Available online at www.sciencedirect.com
ScienceDirect
Landscape and Urban Planning 82 (2007) 1–16
LANDSCAPE AND URBAN PLANNING
This article is also available online at: www.elsevier.com/locate/landurbplan

Preserving natural features: A GIS-based evaluation of a local open-space ordinance

Jason J. Taylor [a,*], Daniel G. Brown [a], Larissa Larsen [b]

[a] School of Natural Resources and Environment, University of Michigan, Dana Building, 440 Church Street, Ann Arbor, MI 48109-1041, USA
[b] Taubman College of Architecture and Urban Planning, University of Michigan, 2000 Bonisteel Boulevard, Ann Arbor, MI 48109-2069, USA

Received 7 March 2006; received in revised form 18 January 2007; accepted 18 January 2007
Available online 13 March 2007

Abstract

To study the influences of a local land-use policy on the preservation of natural features, two sets of ten local-scale landscapes, divided in time by a land-use policy shift in Fenton Township, Michigan, were examined. The new policy implemented a 'sliding scale' for open-space in all new developments within designated zoning classifications. Land-cover data were created to represent pre- and post-development conditions for twenty sites, ten developed before the policy was implemented, and ten after. The magnitudes of the mean change in landscape characteristics from pre- to post-development were compared for the before- and after-policy groups.

According to this analysis, the policy's objectives of preserving natural features and rural character were not fully achieved. This failure may be explained by a lack, within the policy, of several key points: a definition of natural features; a requirement that they shall be preserved; and a spatial context for design decisions. The only significant effect of the policy was that which was clearly defined by it—to increase open or non-developed space. Empirical observations and recommendations were presented to planning officials at Fenton Township. The open-space policy was subsequently updated, based on the findings of the presented research, in an attempt to achieve the broader policy objectives.

Keywords: Open-space policy; Spatial-pattern metrics; Landscape ecology; Spatial analysis; Land planning

1. Introduction

Increasingly, we recognize that landscapes composed of natural land-covers provide a variety of important ecosystem services. For example, forests provide carbon fixation, oxygen production, hydrological flow regulation, prevention of soil erosion, timber harvesting, and recreation (Guo et al., 2001). Wetlands provide carbon and nitrogen cycling, climate stabilization, habitat for a large majority of the species considered endangered or threatened, nutrient and toxic filtering while recharging aquifers, and flood mitigation (Mitsch and Gosselink, 1993). Open fields or grasslands provide erosion control, waste treatment, pollination, and food production (Costanza et al., 1997). In urbanizing areas, these ecologically and socially important land covers are commonly fragmented and replaced by covers and uses associated with human habitation such as residential developments, commercial (e.g., shopping centers) and office facilities, and transportation and utility networks (i.e., infrastructure).

With the recognition of the importance of ecosystem services, many communities are trying to reduce the negative effects of the conversion of natural land-covers to anthropogenic land-covers by requiring or encouraging the use of retention and/or detention basins, porous pavement, vegetative buffers, and the preservation of existing trees. Nevertheless, land-cover alterations that result from development can have profound effects on the environment. These effects include the loss of native biodiversity, the introduction of exotic species, elevated soil erosion, and degraded water quality (Collinge, 1996).

Globally, alterations to the composition and configuration of contemporary landscapes are principally human-induced (Turner et al., 2001). It is estimated that between one-third and one-half of Earth's landscapes have been transformed by human actions (Vitousek et al., 1997). Between 1982 and 1997 within the United States (U.S.), lands considered to be urban or built-up

* Corresponding author. Tel.: +1 734 647 7341; fax: +1 734 936 2195.
E-mail addresses: jayt@umich.edu (J.J. Taylor), danbrown@umich.edu (D.G. Brown), larissal@umich.edu (L. Larsen).

