Modeling the Ecological Consequences of Land-Use Policies in an Urbanizing Region

Working Title: Modeling Consequences of Land-Use Policies

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Abstract

Insight into future land use and effective ways to control land use change is crucial to addressing environmental change. A variety of growth control policies have been adopted by municipal and regional governments within the US to try to minimize the ecological impact of continued urbanization, but it is often unclear if those policies can meet the stated ecological goals. Land use change models provide a way to generate predictions of future change, while exploring the impact of different land-use policies before irreversible transformations occur. In this paper an approach to modeling land-use policies that focuses on their ecological consequences is described. The policy simulation approach was used to predict future land use in the Barnegat Bay and Mullica River watersheds, in southeastern New Jersey, USA. Four commonly used policies were considered: down zoning, cluster development, wetlands/ water buffers, and open space protection. The results of the analysis suggest that none of the policies modeled were able to alter future land use patterns, raising questions about the effectiveness of commonly adopted land-use policies. However, the policy modeling approach used in this study proved to be a useful way to determine if adoption of a given policy could improve the likelihood of meeting ecological goals.

Keywords: Landscape change, Land use, Modeling, Land-use policies, New Jersey

Urban conversions radically impact local environments through destruction and degradation of terrestrial and aquatic habitats, introduction of exotic species, modification of water and radiation fluxes, and alteration of nutrient cycles (Riebsame and others 1994; Alberti 1999). Due to intense local impacts and implications for much larger regions through rural-urban links (Lambin and others 2001), a greater understanding of the patterns of change and effective approaches for controlling urbanization is crucial to addressing environmental change. A variety of growth control policies have been adopted by municipal and regional governments within the US to try to minimize the ecological impact of continued urbanization, but it is often unclear if those policies can meet the stated ecological goals.

Land use change models provide a way to explore the causes and mechanisms of change, generate predictions of future change, and support the design of appropriate policy responses (Lambin 1997). This allows the ecological consequences of future land use and the effectiveness of different management approaches to be identified before irreversible transformations occur (Lee and other 1998). While there has been a recent focus on developing spatially explicit land use models suitable for urbanizing areas (e.g. Clark and others 1997; Wear and Bolstad 1998; White and Engelen 2000; López and others 2001; Schneider and Pontius 2001), there has been little effort to explicitly incorporate land-use policies into these models. Those studies that do consider alternative policy scenarios tend to do so through economic-based models (Veldkamp and Fresco 1997; Bockstael 1996), which examine how a given policy alters land price. These models can provide some indication of the likelihood of successful policy implementation (Parks and Krammer 1995). However, a strong relationship between a policy, land prices and/or successful policy implementation does not mean that the policy will necessarily be able to create conditions where desired ecological goals are met (Walker and Solecki 1999).

In this paper an approach to modeling land-use policies that directly focuses on the ecological consequences of each policy is described. The policy simulation approach is combined with a land use model that is based on the social and spatial drivers of land use change and applied to the Barnegat Bay and Mullica River watersheds, in southeastern New Jersey, USA. The policies modeled are ones currently being considered for adoption in the region and commonly used to manage urban growth throughout North America. The following sections review current approaches to incorporating policies into spatially explicit land use models, describe an alternative spatial constraints modeling approach, and present the results of the spatial constraints policy model for the Barnegat Bay and Mullica River watersheds.

Existing Policy Incorporation Approaches

Land-use policies have primarily been incorporated into spatially explicit land use models using regression equations to predict areas most likely to convert to urban uses. The policy is usually represented through one or more variables included in the calculation of transition likelihood values, with the values of the input variables (hypothesized drivers of land use change) modified based on the policy under consideration (Veldkamp and Fresco 1997). The transition likelihood values are then used to predict the location of specific land use conversions. Other models incorporate a hedonic pricing model, with transition likelihood calculations based on estimated land price (from the hedonic model) and other independent variables (Bockstael 1996; Irwin and Geoghegan 2001). In these models, the likelihood of urban conversion increases as estimated land price increases. Bockstael (1996) used such a model to simulate the effect of a policy that would extend sewer services and allow higher zoning densities in the newly serviced areas. Zoning density was an independent variable in the hedonic pricing model, while presence

of sewer service was an independent variable in the transition likelihood model. Thus, altering the extent of sewer service areas and zoning densities modified the transition likelihood value.

