Current and future patterns of land use change in the coastal zone of New Jersey, USA.

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Abstract

Recent urban development along the US coasts has negatively impacted the local environment, and these impacts will only increase due to rapid regional population growth. Empirical spatially disaggregate land use models provide a way to explore future conditions and environmental impacts before irreversible changes occur. An assumption of many models is that access to urban/employment centers is the major factor locating urban uses within a region, the opposite of the pattern seen in most natural amenity rich areas. As a result, it is unclear if models focusing on center accessibility can be used to predict future land use patterns in urbanizing coastal regions. In this paper, the relationship between accessibility and the location of urban development was examined for coastal New Jersey, USA. Two questions were addressed through the analysis: (1) Is accessibility to urban or employment centers correlated with the location of urban conversions? (2) If accessibility is correlated with the location of urban conversion, does the inclusion of such variables into a land use change model improve the model's ability to locate future urban development? Results from the analysis indicate that traditional accessibility relationships can be used to explain the location of urban conversions in New Jersey's coastal region, but inclusion of accessibility and other locating factors does not necessarily improve a model's predictive ability. The accessibility relationship is contrary to findings in many other high amenity areas, due, in part, to the importance of access to the region's transportation network.

1 Introduction

Recent urban development in many coastal regions has lead to increased water pollution (Beatley et al, 2002; Kennish, 1992), shoreline modification (Nordstrom, 2000), and destruction and degradation of terrestrial and aquatic habitat (Beatley et al, 2002). Threats to coastal environments will only increase in the US, as populations in coastal counties are growing approximately twice as fast as inland counties (Bartlett et al, 2000). In order to develop appropriate responses to address future environmental impacts in coastal regions there needs to be a greater understanding of the factors related to the current patterns of development, as well as the patterns of potential future urbanization (Costanza et al, 1990).

Empirical spatially disaggregate land use models provide a way to explore the current patterns, understand the processes behind those patterns, and predict future conditions before irreversible changes occur. Drawing on several theoretical explanations of land use conversions (Alonso, 1964; Christaller, 1966; Hall, 1966; Ricardo, 1992), variables representing biophysical, socioeconomic, and spatial policy factors are often included in these empirical models to identify sites most likely to convert to a given land use (Berry et al, 1996; Veldkamp and Fresco, 1996; Verburg et al, 2004a). Models representing urban land use change tend to focus on accessibility to existing urban/ employment center(s) as a key determinant of the location of conversions (Berry et al, 1996; Bockstael, 1996; Schneider and Pontius, 2001). However, it is unclear if the emphasis on accessibility is appropriate for urbanizing coastal regions due to the patterns of new development seen in other natural amenity rich areas, as well as existing land use patterns on coastal barrier islands and sites immediately landward of waterbodies. In these situations, urban development tends to occur in isolation and/or closest to natural amenities irregardless of access to urban centers (Nordstrom, 2000; Orr, 1997; Theobald and Hobbs, 1988; Thomlinson and

Rivera, 2000). The pattern of isolated or disjoint urban development is also increasingly occurring in rural counties (LaGro, 1994) and the urban-fringe (Paterson and Connery, 1997) throughout the US. While these patterns may be explained, in part, by homebuyers' tendency to prioritize a natural or rural setting over access to existing urban/ employment centers (Kaplan and Austin, 2004), this behavior is contrary to the emphasis of accessibility in many land use change models, raising questions about the appropriateness of predicting future urban development patterns along the US coasts using standard locating factors.

In this paper, the relationship between accessibility, other hypothesized conversion locating factors, and the location of urban development is considered through an examination of current and future land use patterns in two coastal watersheds located in southern New Jersey, USA. The region's combination of natural amenities (BBEP, 2001a) and distance to several major urban centers (Atlantic City, Philadelphia, and New York City) indicate it is typical of other urbanizing coastal areas in the US. Two questions are addressed through the analysis: (1) Is accessibility to urban or employment center(s) correlated with the location of urban conversions in the study area? (2) If accessibility is correlated with urban conversion location, does the inclusion of accessibility variables into a land use change model improve the model's ability to locate future development? Predicted future land use patterns are then examined in an initial effort to consider possible environmental consequences of additional change in the study area.

2 Accessibility and Other Correlates of Urban Conversions

Numerous models have been used to study land conversions and the location of specific activities in urban landscapes, with differences in the approach employed primarily explained by differences in the purpose of the study (Verburg et al, 1999). One avenue of urban models explicitly examines specific land use location, transportation, and/or public policy interactions using spatial interaction approaches derived from gravity theory (Putman, 1983) or econometrics (Landis and Zhang, 2000; Waddell, 2002). An alternative approach, which is employed in this paper, focuses on changing landscape patterns, due to the location of land use conversions, and the factors correlated with those patterns. When applied to urbanizing landscapes, land use change models primarily represent the conversion from non-urban to urban. These models tend to use spatial transition or regression-based approaches (Theobald and Hobbs, 1998). Spatial transition models include cellular automata, which have been extensively used to represent urban growth patterns (Batty and Xie, 1994; Clarke et al, 1997; White and Engelen, 1993). Spatially explicit Markov models are one form of cellular automata (Zhou and Liebhold, 1995), where future change is based solely on the current land use of the cell or surrounding cells (Turner, 1987). On the other hand, regression-based models emphasizing changes in landscape patterns tend to focus on the relationship between the location of land use change and potential factors correlated with such change as a way to predict future patterns (Schneider and Pontius 2001).