0169-2046/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.landurbplan.2007.01.013

increased by 34% (United States Department of Agriculture et al., 1997; Alig et al., 2004). Between 1990 and 2000, the seven counties that comprise the Southeast Michigan Council of Governments (SEMCOG) region experienced increases in the areas of residential, commercial, and infrastructure land uses of 20%, 14%, and 5%, respectively. Lands considered to be under development (i.e., developing portions of platted parcels) increased by 84%. During the same decade, the categories of grasslands and shrubs, and woodlands and wetlands decreased by 8% and 3%. The most significant decrease within the region was a 14% loss of agricultural lands (Southeastern Michigan Council of Governments, 2004), which were usually converted to residential developments.

Land-use practices are typically guided by cultural factors such as history, economics, aesthetic preferences, social conventions, and politics (Nassauer, 1995; Brown et al., 2000). These factors contribute to the development of land-use policy, the goal of which is to systematically determine where various types of activities should occur in the landscape while optimizing the primary dimensions of land-use planning—ecological conservation and economic vitality (VanLier, 1998). In the U.S., little land-use planning occurs at the Federal or State levels; the majority of land-use policy and planning is controlled by local and regional authorities (Arendt, 2004). Within a typical community, land-use regulations specify lot size, building location, and acceptable uses. Increasingly some municipalities are adopting purchase, or transfer of development rights programs, conservation easements, environmental mitigation requirements, and conservation zoning techniques in an effort to reduce sprawling developments (Michigan Townships Association, 1998). These conservation zoning techniques can include neutral density, enhanced density, estate lots, country properties, and village designs (Arendt, 1997). Each development type differentially provides land conservation via density control, from large lots to cluster development zoning with defined open-spaces. Participation in these conservation options is usually voluntary for the land owner or developer, and designated lands are protected from development in perpetuity. Many municipalities interested in managing development at the urban-rural fringe have adopted the philosophy of large-lot and open-space land-use planning (Dwyer and Childs, 2004). Open-space planning, of primary interest in this study, has specifically been established to reflect human-perceived values related to land use, such as the maintenance of rural character and the preservation of natural features.

The reasons for adopting growth-management or anti-sprawl strategies, such as open-space planning, are presented in an extensive literature on the topic (Nelson and Moore, 1996). Less common in the literature are land-use policy-outcome evaluations that quantify the "real-world" effects of various growth-management policies within the U.S. (Nelson and Moore, 1996; Weitz, 1999; Hollis and Fulton, 2002; Bengston et al., 2004). Although generally absent, there have been a few evaluations addressing patterns of development and effects associated with specific growth-management policies (Nelson and Moore, 1996; Weitz, 1999; Robinson et al., 2005).

Evaluating a land-use policy's effectiveness requires determining how the landscape composition and configuration have changed as a result of the introduced policy. Any strategy for land-use policy evaluation will have limitations; however, some methods will have more limitations than others. Cross-sectional comparisons face the challenge of comparability. Making comparisons of land-use policy outcomes between, for example, states, is problematic. As Knaap and Nelson (1992) write, in the United States, "states differ in too many critical respects for rigorously comparing land use programs among them ..." (p. 37). Within-state comparisons, of the outcomes of land-use policy between different jurisdictions, are slightly less problematic. However, variability between jurisdictions within the same state may still influence the ability to compare outcomes of policy changes. Therefore, it is still important to note systematic variation in each jurisdiction's stated land-use objectives, administrative structure, planning capacity, planning procedures, selection of implementation tools, local land and housing market conditions, and idiosyncratic site characteristics.

Brody et al. (2006) provided an in-state comparison when they reviewed the comprehensive plans and zoning ordinances of 46 contiguous local jurisdictions in Southern Florida. Their research was done in an effort to understand if the community's social or physical characteristics were useful predictors of who was likely to include anti-sprawl land-use policies within official documents. The authors noted that one limitation of their study was that it "evaluates plans as guides for future development as opposed to determining how these policies are implemented after the plans are adopted..." (pp. 299–300). Brody et al. (2006) recommend that a "case-study analysis of specific jurisdictions would complement statistical analyses and provide a more detailed contextual picture" (p. 307).

Unlike cross-sectional comparisons, longitudinal comparisons remove jurisdictional variation but introduce temporal changes. Interest in evaluating the effectiveness of urban growth boundaries or, more recently, in smart growth policies has prompted some useful longitudinal evaluations (Nelson, 2001; Jun, 2004). However, these longitudinal evaluations of policy effectiveness generally use land values, housing prices, and farmland acres as the basis for their determinations.