The policy simulation approach described above requires that: (1) variables representing the specific policy (or proxies) are present in the transition likelihood calculations; (2) the calibration data include observations sufficiently similar to the conditions expected under the policy, so it is appropriate to use the pre-defined regression equation to make predictions; (3) the relationship between the modified variable(s) in the model and the policy is known, if the variable(s) represents a proxy of the policy; and (4) ownership parcel data is available, if the model incorporates a hedonic pricing model. Most land use models are raster-based, not ownership parcel-based, allowing for easy incorporation of remotely sensed land use/ land cover data. Additionally, and perhaps more importantly, digital parcel data is often not available and costly to create. The lack of parcel data means that using a hedonic pricing model is logistically difficult and may not be easily incorporated into existing raster-based models. The following sections describe an alternative modeling approach focusing on the ecological consequences of adopting a given land-use policy.

A Spatial Constraints Approach to Modeling

An alternative modeling approach is to use spatial constraints to represent land-use policies. A spatial constraints approach focuses on the ability of a policy to alter land use patterns. As changes in landscape pattern are often related to changes in ecological processes (Turner and others 2001), examining pattern change is a good starting point when considering the ecological implications of a given policy. A spatial constraint is defined as a transition restriction placed on a particular cell (or neighboring cells) based on characteristics of that cell. Spatial

constraints are similar to rules used in cellular automata models, and can be easily integrated into standard land use change models. A spatial constraints approach does not require (1) the policy be represented by variables in the regression equation, (2) the calibrating data include observations with characteristics similar to conditions predicted by the policy, or (3) ownership parcel data. Several existing models already use simple spatial constraints to account for preserved open space (Swenson and Franklin 2000; Schneider and Pontius 2001), where constrained areas are not allowed to convert to certain land use/ land cover classes.

A central assumption of this approach is that the policy constraint overrides other factors associated with land use conversions. While clearly the case when the policy is permanent protection of open space, transition restrictions due to zoning regulations may not always supercede other conversion factors. Additionally, a spatial constraints approach does not try to directly model individual land owners' responses to changing land prices. Rather, the approach identifies conditions that are similar to previous situations where the decision to convert was made, and allows those conversions to occur if the cell is not constrained by the new policy. The assumption that the independent variables in the model can adequately capture the decision-making process by including factors that are associated with past change is common to most land use models (Berry and others 1996; Wear and Bolstad 1998; Schneider and Pontius 2001). In regions where it is predicted that all available land will be converted to urban uses within a few decades (as is the case with many urbanizing regions) focusing on specific parcels changing use, based on individual choices or shifts in land price, is less important than the overall patterns derived from the process of land use change. The next section describes a case study of the Barnegat Bay and Mullica River watersheds where four land-use policy types (down zoning, cluster development, wetlands/water buffers, and open space protection) were modeled using the spatial constraints approach.

Case Study: Barnegat Bay and Mullica River Watersheds

The Barnegat Bay and Mullica River watersheds are located on the outer coastal plain in southeastern New Jersey, USA (Figure 1). The 2,900 sq. km study area is part of the Pinelands ecosystem, which is characterized by pine-oak uplands, extensive forested wetlands, and salt marshes near the estuary shore. The population in the region increased by more than 800 percent between 1950 and 2000 (US Census 1990, 2001), making it representative of other coastal and ex-urban areas experiencing high levels of suburban residential growth. The proximity of the study area to New York City and Philadelphia and the amenities associated with the coastal zone are expected to drive future regional urbanization. While the study area is relatively undeveloped, with only 17 percent classified as urban in 2000 (Lathrop 2003), current development has already (1) reduced stream flow to such an extent that localized salt water intrusion has occurred, (2) contributed to shifts in aquatic biota due to increasing non-point source pollutants, and (3) caused significant destruction and alteration of aquatic and terrestrial habitat (BBEP 2001, Zampella and others 2001). Future urban development will only increase these impacts.

Several groups are currently trying to protect the region's unique natural features from future urbanization: (1) the New Jersey Pinelands Commission regulates land use within the Pinelands Management Areas, which extend into the western section of the study area (Figure 1; Pinelands Planning Commission 1982); (2) the New Jersey Department of Environmental Protection (NJDEP) is involved in water resource management (NJDEP 2001a) and coastal zone management (NJDEP 1993) in the non-Pinelands Management part of the study area; and (3) county and municipal land use planners have created land use plans and established zoning

regulations. The goals of these groups include protecting large patches of pristine natural cover, minimizing fragmentation from urban development, and protecting regional water quality through land-based strategies. Policies under consideration for adoption in the region were identified based on discussions with regional and municipal planners and local environmental organizations. From these discussions, four types of policies to control future urban development and protect ecological features were identified: (1) down zoning, (2) cluster development, (3) wetlands/ water undevelopable buffer zones, and (4) open space protection. All four policies are commonly used to regulate urbanization in the US and are likely to be adopted in the region. Future land use scenarios were developed for each of the policy types, as well as baseline conditions, to examine the potential impact of each policy on future land use patterns throughout the study area.

