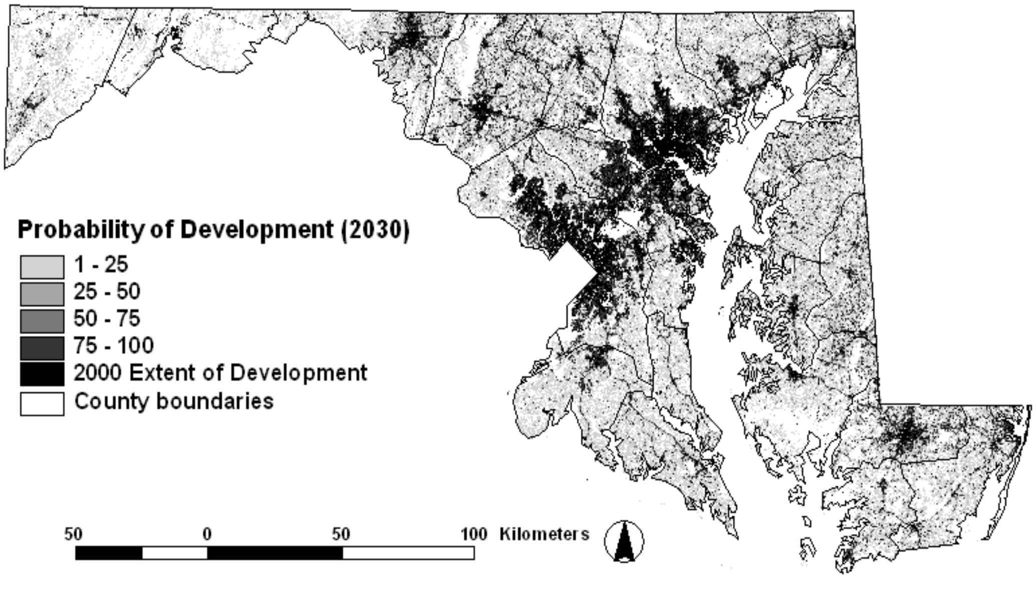

Figure 6. Forecast of future development under current trends for Maryland.

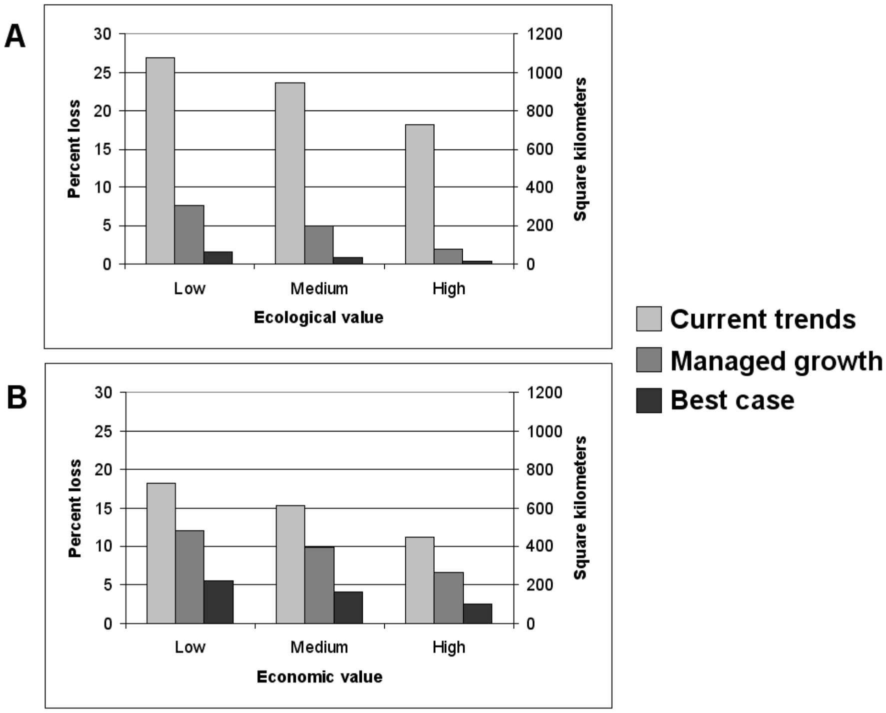

Figure 7. Forest loss in each value category for ecologic (A) and economic (B) strategic forest lands according to the three future policy and growth scenarios.

The vulnerability analysis of green infrastructure hubs shows that fragmentation is a more serious problem than wholesale loss. In the current trends scenario, for example, many of the hubs in western Maryland are projected to lose less than 1% of their total area to development, and most hubs in the state are projected to lose less than 25% of their area (Figure 8). The potential area affected by development within each hub shows a higher risk for fragmentation (Figure 9).