Few longitudinal, land-use comparisons focus on the measurement of natural features or their subsequent ecosystem services. Girling and Kellet (2002) conducted a comparison of how residential design impacted storm water flows on a single site. They simulated the application of three subdivision designs (conventional low density, mixed-use medium density, and mixed-use lower density open-space design) to measure how design influenced storm water peak flow and stream nutrient loading. Findings pertaining directly to land-cover changes demonstrated that an open-space design provided over two-times as much open space, with only a moderate increase in planted or protected forest, as compared to conventional status quo, and medium-density mixed use medium density designs. Pollutant loads are noted as being "less than compelling" (p. 107) for all three development options. In reporting increased pollutant loads ranging from 200% to 500%, the authors demonstrate that any change in the site's land-cover has negative effects on surface water quality. The authors conclude that land-use policies that support higher density, mixed use, and greater human connectivity can either compete with, or complement, the goal of water resource protection. Girling and Kellet's study included simulated landscapes that were created by site planners and landscape architects for the sole purpose of analysis. Therefore, the scenarios are probable but not actual site plans, and the article does not state whether the designers of the three development scenarios were blind to the study's intent. Another challenge of that study is its applicability to other locations. Girling and Kellet's (2002) single-site case study provides encouragement for residential developments that contain significant areas of open space based upon storm water quantity and quality issues. Expanding the number of sites would be helpful in understanding how variations between sites influence the outcomes and this would help us to generalize the initial findings.

The intent of this paper is to evaluate the effectiveness of a zoning ordinance that encourages the preservation of open space within the developable portion of a site (exempting wetlands and floodplains) in exchange for increased residential densities elsewhere on the site. Our study adds to a limited literature by empirically assessing the effects of a newly introduced open-space policy on land-cover patterns in Southeastern Michigan's Fenton Township, and by comparing outcomes at multiple sites. Although we do not measure specific ecosystem services directly, the analysis of land-cover patterns is an appropriate strategy given that the policy is defined in terms of land cover.

Because the stated intent of the policy is to preserve natural features and rural character, we hypothesized that developments established after the policy was introduced would have a more positive effect (i.e., less decrease or greater increase in area) on forest and other natural land-cover classes as compared to developments established before the policy was introduced. Additionally, we hypothesized that the effect on wetlands would remain constant, primarily because they are federally protected and by Fenton Township definition are considered to be non-developable.

To test these hypotheses and measure the effects on subdivision-scale land covers, we drew on theories and techniques from the field of landscape ecology (Turner et al., 2001). To quantify landscape composition and configuration, landscape ecologists typically employ spatial-pattern metrics (McGarigal et al., 2002). Although Gustafson (1998) cautions that many pattern indices are of little use by themselves, their value in this case was in providing an objective means to compare alternate landscape configurations of the same landscape at different times. We compared the changes in landscape compositions and configurations caused by developments created before the policy with those created after the policy. Following a presentation of these results, we discuss the importance of spatial aspects to planning that can have substantial effects on landscape outcomes from development.

2. Methods

2.1. Study area

The Charter Township of Fenton in Genesee County, MI, USA (Fig. 1) is located on the northwestern edge of the most

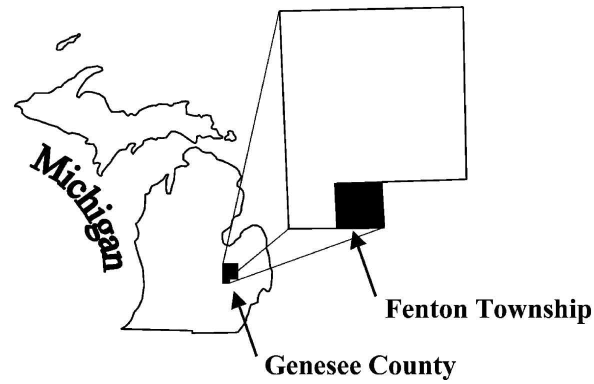

Fig. 1. The Charter Township of Fenton, Genesee County, MI, USA.