Base Land Use Change Model

A regression-based land use change model (Conway in review) was used to create the baseline (where no additional policies are adopted) and other policy scenarios. The model was run from 1995 to 2020, using a five year time step and a 63 m cell (approximately 1 acre) as the unit of change. The predicted location of urban development was determined from transition likelihood values calculated using logistic regression. The model was calibrated using land use/ land cover data from 1986 and 1995 (NJDEP 2001b), with the dependent variable defined as no change (0) or change to urban (1). Independent variables were identified based on an extensive review of the literature, reflecting land accessibility, neighborhood characteristics, and site characteristics. Six independent variables were retained based on a step-wise selection process: distance to nearest highway exit, distance to nearest road, percent of urban land within a 1 km neighborhood, percent of open space within a 1 km neighborhood, a starting state of forest or

non-forest, and a starting state of barren or non-barren. Conversions between non-urban classes (agriculture, barren, forest, and wetlands) are occurring in the study area and were represented using a simple Markov model (Turner 1987), as these conversions were not the focus of the study.

Linear extrapolation of the historic population change was used to represent the amount of urban change in each time step, because the population in the study area has been increasing at a constant rate since 1960. There are two assumptions associated with this approach. The first is that the level of population growth will remain the same in the future. As there is sufficient land available in the study area and continued growth expected in the region, this assumption does not seem unreasonable. The second assumption is a constant relationship between population growth and the area of new urban land. While a constant urban land per person ratio is a common assumption (Theobald and Hobbs 1998; Schneider and Pontius 2001), there is the potential that the ratio will alter in the future. However, by holding constant the amount of new urban development, the ability of each policy scenario to alter the location of urban development could be assessed in isolation, without the effects of varying amounts of land converting. Based on US Census estimates for 1986 and 1995, the population in the study area increased by approximately 92,000, corresponding to 15,374 new urban cells over the nine year period. If a linear increase and constant land to person ratio is assumed, then 8,570 cells are predicted to convert to urban land uses every five years.

The model was validated by comparing predicted land use in 1995 and 2000 to reference datasets for each date. The 1995 reference dataset was the same land use/ land cover data used to calibrate the model (NJDEP 2001). The 2000 dataset is an update of the 1995 data derived from SPOT satellite imagery. Only conversions to urban land uses were identified in the 2000 update, while changes between land cover classes (i.e. forest to wetlands) were not delineated (Lathrop

2003). In addition to comparing the model to reference data for the study area, the model was also applied to the Great Egg Harbor watershed, which borders the southern edge of the study area, to assess the ability of the model to predict land use in a region experiencing similar urban growth pressures.

The ROC statistic was used to compare the transition likelihood values with the reference data (Pontius and Schneider 2001), and a Kappa statistic commonly employed to compare categorical maps was used to evaluate predicted and reference land use (Rosenfield and Fitzpatrick-Lins 1986). For both the ROC and kappa statistics, values closer to one represent a higher degree of similarity between the predicted values and reference dataset. Based on the results of the two statistics, the model is correctly identifying areas that are likely to convert to urban uses (Table 1), indicating that the model can be used to predict future land use in the study area under the assumption that the relationship between urban conversion location and the variables used to calculate transition likelihood values does not change in the future. The policies examined and the spatial constraints used for each scenario are described in more detail below (Table 2).

Down Zoning

Down zoning is a tool commonly used by municipal planners to limit the extent and intensity of urban development. For several years the State of New Jersey has been considering adopting regulations that would effectively impose minimum lot sizes in areas without sewer service through site review of water discharge impacts. In 2001, the NJDEP proposed and adopted changes to the Water Quality Management Planning Rules (NJDEP 2001a). Based on the rule changes, residential development on lots smaller than 1.3 ha in non-sewer service areas would likely not be approved. While these water quality rules were repealed due to improper

implementation procedures, it is believed that the NJDEP will again propose similar rules (Springer 2002). Locally there is tremendous interest in such a proposal as a way to protect water quality (McKeon 2001).

Down zoning was represented in this model by placing a constraint on cells adjacent to all new urban development cells. The size of the constraint neighborhood corresponds to the zoning density allowed in the area. For example, urban cells in a 1.2 ha (three acre) lot zone were given a constraint buffer of 127 meters. This creates a landscape where the maximum density would correspond to one out of three cells allowed to convert to urban (Figure 2B). Assuming that 0.4 ha (one acre) of development would be associated with every new development unit, this would correspond to a maximum density of one house every 1.2 ha. If ownership-parcel data were used a more uneven pattern of urban development might emerge, as many of the parcels in the study are not based on a square grid. However, this approach creates the same maximum density of development as a model that uses ownership-parcel data.