Considerable attention has been given to identifying both large scale driving forces and more local determinants of land use change. Large scale driving forces include socioeconomic and biophysical factors (Lambin et al, 2001), such as shifting economic conditions, technological innovations, population growth, and climate change (Meyers and Turner, 1994). Alternatively, the specific location of change is usually assumed to be related to biophysical, spatial policy, and socioeconomic factors affecting site or neighborhood characteristics (Verburg et al, 2004a). It is these locating factors that are often incorporated into spatially disaggregated regression-based models emphasizing land use patterns.

Biophysical characteristics and social policies are potential locating factors that either enable or constrain conversions to a given land use. In models of urbanizing landscapes, existing land cover or vegetation is often used to represent the ease of clearing the land for development (Turner et al, 1996). Steeper slopes are assumed to be more difficult, thus less likely, to develop (Turner et al, 1996), while elevation has been used to represent vegetation and climatic differences (Berry et al, 1996; Turner et al, 1996), flooding potential (Schneider and Pontius, 2001), and/or view (Wear and Bolstad, 1998). In natural amenity rich and ex-urban areas, view is often an important consideration for new homebuyers (Kaplan and Austin, 2004), with a view of natural features correlated with the likelihood of a given site being developed (Geoghegan et al, 1997). Spatial policies such as open space protection (Bockstael, 1996; Veldkamp and Fresco, 1997) and zoning regulations (Bockstael, 1996) also influence or restrict the location of land use change within a given region (Verburg et al, 2004a).

While land price (Geoghegan et al, 1997), population density (Berry et al, 1996; Turner et al, 1996), and available services (Bockstael, 1996) are considered important socioeconomic factors in determining the location of urban development, accessibility to urban or employment centers is a common focus of predictive land use change models. The emphasis on accessibility is due, in part, to assumptions associated with equilibrium and utility maximizing individuals inherent in many of these models (Verburg et al, 2004a). While there is no single measure (Handy and Niemeier, 1997), accessibility is often represented as Euclidean (Bockstael, 1996; Schneider and Pontius, 2001) or functional distance (Berry et al, 1996; Turner et al, 1996; Wear and Bolstad, 1998) to a given center. An appropriate measure is more difficult to identify in regions with no clear urban or employment center(s). In these cases, alternative accessibility measures have been defined as the amount or percent of land covered by a given feature within a specified neighborhood (Geoghegan et al, 1997), Euclidean or functional distance to nearest highway exit following the local road network (Verburg et al, 2004b; White and Engelen, 2000), Euclidean distance to nearest urban cell (Pijanowski et al, 2002), and Euclidean distance to nearest road (Pijanowski et al, 2002; Turner et al, 1996). Pijanowski's et al (2002) findings in Michigan suggest even when a clear center does not exist accessibility to previously developed areas and transportation corridors may still be important.

3 Methods

3.1 Study Area and Land Use Data

The study area is the Barnegat Bay and Mullica River watersheds, located on the outer coastal plain in southeastern New Jersey, USA (Figure 1). The watersheds drain 2,900 sq km into the Great Bay and Barnegat Bay estuaries. Oak-pine upland forests dominate the region, while freshwater wetlands are located throughout the study area and salt marshes are present along the estuaries' edge. The region has long been valued for its natural amenities, with tourism beginning as early as the 1700s on the barrier islands (Lloyd, 1990). The number of summer tourists greatly increased with the completion of the railroad lines from New York City and Philadelphia in the 1870s, and a second wave of tourism growth occurred in the 1940s and 1950s with the completion of two bridges from the mainland to the barrier islands and a highway (the Garden State Parkway) running along the New Jersey coast (Cunningham, 1958). During this period, development followed typical near shore patterns, with most buildings located immediately landward of the shoreline (BBEP, 2001a). Today the barrier islands are completely built-out.

The year round population was very low and inland urban development limited to a few small towns scattered throughout the region until in the middle of the 20^{th} century (BBEP, 2001a). However, the rate of urban development exploded after WWII, associated with a population increase of more than 800 percent between 1950 and 2000 (US Census, 1990a, 2001). Post-WWII growth primarily took the form of large-scale suburban residential development located on the mainland. Several retirement communities were also built in the study area (Lathrop and Bognar, 2001), and the watersheds continue to attract retirees.

In 1995, the study area was 15 percent urban, 47 percent forest, and 31 percent wetlands. Four percent of the study area was used for agriculture and two percent was classified as barren land, a combination of transitional land and surface gravel mines (NJDEP, 2001). Though the absolute level of urban development in the two watersheds is relatively low (as compared to the rest of the Boston-Washington corridor), existing urban development has been associated with an increase in pollutants entering the estuaries, increased water withdraws reducing stream base flow and contributing to localized salt water intrusion, destruction of coastal habitats, and shifts in aquatic biota (BBEP, 2001a; Kennish, 2001; Zampella et al, 2002). Future urban development is expected to continue in the study area due to expansion associated with Atlantic City, Philadelphia, and New York City metropolitan areas, as well as people drawn to the area due to the natural amenities of the region.

As early as the 1960s there were efforts to protect the unique natural resources from urban development. In 1979, the Pinelands Management Areas (PLMA) and Pinelands National Reserve were established (Collins and Russell, 1988). Development in the PLMA (Figure 1), which includes the western section of the study area is now strictly limited in an attempt to maintain pristine habitat, protect water resources, and retain traditional agricultural practices. In response to human induced threats to the estuaries, the Barnegat Bay was accepted into the EPA's National Estuary Program in 1996, and the Jacques Cousteau National Estuary Research Reserve, focusing on Great Bay, was created in 1997. A watershed-wide management approach is used by both groups, due to the impact of land-based activities throughout the watersheds on the estuaries. Information about potential future conditions is essential for all three groups to develop appropriate management responses for the region.