densely populated portion of the state (i.e., southeast Michigan). According to the 2000 Census, 12 968 residents and 5248 housing units were located within the 8500 ha (32.8 mile^2) township. Between 1990 and 2000, the township grew by 1556 new housing units, its largest recorded growth in a single decade. The previous three decades, 1980–1990, 1970–1980, and 1960–1970 grew by 629, 1065, and 901 new housing units, respectively. A review of historical aerial photography from 1941 to the present reveals the township's transition from agriculture with sparse tree cover to primarily residential with regenerating forests; isolated agricultural areas still remain throughout the township today. Notable is the amount of water and shoreline present within the township; it consists of 16% surface water, with 17 'named' lakes and a significant number (385) of other wetlands and water bodies totaling 1357 ha (5.2 mile^2). Until recently, the majority of the township's development was focused on the shorelines of the 17 primary lakes.

To support the community's rapid growth and protect its many water bodies, the Township introduced sanitary sewers to the most heavily populated portion of the township in 1968 (personal communication, Township staff). By 2003, the township was serviced by more than 110 mile of public sewer lines.

In 1999 the Planning Department at Fenton Township established a 'sliding scale' open-space policy for all new developments within specified zoning classes. This amendment to the Fenton Township Zoning Ordinance generally decreased development densities within the community in response to public opinion, and at the same time moved the Township away from traditional single-family residential zoning in an attempt "to encourage the preservation of unique natural features and the township's rural character" (Fenton Charter Township, 1999, Article 3.i). The goal of the "sliding-scale" policy was to encourage developers to use an open-space preservation option in exchange for a density bonus. The open-space set-aside and density bonus work in tandem by increasing the density in some areas in exchange for the retention of undeveloped land. Calculations for determining the amount of open-space required 'protected' landscape features or bodies of water to be considered as separate entities; the ordinance states that "... only useable land shall be considered. Wetlands, floodplains, or submerged land such as a lake, pond or stream shall be excluded from the land area calculation" (Fenton Charter Township, 1999, Article 3.h). The two eligible zoning classes are medium-density single-family residential (R-3; 2.20 units per acre prior to the policy) and single-family residential (R-4; 2.90 units per acre prior to the policy). For new developments in areas designated as R-3, the open-space ordinance allows a maximum density of 1.00 unit per acre in exchange for the preservation of 20% of the total land as open space. When 50% of the land is preserved as open space, allowable densities increase to 1.50 units per acre. Similarly, in areas designated as R-4, a maximum density of 1.25 units per acre is permitted in exchange for the preservation of 20% of the total land as open space. When 50% of the land is preserved as open space, densities can increase to 1.88 units per acre.

2.2. Site selection

With help from Township planning officials, twenty residential sites were selected. Ten of the sites were developed after the 1999 policy was implemented, i.e., the *after-policy* group, including all developments approved between 1999 and 2003. Aside from two large sites that were 73- and 88-ha in size, these sites ranged in size from 3.2 to 29.7 ha with an average and standard deviation of 15.0 and 7.8, respectively. Predominant pre-development land covers for after-policy group include, in descending order of area, agriculture, forest, and mixed natural. The ten sites that were developed in the 3 years prior to the policy implementation (between 1996 and 1998) were selected as the *before-policy* group. These sites ranged in size from 5.9 to 35.8 ha with an average and standard deviation of 14.7 and 9.1, respectively. Predominant pre-development land covers for before-policy group include, in descending order of area, forest, agriculture, and open field. The geographic extent of each of the sites was defined by the platted boundary of the development.

Since the composition of the local landscape may influence development decisions within the sites, the distribution of pre-development land-covers was summarized using the mean, standard deviation, and range of land-cover percentages. For each land-cover class, the before- and after-policy group-mean values were compared using a two-tailed Student's *t*-test.

2.3. Pre-development land-cover

Using a minimum mapping unit of 300 m squared, pre-development land-cover for all study sites was mapped with 1992 color aerial photography acquired from Michigan State University. Each photo had a resolution of about three meters and covered an extent of approximately 260 ha (one square mile). A statistical coordinate transformation process was applied to the original photos to geographically rectify them to an existing dataset containing road centerlines for Fenton Township. The centerlines were derived from ortho-photographs and had a spatial accuracy of ±1 m.