Cluster Development

Cluster development has long been proposed as a way to minimize impacts of residential development on agricultural land (Whyte 1964) and habitat (Theobald and others 1997; Odell and others 2003). Assuming that each house has a disturbance zone around it which impacts habitat, Theobald and others (1997) found that by clustering houses the disturbance zone can be reduced by approximately 50 percent, without altering house footprints. Cluster development is also associated with a lower habitat edge length and shorter road length. While landscape-level disturbances may be reduced by cluster development, Nilon and others (1995) found that fewer forest birds, more nest predators, and more brood nest parasites were present around cluster

developments (more than one dwelling units per ha) as compared to more dispersed development (less than one dwelling unit per ha). Thus, cluster development creates small areas with higher impacts while larger areas of unaltered land remain, as compared to the usual patterns of development.

In this case a weak form of cluster development was modeled where new urban development was forced to occur (1) adjacent to existing urban development or (2) in clusters of two or more cells of new urban development. This was represented in the model by first running the standard model used in the baseline scenarios for one time step. New urban cells that were not adjacent to existing development or in a cluster of new cells were re-located to the cells with the highest urban transition likelihood values that were adjacent to urban cells (Figure 2C). The number of new urban cells that needed to be re-located each time step ranged from 17 to 34 percent, with the number increasing each time step.

Wetlands/ Water Buffers

Another policy under consideration for adoption in the study area is creating undevelopable buffer zones around wetlands and water. Like down zoning, this policy would be adopted to protect water resources from non-point source pollution by requiring a protected natural buffer zone to filter pollutants and slow storm water before it enters waterways (Peterjohn and Correll 1984). Due to the linear nature of wetlands in the region, the buffer zone would also create corridors that may facilitate movement between larger areas of undeveloped habitat.

Wetlands/ water buffer zones were modeled by placing a spatial constraint on all land within 91 m of wetlands and freshwater and within 152 m of tidal areas. Ninety-one meters is the buffer size currently used in the Pinelands Management Areas, as it is the minimum width

sufficient to maintain biological integrity within the region's wetlands (Pinelands Planning Commission 1982), while 152 m represents the furthest distance from tidal areas that can currently be regulated under New Jersey's Coastal Zone Management Rules (NJDEP 1993). The constraint does not allow conversions to urban or agricultural land uses, but does allow conversions between forest, wetlands, and barren cells. Because a 63 m cell size is used as the unit of change in the model, in some cases more than 91 m away from water is constrained. However, a raster representation where the unit of change (the cell) is often smaller than the ownership-parcel is an appropriate way to depict this policy, because the policy may limit development to only part of a parcel but not exclude urban uses from the whole parcel.

Open Space Protection

Open space protection is a common tool used to preserve recharge areas, protect surface water quality, maintain viable farming communities, and meet communities' quality of life goals. Open space protection is also often used to preserve local and global biodiversity, due to the time, resource, and knowledge constraints associated with focusing on individual species (Franklin 1993). There have been several debates in the literature over how to protect open space. The SLOSS debate in the 1980s was based on interpretations of island biogeography theory that specifically considered the comparative benefits of protecting a single large area versus several small ones (Lahti and Ranta 1985; Lahti and Ranta 1986; Murphy and Wilcox 1986), while more recent debates have focused on the process used to identify sites for protection (Prendergast and others 1999; Menton and others 2001) and the optimum spatial arrangement of those sites (Ahern 1991).

Although these debates have occurred in the literature, theories of open space protection have not always translated into practice, with ad hoc selection of open space predominately occurring in the US (Pressey 1994). This ad hoc selection is often biased and not very efficient, requiring a greater total area needed to capture the same diversity of habitats. Prendergast and others (1999) attribute the gap between selection theory and practice to open space protection being driven by threat and opportunity, with landowners dominating the process.

In the study area, the Trust for Public Land and Pinelands Commission have taken a more proactive approach to protecting key open space. The Trust for Public Land created the Century Plan (Blanchard 1995), which identified 100 pieces of land they felt were critical to protect in the Barnegat Bay watershed. While the Trust for Public Land has taken the lead in purchasing several parcels, they hope that the plan will guide open space protection for all organizations in the region. By May 2000, 15 of the 100 pieces were protected. In the Mullica River watershed, the Pinelands Commission has been obtaining open space through fee simple purchase and purchase of development rights for several decades. As a result of receiving federal money for open space protection, the Pinelands Commission has targeted pieces of land they would like to protect in the future. Together the Trust for Public Land and Pinelands Commission's targeted land represents 15 percent of the total land in the study area.