Land use data was available for three years in the study area: 1986, 1995, and 2000. The 1986 and 1995 datasets, created by the New Jersey Department of Environmental Protection (NJDEP), are based on digital orthophotos and classified using a mixed land use/ land cover classification scheme (NJDEP, 2001). The 2000 dataset is an update of the NJDEP's 1995 data, based on airphoto and SPOT satellite imagery (Lathrop, 2003). 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. The three datasets were rasterized to a 63 m length cell (approximately 1 acre), and re-classified into five classes: urban, forest, barren, agriculture, and wetlands. As a result of the rasterization, each dataset contained 738,087 cells, of which 376,497 were available for development in 1986 (i.e. not already urban or permanently protected open space). The 1986 and 1995 data were used to identify the relationship between hypothesized conversion factors and the location of urban development, while the 2000 dataset was used in the validation of the future land use model.

3.2 Current Land Use Pattern Correlates

The relationship between the location of urban conversions, accessibility, and other factors was explored through a regression analysis of change between 1986 and 1995. The equation derived from this analysis was then used to predict future transition likelihood values as a way to further assess the importance of selected variables in locating urban development, and to begin to consider the environmental impacts of future development patterns. A logistic regression approach was used due to the categorical dependent variable, defined as no change (0) or change to urban (1), with change as the predicted outcome. The logistic function is based on a curvilinear response between the dependent and independent variables, defined as:

$$\pi(x) = \mathrm{E}(Y \mid X) = \frac{e^{(\beta_0 + \beta_i x_i)}}{1 + e^{(\beta_0 + \beta_i x_i)}}$$

where the expected value of Y for a given x (E(Y|x)) is bounded between 0 and 1 in the binomial model. Logistic regression is sensitive to spatial autocorrelation (Anselin, 1988), which is often present in spatially disaggregate land use datasets. Moran's I under a randomized assumption was calculated to test for autocorrelation. The results indicate that there is positive spatial autocorrelation of the dependent variable, so the data was sampled at a spatial distance above the level of influence (630 m). Cells were sampled on a regular lattice with every 10^{th} cell retained, resulting in 3,804 cells included in the logistic analysis.

Table 1 gives the hypothesized correlates of urban development location considered for inclusion in the logistic model, including eight measures of accessibility. DEXIT represents the accessibility of each cell to the existing regional transportation network (limited access state and interstate highways). This was used as the primary accessibility measure as the region lacks a clear center and residents of the study area work in over twenty counties throughout New Jersey, Pennsylvania, and New York State (US Census, 1990b). DROAD is a simple accessibility measure representing the ease of gaining access to the site during construction and the degree of isolation from neighboring development. Accessibility to urban areas was also considered using the percent of urban land within a 1.0 km neighborhood (a walkable distance) surrounding each cell (PURBAN_1.0) and Euclidean distance to the nearest existing urban cell (DURBAN). If normal assumptions associated with accessibility hold, the shorter the distance to the nearest highway exit, local road, and existing urban cell or the greater the percent of urban uses within a 1.0 km neighborhood the greater the likelihood that the cell converted to urban uses between 1986 and 1995. Alternatively, development patterns immediately adjacent to shorelines and in other natural amenity regions are often related to access to natural features. Thus, four additional accessibility variables were included to represent accessibility to protected open space and water (freshwater lake, estuary, or ocean).

Eleven variables representing biophysical, spatial policy, and other socioeconomic factors were also included in the analysis. Land cover and land use in 1986 was the sole biophysical factor included, as other commonly considered factors (elevation, slope, and soil type) are very homogeneous in the study area. Three variables (FLOOD, PLMA, ZONE_DEN) were included to represent areas where land use policies have spatially constrained the type of development that can occur on a site. In addition to the accessibility measures, three other socioeconomic factors were considered: population density, sewer service availability, and view. View was defined using neighborhood variables, following Geoghegan et al (1997), as the study area lacks any substantial elevation change. Based on traditional relationships, it is assumed urban conversions were more likely to occur on land currently used for agriculture or barren, outside the floodplain, in zones allowing high intensity development, outside the PLMA, in municipalities with higher population densities, and at sites with sewer service. A view of water (freshwater lakes, estuary, or ocean) or protected open space is assumed to be a desired amenity based on relationships in other regions (Geoghegan et al, 1997; Nordstrom, 2000; Orr and Pickens, 2003), while a view of urban land uses was assumed to be undesirable.

Significant explanatory variables were identified using a step-wise selection process. As there was some correlation between the independent variables, most notably the features define by Euclidean distance, a 1.0 km neighborhood, and a 0.1 km neighborhood, alternative combinations of variables were included in different analyses. A correlogram of the residuals was calculated using Moran's I to test for autocorrelation, and tolerance and inflation values were calculated to further explore the possibility of mulitcolinearity (Davis et al, 1986).

3.3 Land Use Change Model

The analysis of 1986 to 1995 urban change was used to calibrate the future land use change model. Urban land use is considered a terminal state in this model, so conversions from urban to non-urban classes were not allowed. However, conversions between non-urban classes were included using a spatially explicit Markov model (Turner, 1987), with transition likelihood defined by a 10 x 10 cell neighborhood. Conversions to urban land uses were restricted from cells protected as open space, open water, or already urban cells, while conversions between non-urban classes could occur on any non-urban, non-open water cell.

The model was run using a five year time step from 1995 to 2020. For each time step, the cells with the highest urban transition likelihood values, based on the regression equation, were selected to convert to urban uses. The number of cells converting was determined using a linear extrapolation of historic growth. While it is likely that the rate of growth will change over time, a simple linear extrapolation was used because the location, not the exact timing, of urban conversions is the focus of the model. Between 1986 and 1995, 15,374 new urban cells were identified, so for every five year time step the 8,541 cells that are predicted to have the highest transition likelihood values are converted to urban. After each time step, the input variables are updated and the transition likelihood values recalculated.