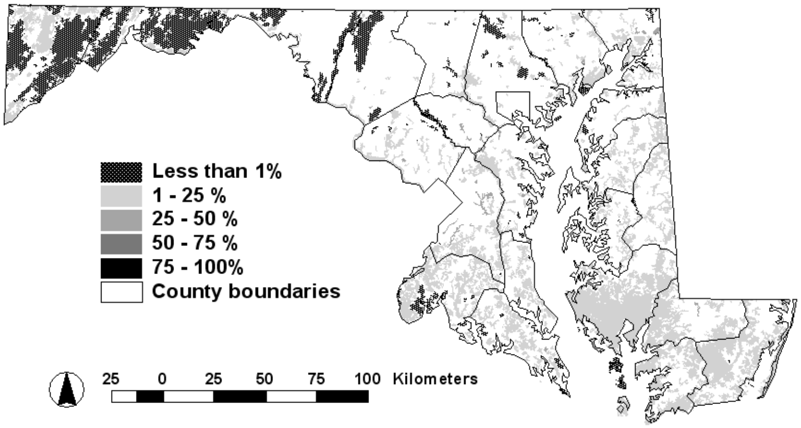

Figure 8. The potential loss of area within each green infrastructure hub by 2030 for the current trends scenario, expressed as a percent of the total hub area.

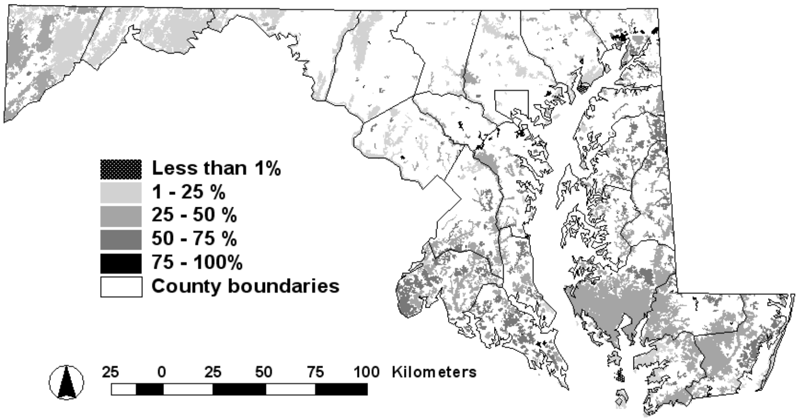

Figure 9. The potential area affected within each green infrastructure hub by 2030 for the current trends scenario, expressed as a percent of the total hub area.

When the percent area lost and the percent potential area affected for the hubs are compared across scenarios (Figure 10), the effect of protection policies can be evaluated. While the managed growth and best case scenarios both show a decrease in the loss of hub area, only complete protection of the existing hubs offered in the best case scenario will significantly lower the risk associated with fragmentation.

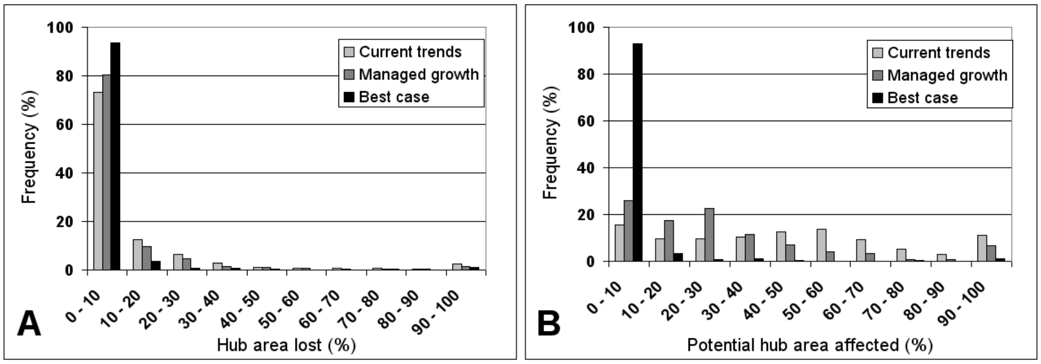

Figure 10. Frequency histograms of green infrastructure hub loss (A) and potential area affected (B) for all three future policy scenarios.

CONCLUSIONS

This research clearly shows the value of remote sensing and GIS techniques for regional natural resource assessments. The estimates of resource lands lost between 1990 and 2000 can provide an important baseline for the monitoring of the impacts of development across the Chesapeake Bay watershed. In turn, this can help states set goals for resource land protection and acquisition that are consistent with Chesapeake 2000. Forecasts of development are also important for regional goal-setting. While this analysis used Maryland-based forecasts, we are currently developing Bay-wide forecasts. Analytical techniques developed in the Maryland case study will be applicable to the watershed and have emphasized the importance of recognizing the threat of fragmentation posed by current development trends.

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