Plans Based on Targeted Lands Three policy scenarios were created based on the open space plans of the Trust for Public Land and the Pinelands Commission (TPL/PC; Table 2): (1) hotspot protection, (2) coldspot protection, and (3) prioritizing large pieces of land. The hotspot scenario (TPL/PC-hotspot) prioritized land that had the highest urban transition likelihood values in 2000, as defined in the base land use model. Hotspot protection represents the common reactive approach where actions are not taken until the land is considered threatened. Another

interpretation of this approach, however, is that once a piece of land is converted to urban uses it can not be protected, so open space protection needs to focus on those places most vulnerable to development.

The coldspot protection scenario (TPL/PC-coldspot) is the opposite of the hotspot scenario, as it prioritizes land with the lowest transition likelihood values. A coldspot approach may be desirable because land most likely to be developed is often more expensive than land which has lower development pressures, so if land in “cold” areas is targeted a greater total area may be protected at the same cost. The final simulation based on the TPL/PC land prioritized the largest pieces of land (TPL/PC-large), as these pieces are more likely to support viable species populations and include greater habitat complexity.

Plans Based on Non-targeted Lands The land targeted for open space protection by the Trust for Public Land and the Pinelands Commission has clearly gone through a screening process to meet each group’s desired set of goals. Three alternative open space scenarios were also created where the same total area of land was targeted (15 percent of the study area) but patches were selected using different methods (Table 2). The first scenario (Other-hotspot) identified non-urban patches that were greater than 4 ha, and prioritized protection of those patches based on the hotspot selection process described above, until 15 percent of the total study area was selected. Two more scenarios (Other-coldspot, Other-large) were created following the Other-hotspot methods using coldspot and large patch selection approaches.

Open Space Scenario Methods For each of the six open space scenarios, 25 percent of the selected pieces of land were “protected” every five years between 2000 and 2020, with 100 percent of the land potentially protected by 2020. If the cell(s) had already converted to urban,

then the “protection” was not successful. The open space constraint placed on the protected cells did not allow the cells to convert to urban uses, but the cell could convert between agriculture, barren, forest, and wetlands.

Policy Scenario Comparisons

The ability of each policy to re-locate future urban development between 2000 and 2020 was assessed using a cell-by-cell comparison of land use/ land cover classes. Pattern metrics were also used to explore predicted changes between 2000 and 2020 under baseline conditions and the impact of each policy on general landscape patterns, as a first step in identifying potential ecological impacts (Turner 1990, Turner and others 2001). Four pattern metrics were used: percent of total area, number of patches, mean patch size, and perimeter-area ratio. These represent common landscape metrics that have been used to compare different specifications of land use change models and predicted landscapes (Flamm and Turner 1994; Swenson and Franklin 2000). If the policy is not predicted to alter the location of urban development as compared to the baseline scenario, then the ecological impact will likely be the same. If there are differences, the pattern metrics are then used to determine if the change will be greater or less than predicted under baseline conditions.

Results

The results of the pattern metrics for the baseline scenario are shown in Figure 3. In 2000, the study area was primarily forest, with substantial wetlands and urban land present but very little barren land or agriculture. The relatively large mean patch size for forest and wetlands and high number of urban patches indicates that forest and wetlands are highly aggregated, while

urban uses tend to be more dispersed. The relatively large perimeter-area ratio for urban may reflect the linear nature of development along roads, while the high perimeter-area ratio for forest and wetlands is probably a result of the linear wetlands found within forested areas.

The largest difference between 2000 and the 2020 baseline predicted landscapes is the decline in forest land and increase in urban. New urban development is predicted to cover an additional five percent of the land in the study area, locating in the northern section of the Barnegat Bay watershed, the central North-South corridor, and along the southern edge of the study area (Figure 4). In 2000, urban land was fairly dispersed, but most future urban cells are predicted to occur adjacent to existing development, increasing individual patch size and connecting previously disjoint patches (Figure 3). The relatively high perimeter-area ratio for all years suggests that urban patches will remain fairly linear, reflecting the model's focus on urban development near existing roads. From 2000 to 2005, forest patches are predicted to continue to fragment, evident from the decrease in patch size and perimeter-area ratio. From 2005 to 2020, forest attrition will primarily occur, based on the predicted decrease in the number of patches and the perimeter-area ratio. The increase in mean forest patch size suggests that smaller patches will be eliminated, while larger patches are preserved in the baseline scenario.