3.4 Model Validation

One of the limitations of most future land use models is that they are calibrated using past land use change, while conditions are likely to alter in the future. Long calibration time periods can be used to try to minimize this problem, but do not eliminate it. The calibration data for this study represents a fairly narrow time period (nine years). Previous studies in the region (Luque, 2000; Walker and Solecki, 1999) found that there was a shift in the amount and pattern of urban growth between the 1970s and 1980s, likely a result of the adoption of the Pinelands Management Plan. Thus, the patterns of conversions seen during the calibration time period are quite different from previous decades, but likely similar to future patterns if no new land use policies are adopted.

The amount of urban growth appears to be high during the calibration years, with an average of 8,541 cells converting every five years from 1986 to 1995 and only 5,742 cells converting between 1995 and 2000. While it is likely that some of the rate variation is due to data creation and classification issues, the 33 percent decrease suggests that urban growth was occurring at a slower rate during the second time period. However, the population in the region increased at a constant rate between 1980 and 2000 (US Census, 2001). The difference in the rate of urban conversions and population growth could be a result of (1) the land use data dates (1986, 1995, 2000) highlighting non-linear populations increases which are masked in the decadal census counts and/or (2) many more second homes being constructed between 1986 and

1995 than in the later time period, corresponding to a higher urban conversion rate but similar increase in population growth.

The factors contributing to the change in the rate of urban growth could also alter the spatial pattern of new urban development, meaning that the model would not be able to accurately predict the location of future development. To minimize the potential for future predictions to be based on a calibration time period where a unique or unusual set of factors were driving the urban development process, the model was tested to see if it could (1) predict the location of conversions in another time period (1995 - 2000) if the rate of urban conversions was correctly calibrated for that time period and (2) predict the location of urban development in a neighboring region with similar characteristics. If the model is adequately able to predict land use in these scenarios, then it should be appropriate to use the model to predict future land use.

As a final step, to test if including the significantly correlated locator variables improves the accuracy, predicted land use from the logistic model was compared to the results of a simple Markov model, with change based solely on the land use at the start of the time step for the cell and surrounding 5 x 5 cell neighborhood. Results for both models were examined for three dates (1995, 2000, and 2020) and two locations (Barnegat Bay and Mullica River watersheds and the neighboring Great Egg Harbor watershed; Figure 2). The Great Egg Harbor watershed dataset has 355,331 cells, of which 245,299 are available for urban development in 1986.

The different model specifications were evaluated for accuracy of predicted cell location using visual interpretation, the ROC statistic to compare transition likelihood values with reference data (Pontius and Schneider, 2001), and a Kappa statistic commonly employed to compare categorical maps (Rosenfield and Fitzpatric-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. However, the Kappa values may be inflated as the majority of cells will not be predicted to change in a given time step, increasing the likelihood that the correct state of a cell has been predicted simply due to class persistence (Pontius et al, 2004). This limitation highlights the importance of visually comparing the location of cells predicted to change with a reference dataset.

To further explore the differences between the predicted land use patterns and reference datasets, several common spatial patterns metrics (Flamm and Turner, 1994; Swenson and Franklin, 2000) were calculated: percent of total landscape, number of patches, and mean patch size. Landscape patterns are also a good way to begin to consider environmental impacts as changes in landscape pattern often result in alteration of ecological processes (Forman, 1995).

4 Results

The explanatory variables that were best able to account for the location of new urban development between 1986 and 1995 are given in Table 2. The ROC value of 0.89 indicates that the equation is a good fit (Hosmer and Lemeshow, 2000), while the residuals do not show spatial autocorrelation and the tolerance and variance inflation values indicate no multicolinearity present between the six significant variables.

Based on the estimated coefficients for DEXIT, DROAD, and PURBAN_1.0 traditional assumptions of accessibility appear appropriate for the study area, contrary to urban development patterns in other natural amenity rich areas. Distance to nearest urban cell, open space, and water were not significantly related to urban development. Surprisingly, only one amenity variable was included (POPEN_1.0) but the negative coefficient indicates greater accessibility to open space is related to a lower rate of urban conversion, the opposite of the relationship in other regions (Geoghegan et al, 1997). The inclusion of FOREST and BARREN is not surprising since forest is the dominant land use/ land cover class and cells classified as barren often represent transitional land about to be developed.

4.1 Future Model Validation

The logistic model has high ROC values for both dates and locations (Table 3), indicating that the model using the six significant variables is accurately differentiating between cells more and less likely to convert to urban from 1986 to 2000. A comparison of the kappa statistics for the logistic and Markov models indicate that the models performed equally well in the Barnegat Bay and Mullica River watersheds in 1995 and 2000, but the Markov model was better able to predict the location of urban development in Great Egg Harbor watershed in 1995 (Table 3). These results are confirmed by a visual examination of the predictions and reference data (Figure 2), with the logistic model predicting less aggregated urban development than seen in the Markov model or reference dataset.

The relatively poor performance of the logistic model in Great Egg Harbor is likely due to the calibration process. The Markov model was re-calibrated for the Great Egg Harbor watershed, while the logistic model was calibrated to the Barnegat Bay and Mullica River watersheds. Applying a Markov model calibrated using Barnegat Bay and Mullica River watershed data to the Great Egg Harbor watershed results in predictions that have a similar level of accuracy as the logistic model. The logistic model appears to over-emphasis the importance of DROAD, which may be a result of the higher road density within the Great Egg Harbor watershed as compared to the Barnegat Bay and Mullica River watersheds. Overall, the comparison of these two models indicates that incorporation of the correlates of urban development location, as oppose to only starting cell states, does not appear to improve the accuracy of future predictions.