Policy Comparison

While the model forced the amount of new urban development to be the same for each policy scenario, the location of that development could vary. Figure 5 shows the percent similarity between the predicted baseline scenario and policy scenarios in 2020 based on a cell by cell comparison of land use/ land cover classes. Four scenarios have less than 75 percent of the new urban cells in the same location as the baseline scenario. Of these, the down zoning scenario is by far the most different, with only 38 percent of the predicted new urban cells in the same

location as in the baseline scenario. However, if the similarities between cells of all land use/land cover classes are compared, all scenarios are predicted to be 95 percent or more similar to the baseline scenario in 2020, reflecting the stability of most locations as compared to the total number of cells.

Very little difference is predicted between new urban land location in the baseline, cluster development, and five of the open space (TPL/PC-hotspot, TPL/PC-coldspot, TPL/PC-large, Other-coldspot, Other-large) scenarios between 2000 to 2020 (Figure 6). There are, however, some differences in new urban cell location between the baseline scenario and the down zoning, wetlands/ water buffer, and Other-hotspot scenarios. The down zoning and wetlands/ water buffer scenarios predict more disaggregated urban development than the baseline scenario, with more patches and a smaller mean patch area in 2020. The Other-hotspot scenario has an opposite trend, with slightly fewer patches and a slightly larger mean patch area than the baseline scenario in 2020. However, the values for the Other-hotspot scenario were within five percent of the baseline scenario.

The pattern metrics for forest are in Figure 7. Unlike urban conversions, forest was not forced to convert at the same rate in the different scenarios. However, the predicted loss of forest is similar for all scenarios and years, a result of most new urban development predicted to occur on forested land. Again, very few differences are predicted between the baseline scenario and six of the policy scenarios (cluster development, TPL/PC-hotspot, TPL/PC-coldspot, TPL/PC-large, Other-coldspot, and Other-large). The down zoning scenario is predicted to change in the opposite direction from the baseline scenario, so that by 2020 the down zoning scenario is predicted to have 40 percent more patches and a mean patch size 28 percent smaller than the baseline scenario. The wetlands/ water buffer and Other-hotspot scenarios predict slight (6 to 8 percent) increases in fragmentation as compared to the baseline scenario.

Open Space Protection Success

All of the open space scenarios attempted to protect 15 percent of the total land as open space but the number of patches that represents varied greatly, highlighting how different selection approaches can result in a different number of patches (and/or ownership-parcels) needing to be protected. Not surprisingly, the scenario focusing on the largest patches required the fewest number of patches to reach 15 percent (Table 3), which may mean that this approach would be logistically easiest to implement as far fewer landowners will likely need to be involved to protect the same total area.

Since open space protection sites were based on land use/ land cover patches, not ownership-parcels, determining the ability of each modeled selection scenario to protect open space before the site converts to urban uses is complicated because each patch may represent more than one ownership-parcel. As a result, the success of each scenario is summarized by the percent of area and patches that are not predicted to have any urban land on them as well as the percent of the selected patch area that is not urbanized (Table 3). In the first case, which assumes that if even one cell of urban is predicted to occur on the site before it is protected then none of the patch can be protected as open space, only the Other-coldspot scenario is even moderately successful. The TPL/PC scenarios are predicted to fully protect only nine percent of the total area and 55 percent of the patches. If part of a patch is urbanized but the remainder could still be protected as open space, greater success is predicted for all open space scenarios, with the total area protected ranging from 91 to over 99 percent.

Overall the results of the open space scenarios indicate that the selection process does not matter if the land targeted by the Trust for Public Land and Pinelands Commission is protected

between 2000 and 2020, as all three TPL/PC scenarios performed the same. Selecting alternative patches, however, showed mixed results. The Other-hotspot scenario has predicted success similar to the targeted scenarios, while the Other-coldspot and Other-large were more successful.

Discussion and Conclusions

The results of the cell by cell comparison and landscape pattern metrics indicate that adopting any of the modeled land-use policies will likely have either no impact on future trends or create an even more fragmented landscape than if no new policies are adopted. The inability of most of the modeled policies to alter the location of less than 25 percent of the future urban development may be a result of the short time period considered, as only 33 percent of the land available for development in 2000 is predicted to be urbanized by 2020, suggesting there is the potential for greater divergence if the scenarios were run for a longer time period. However, previous work looking at build-out conditions (Conway and Lathrop in press) indicates that even over a longer timeframe the policies will only moderately differ from baseline conditions.