The kappa index of agreement for predicted location of new urban cells between 1995 and 2020 for the logistic and Markov models is 0.91, although these values are likely inflated due to the relatively low percentage of cells predicting to convert to urban. Differences between the logistic and Markov models are more apparent from the landscape metrics (Table 4). The logistic model predicts slightly more urban cells and greater urban aggregation than the Markov model, resulting in 14 percent fewer urban patches and a mean patch size 23 percent larger. As a result of the predicted urban cell locations, forest, barren land, and wetlands are more aggregated in the logistic model predictions than in the Markov model predictions. These differences are primarily a result of the logistic model's emphasis on new urban development locating near roads (Figure 3), particularly in the Southeast section of the study area. Although the logistic model appears to over-emphasize accessibility to local roads in Great Egg Harbor watershed, the focus on local road accessibility in the Barnegat Bay and Mullica River watersheds is more reasonable, as many cells are further than two kilometers from the nearest road indicating there will likely be a wide range in construction costs and general isolation associated with distance to nearest road. Since the logistic model's predictions appear more appropriate for the study area through 2020 those results are examined in-depth below.

4.2 Predicted Future Change

Between 1995 and 2020, urban land uses are predicted to increase by 40 percent, while forest land is predicted to decrease by 9 percent (Table 5). Most of the new urban development is located outside the PLMA in the northern section of the watershed, landward of the estuary's western edge, and along the southern edge of the study area (Figure 4). Wetlands and agriculture are predicted to remain stable, with most new urban development predicted on forest and barren land. While the model indicates that the absolute level of barren land will likely be constant through 2020, most barren cells in 1995 will not be barren in 2020, with existing barren land developed and new land cleared.

In 1995, the relatively large mean patch size for forest and wetlands and high number of urban patches indicates that forest was still highly aggregated, although the urban patches dispersed across the study area suggest some fragmentation had already occurred (Table 5). From 1995 to 2000, forest continued to fragment, with a four percent increase in the number of patches and six percent decrease in mean patch size. Patch shrinkage is predicted to be the dominant spatial process affecting forest between 2000 and 2005, with mean patch size decreasing by four percent and the number of patches remaining stable. Finally, from 2005 to 2020 forest attrition is primarily predicted, illustrated by a 13 percent decrease in the number of patches. On the other hand, linear changes are predicted for urban patches. Mean patch size is predicted to increase 104 percent, while the number of patches is predicted to decrease 33 percent between 1995 and 2020. These results indicate new urban land use is predicted to occur adjacent to existing development, connecting previously disjoint urban patches.

5 Discussion and Conclusions

Results of the regression analysis suggest that urban development in New Jersey's coastal region is occurring in the most accessible areas, contrary to many other natural amenity rich areas (Theobald and Hobbs, 1988; Thomlinson and Rivera, 2000). The relationship between accessibility to highways and the location of new urban development is not surprising because the region's commutershed, defined as the location of employment for local residents, includes every county in New Jersey and extends into Pennsylvania and New York, with most residents working outside their county of residence (US Census, 1990b). Access to highways is also seen a key determinant of the location of urban conversions in other urbanizing regions (Stanilov, 2003).

While access to the existing transportation network and existing urban development are related to urban conversions, cells closer to natural amenities were no more likely to be developed and cells closest to protected open space were actually less likely to convert to urban uses. The natural amenity results could be due to amenity misidentification, existing development patterns, and/or land use regulations. The large percentage of second homes in waterfront municipalities within the study area (US Census, 2001), high boat traffic in the estuary (BBEP, 2001a), and relationship between protected open space and land price in other areas of the Mid-Atlantic region (Irwin and Bockstael, 2001) indicate that water and protected open space are desirable neighborhood amenities. Water presence within a 1.0 km or 0.1 km neighborhood zone is not positively or negatively related to urban development probably because most of these areas are already developed, while exclusion of the Euclidean measure of water accessibility may be a result of a steep distance decay relationship between distance to waterfront and urban development likelihood.

Zoning density and inside/outside the PLMA (where most of the open space and restrictive planning zones are) were not significant explanatory variables, but the 1.0 km neighborhood around open space may represent a specific aspect of the land use regulations that is impacting the location of urban development, with very restrictive planning zones often located next to existing open space (Walker and Solecki, 1999). Furthermore, the absence of zoning density as a significant explanatory variable is not surprising as much of the urban development in the region is occurring below maximum density (McKeon, 2001), suggesting that zoning densities are often not a constraining factor.

Future land use can be used to determine potential environmental impacts and likelihood of management plan success based on current conversion trends. Protection of the region's water resources is the focus of several regional management plans (BBEP 2001b; Pinelands Planning Commission 1982), but the results of this analysis indicate mixed success in the study area. Urban conversions are predicted to occur on less than one percent of wetlands, suggesting that the freshwater wetlands and salt marshes in the region will be maintained. However, urban development was predicted adjacent to many wetlands and streams, likely impacting the natural integrity of the headwaters and downstream estuary due to the strong relationship between land use, water quality, and biota in the region (Zampella et al, 2002). Urban growth is also predicted to occur inside designated regional growth areas, even though this is not forced in the model, highlighting the appropriate placement of the Pinelands Management Plan's growth and preservation areas. While future forest uplands are predicted to continue to fragment, suggesting many ecological processes may be impacted between now and 2020, urban uses will become more aggregated. This would result in the elimination of remnant forest patches, but cause few changes to the more intact forested areas. Finally, agricultural land was predicted to remain stable, indicating regional goals of maintaining current agricultural activities will be met. Future work should to more explicitly explore the impact of predicted changes on the local environment, with particularly emphasis on water resources.

The results of this study do not reflect the relationships seen in many other high amenity areas, but the trend of increased commuting from rural, amenity rich areas to other regions is highlighted. Nationally, working age people are disproportionately moving to the Gulf and Atlantic coasts in the US (Frey, 1995), supporting the result that commuting ease will be an increasingly important consideration in locating urban development in these regions. Thus, predictive models emphasizing accessibility are appropriate if current population trends continue.

Although accessibility characteristics were correlated with the location of urban development, including these variables into a land use change model did not necessarily improve the predictive ability of the model. In the short-term (5 years) the logistic and Markov models performed equally but in the long-term (25 years) the predictions associated with the logistic model appear more reasonable. The mixed results are partly due to difficulties in validating future predictions. Lacking a crystal ball, one can evaluate future predictions based on reference datasets, knowledge of the study area and model, and/or comparisons of predicted historical conditions and reference datasets. The first two methods were used here, while predicting historical conditions was not appropriate for the study area due to clear shifts in the urban development process between the 1970s and 1980s (Luque, 2000; Walker and Solecki, 1999).

Of course validation approaches, as well as most calibration processes, are limited because they assume that the land use conversions process will be stable over time. As land use change is a result of many complex driving forces (Meyer and Turner, 1994) and locating factors

(Verburg et al, 2004a), it is unlikely that the process will remain static. By including hypothesized factors associated with the location of urban development, a model can be further tested by considering how changes to driving factors would alter the location of land use changes and the sensitivity of the model to input variables. Thus, while this study indicates models emphasizing accessibility variables can be used in the urbanizing coastal regions of the US, further work should more specifically explore how changes in accessibility would alter patterns of development, as well as the environmental and socioeconomic consequences of those changes.

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Table 1. Explanatory variables used to represent correlates of urban development location.

Name	Description
DEXIT	Meters to nearest highway exit following the local road network
DROAD	Meters to nearest road
PURBAN_1.0	Percent of urban land within 1 km neighborhood
DURBAN	Meters to nearest urban cell in 1986
DOPEN	Meters to nearest protected open space in 1986
DWATER	Meters to nearest body of water in 1986
POPEN_1.0	Percent of protected open space within 1.0 km neighborhood in 1986
PWATER_1.0	Percent of open water within a 1.0 km neighborhood in 1986
BARREN	1986 state of cell is barren
FOREST	1986 state of cell is forest
WETLANDS	1986 state of cell is wetlands
AGRICUL	1986 state of cell is agriculture
FLOOD	Cell is located within 100 year floodplain
PLMA	Cell is located within PLMA
ZONE_DEN	Minimum lot size allowed by municipal zoning regulations
POPDEN	1986 population density of municipality
SEWER	Presence of sewer service
PURBAN_0.1	Percent of urban land within 0.1 km neighborhood in 1986
POPEN_0.1	Percent of protected open space within 0.1 km neighborhood in 1986
PWATER_1.0	Percent of open water within 1 km neighborhood in 1986

Table 2. Estimated parameters for urban conversions between 1986 and 1995.

Variable	β	S.E. (β)	Wald χ^2	$P > \chi^2$
Intercept	-1.8727	0.3134	35.7141	<.0001
DEXIT	-0.00014	0.000023	37.5350	<.0001
DROAD	-0.0108	0.00131	67.8048	<.0001
POPEN_1.0	-0.0472	0.0154	9.3541	0.0022
PURBAN_1.0	0.0168	0.00485	12.0314	0.0005
BARREN	1.0657	0.2381	20.0433	<.0001
FOREST	1.9469	0.4244	21.0485	<.0001

Table 3. Statistics comparing predicted urban transitions and reference data.

Model	1995 Study Area	2000 Study Area	1995 Great Egg Harbor
		ROC	
Logistic model	0.86	0.77	0.76
		Kappa	
Logistic model	>0.99	0.93	0.89
Markov model	>0.99	0.94	>0.99

Table 4. Pattern metrics for 2020 predictions.

Class	Logistic Model	Markov Model
	Percent of Total Area	
Urban	21.3	20.1
Forest	43.1	44.2
Agriculture	3.6	3.3
Barren Land	1.1	1.5
Wetlands	30.9	30.9
	Number of Patches	
Urban	2840	3311
Forest	3983	3088
Agriculture	1195	1007
Barren Land	435	747
Wetlands	3405	3078
	Mean Patch Size	
Urban	21.9	17.8
Forest	31.6	42.0
Agriculture	8.7	9.7
Barren Land	7.7	5.7
Wetlands	26.6	29.4

Table 5. Pattern metrics for 1995 to 2020[a].

Class	1995	2000	2005	2010	2015	2020
			Percent of Total Area			
Urban	15.4	16.6	17.8	19.0	20.1	21.3
Forest	47.2	46.5	45.5	44.7	43.8	43.1
Agriculture	4.3	4.1	4.0	3.9	3.7	3.6
Barren Land	1.7	1.5	1.4	1.3	1.2	1.1
Wetlands	31.3	31.3	31.3	31.2	31.1	30.9
			Number of Patches			
Urban	4234	3934	3600	3271	3052	2840
Forest	4318	4525	4599	4394	4181	3983
Agriculture	1485	1330	1266	1206	1190	1195
Barren Land	709	810	773	517	460	435
Wetlands	3354	3344	3361	3367	3412	3405
			Mean Patch Area			
Urban	10.7	12.4	14.5	16.9	19.3	21.9
Forest	31.9	30.0	28.9	29.7	30.6	31.6
Agriculture	8.6	8.9	9.1	9.3	9.1	8.7
Barren Land	6.9	5.5	5.5	7.3	7.7	7.7
Wetlands	27.3	27.4	27.2	27.1	26.6	26.6

[a] Values for 1995 from the NJDEP LULC dataset, values for 2000 from the LU update, and values for 2005 to 2020 are based on logistic model predictions.