Policy Implications

The policy of down zoning outside sewer service areas is predicted to create the most diffuse urban development and fragmented non-urban areas. While the intensity of new urban development would be reduced, a larger total area will be impacted making mitigation efforts more difficult. Additionally, this policy is predicted to create conditions contrary to existing management goals as the lower density of urban development means that more new urban uses will be pushed westward, into the Pinelands Management Areas. While this policy is assumed to help protect water quality from non-point source pollution associated with septic tanks, the

results of the model highlight the limitations of using a down zoning approach to meet other ecological objectives associated with terrestrial fragmentation. The results of this study and the other potentially negative impacts of a down zoning policy that were not examined (a lower total number of dwelling units by build-out, additional air and water pollution from increased driving due to less compact development patterns, and increased species movement barriers due to the number of roads needed to support such development patterns) raise questions about the appropriateness of down zoning as way to reduce the ecological impact of urban development.

A cluster development policy takes an opposite approach to the down zoning policy, forcing greater aggregation of new urban development. Nevertheless, the clusters of urban development are still predicted to cause slightly greater forest fragmentation than in the baseline scenario. The changes, however, are a result of the fragmentation of remnant urban forest patches in the Northeast of the study area, while fewer changes are predicted in the forest dominated central region than under baseline conditions. These results suggest that the cluster development policy will be able to protect the more pristine locations in the study area. The cluster development policy modeled here forces new urban cells to be more aggregated, but requires that the same total number of urban cells be added in each time step as in the baseline scenario, resulting in a weak form of cluster development. A stronger cluster development policy would assume fewer cells are needed to represent the same number of dwelling units. This more aggressive approach, possibly coupled with open space protection, would increase the likelihood current landscape patterns will be maintained.

The wetlands/ water buffer scenario is predicted to deviate second most from the baseline scenario based on a cell-by-cell analysis. The shift in the location of urban development is away from water body edges, ensuring continuous natural corridors along streams and wetlands are protected. As a result, increased forest fragmentation is not predicted to occur in the wetlands/

water buffer scenario and unlike the down zoning policy, a wetlands/ water buffer scenario appears to be able to create patterns benefiting water quality (assuming the buffer zones are effective) while minimizing terrestrial habitat fragmentation. However, like the down zoning scenario, the wetlands/ water buffer scenario is predicted to push additional development into the Pinelands Management Areas, to make-up for the greater amount of land outside the Pinelands Management Areas that is constrained.

The results of the open space scenarios raise some concerns about open space protection as a way to protect regional conditions. Although preserving open space may have large local benefits, none of the scenarios were successfully able to reduce the level of forest fragmentation and attrition predicted to occur across the region under baseline conditions. These results may be because attempting to protect 15 percent of the landscape is too little, but when a scenario protecting 30 percent of the study area was modeled similar forest changes were still predicted. The similarity between all open space scenarios and the baseline scenario may be a result of the selected pieces of open space, which tended to have relatively low transition likelihood values, indicating that many cells would not have converted to urban uses in the model anyway. Thus, in the short-term the location of urban development is not predicted to vary greatly, but in the long-term additional open space would reduce the overall level of urban development.

If the pieces of land targeted by the Trust for Public Land and Pinelands Commission are the focus of protection, then the specific selection process should not matter, but there were differences between the other open space scenarios. The most common open space selection method, hotspot selection, is predicted to be least successful at protecting open space. It is associated with greater forest fragmentation as land is protected adjacent to existing development, forcing new development to leapfrog outwards. The greater protection success of the coldspot selection method, suggests it may be more effective to select land that is not currently threatened

by development rather than trying to stay one step ahead of developers by protecting hot-spots. Coldspot selection would also translate into a larger positive effect over a longer timeframe, because it may take several more years for urban development to reach the areas where open space is protected under the coldspot process, whereas development pressures are already affecting the land around the areas targeted under a hotspot selection approach.

The results of this study suggest that adoption and reliance on commonly used planning approaches will be insufficient for this and other areas experiencing similar patterns of urban development if the goal is to maintain current conditions. While the model was designed to focus on shifts in location, the results of the study indicate that it will require more than just locational shifts to alter future impacts. At a minimum, reducing the per capita consumption of land for urban uses is needed. Down zoning and open space protection strategies may have some positive localized ecological benefits, but the results of this study indicate that both strategies have the ability to increase negative impacts by creating more dispersed development patterns.

Model Design and Limitations

One of the advantages of examining policies by predicting future land use is that alternative plans can be developed before irreversible land use conversions occur (Lee and others 1998). As a result of the future land use model design, questions about the long-term success of commonly used policies adopted to minimize the ecological impacts of urban development are raised, indicating alternative approaches should be explored. A potential criticism of the approach used here is that it assumed any policy would have full implementation and compliance. While this is unlikely, evaluating the potential consequences of fully implemented policies is important as Walker and Solecki (1999) noted successful plan implementation does not guarantee a plan's stated goals will be met. In this case, it appears that even full implementation and

compliance of any of the policies examined would not help meet stated regional goals. However, only patch level impacts are explicitly considered in this paper, while other ecological impacts such as water quality, terrestrial habitat connectivity, and site/ species specific conditions are not explicitly examined. More work is needed to identify additional ecological indicators that can be incorporated into the modeling approach to address the broader impact of different land-use policies.