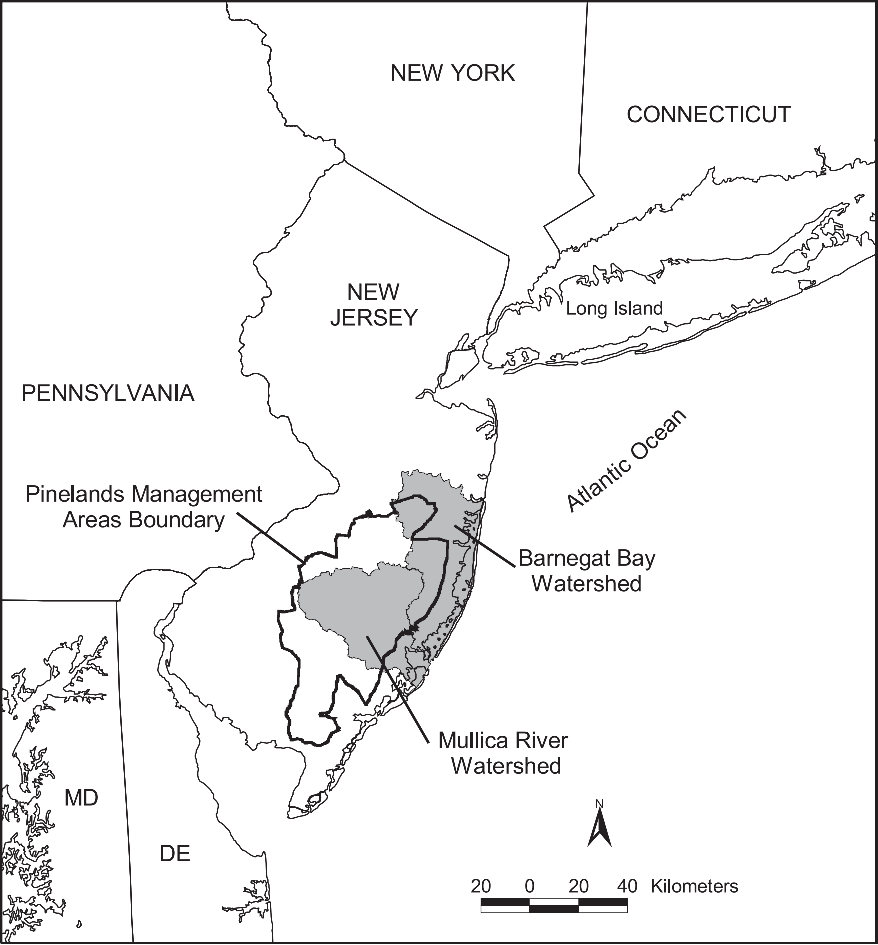
Figure Captions

Figure 1. The Barnegat Bay and Mullica River watersheds.

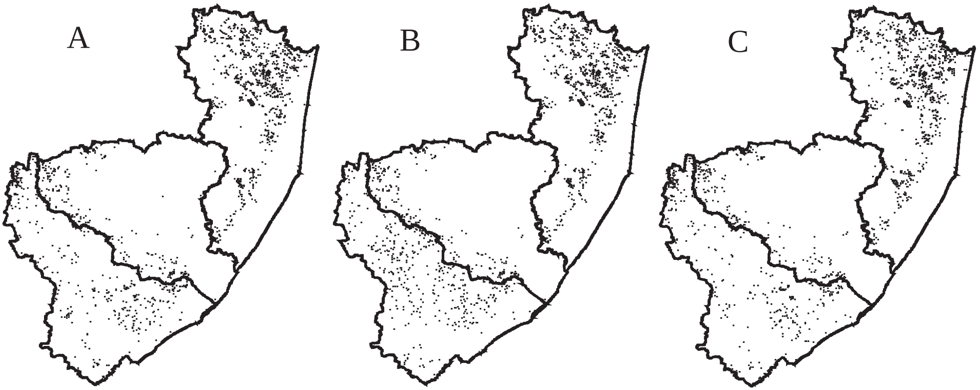
Figure 2. The location of new urban development from 1986 to 1995 and 1995 to 2000 for the (A) reference data, (B) logistic model, (C) Markov model.

Figure 3. Predicted urban change between 1995 and 2020 for the (A) logistic and (B) Markov models.

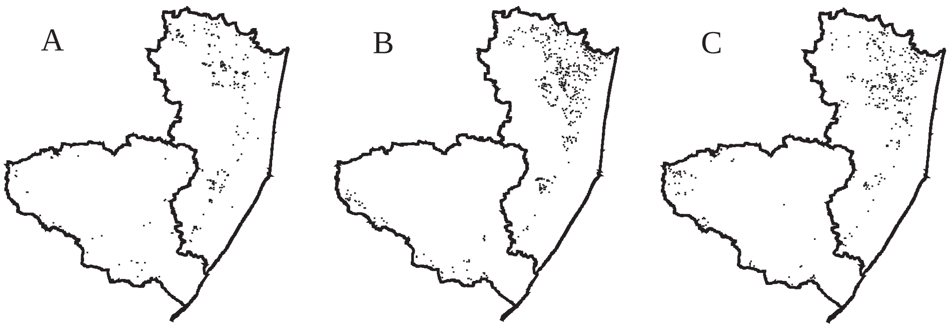
Figure 4. Urban land in (A) 1995 and (B) 2020.