The ability to test goal success (or ecological impact), rather than plan implementation success, is a result of the policy modeling approach focusing on the spatial implications of the modeled policies rather than how a given policy might alter the social process of development. While an ecological policy modeling approach may appear to be limited in some respects, as urban development is primarily a social process, if the given policy is unable to produce the desired ecological conditions, then the social impact is irrelevant. Only after a policy has been evaluated for its potential ecological success, should the economic and/or social impacts of the given policy be explored.

The approach outlined in this paper has two key limitations. First, the model assumes the same number of cells will convert under each policy. Yet this is unlikely, especially for policies such as cluster development, which often lead to a different housing type. Alternative footprint sizes would also be likely under affordable housing and “Smart Growth” policies attempting to create more compact forms of development. Future works needs to consider how policies associated with these altered housing topologies can be incorporated into the model. The second limitation is that each policy is considered separately even though several of the policies modeled are not mutually exclusive. It is also possible that the effects of adopting two or more policies would not merely be additive, with more complex interactions effects existing. While the model can now account for the additive constraints of multiple policies, it does not allow for other

interactions between policies. Future work should explore the possibilities of representing more complex interactions, as it is reasonable to assume that several of these policies may be adopted simultaneously.

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Table 1. Model validation results.

Statistic	1995 Study Area	2000 Study Area	1995 Great Egg Harbor
ROC	0.866	0.748	0.763
Kappa	0.997	0.927	0.887

Table 2. Land use policy scenarios modeled

Scenario	Description
Baseline	Is based on current land-use policies.
Down zoning	Imposes a minimum lot size of 1.2 ha in non-sewer service areas.
Cluster	Requires new urban development to occur in clusters of two or more cells or adjacent to existing urban development.
Water buffers	Creates an undevelopable buffer zone of 91 m around all freshwater and 152 m around all tidal areas.
TPL/PC-hotspot	Selects targeted land equal to 15 % of total study area to protect as open space, prioritizing protection of areas most likely to develop.
TPL/PC-coldspot	Selects targeted land equal to 15 % of total study area to protect as open space, prioritizing protection of areas least likely to develop.
TPL/PC-large	Selects targeted land equal to 15 % of total study area to protect as open space, prioritizing protection of largest patches.
Other-hotspot	Selects non-urban patches greater than 4 ha to protect as open space, prioritizing protection of areas most likely to develop, until 15 % of total area protected.
Other-coldspot	Selects non-urban patches greater than 4 ha to protect as open space, prioritizing protection of areas least likely to develop, until 15 % of total area protected.
Other-large	Selects non-urban patches greater than 4 ha to protect as open space, prioritizing protection of large patches, until 15 % of total

area protected.

Table 3. Total area and patches of land protected in open space scenarios

Scenario	Area			Patches	
	Considered for protection (ha)	Percent fully protected ¹	Percent not urbanized ²	Considered for protection	Percent fully protected ¹
TPL/PC- hotspot	45,451	9	94	195	55
TPL/PC- coldspot	45,451	9	95	195	55
TPL/PC- large	45,451	9	96	195	55
Other- hotspot	45,451	9	92	1,013	29
Other- coldspot	45,451	60	>99	653	95
Other-large	45,451	34	99	83	29

1. Assumes that if any urban cells are predicted to occur within the designated open space patch before it is scheduled for protection then none of the patch will be protected.

2. Assumes that even if urban cells are predicted to occur within a designated open space patch the remaining non-urbanized area can be protected.

Figure Captions

Figure 1. The Barnegat Bay and Mullica River watersheds.

Figure 2. The process used to locate new urban development in the baseline (A), down zoning (B), and cluster development (C) scenarios.

Figure 3. Pattern metrics for the baseline scenario from 2000 to 2020.

Figure 4. Predicted urban development between 2000 and 2020 under baseline conditions.

Figure 5. Predicted degree of cell class similarity between 2020 baseline and other policy scenarios.

Figure 6. Predicted urban land use pattern metrics for the policy scenarios.

Figure 7. Predicted forest pattern metrics for the policy scenarios.

Year 1

Interim Stage

Year 2

A

B

C

Existing Urban Development

New Urban Development

Constraint

2000

2005

2010

2015

2020

Land Use

Urban

Non-urban

Water