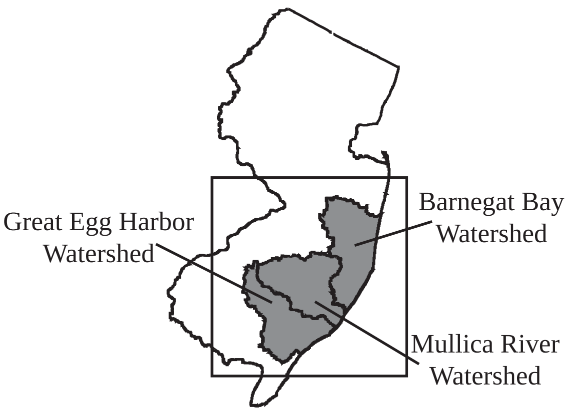

NEW YORK
CONNECTICUT
NEW JERSEY
Long Island
PENNSYLVANIA
Atlantic Ocean
Pinelands Management Areas Boundary
Barnegat Bay Watershed
Mullica River Watershed
MD
DE
N
20 0 20 40 Kilometers

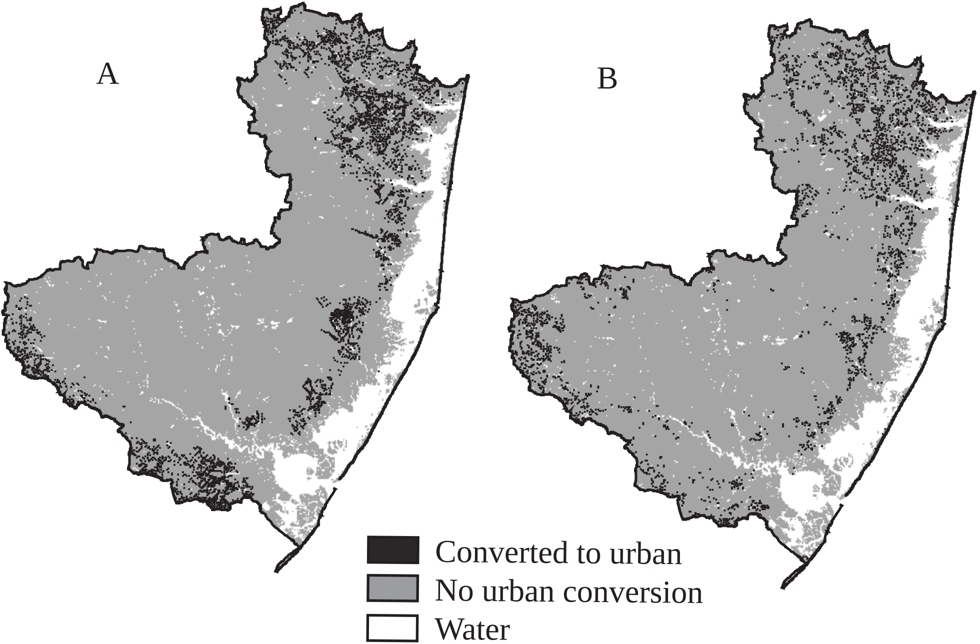
Urban Change 1986 to 1995



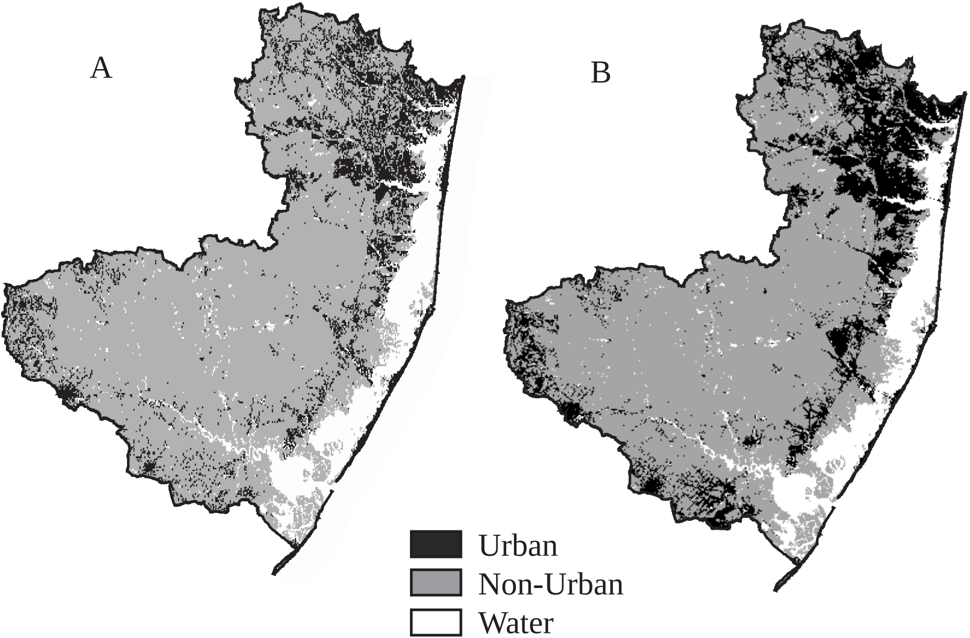
Urban Change 1995 to 2000







A
B
Converted to urban
No urban conversion
Water



A
B
Urban
Non-Urban
Water