Next, land-cover classes (Table 1), selected to represent the mix of local natural and anthropogenic landscape features, were screen digitized for each site from the 1992 rectified photos (Fig. 2). To account for the possibility of edge effects in later analyses a buffer of 100 m was appended to the platted boundary of each site; land cover was also interpreted within the buffer.

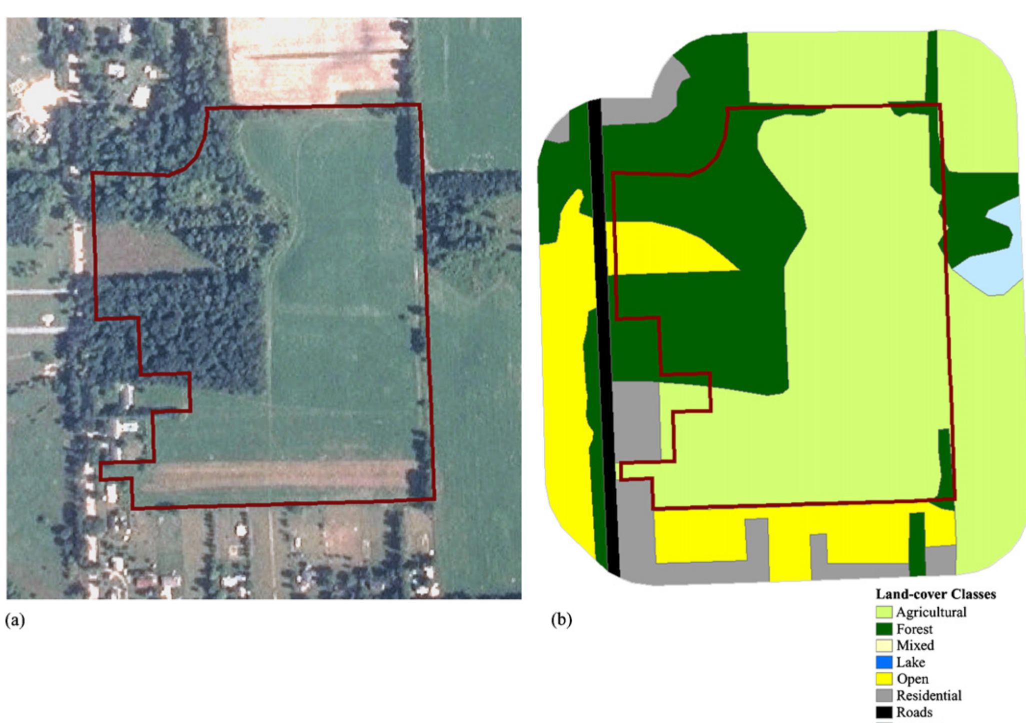

Fig. 2. An example subdivision (River Oaks Hollow, a 17-ha site), typical to other sites in area and forest percent, to illustrate land-cover interpretations: (a) 1992 color aerial photography and (b) the interpreted categorical land-covers (defined in Table 1).

Table 1
Land-cover class descriptions for categorical mapping

Grid code	Label	Label code	Description
1	Agricultural	Ag	Active agricultural fields
2	Forest	Forest	Forest stands, 60–100% tree cover
3	Lake	Lake	Open water or ponds (excluding open water within wetlands)
4	Mixed	Mix	Mixture of forest and open field, 20–60% tree cover
5	Open	Open	Fields and other open areas, 0–20% tree cover
6	Residential	Res	Structures and adjacent maintained lawns
8	Roads	Roads	Primary traffic flow surfaces (excluding driveways and trails)
9	Wetlands	Wet	Observable wetland features

2.4. *Predicting post-development land-cover*

The best method for mapping the post-development land-cover would have been to duplicate the land-cover interpretation process by simply digitizing the appropriate classes from 2003 photography. From 1999 to 2003, the ten new subdivisions slated for development were examined. However, the newest available photography at the time of this study was from 2001, and several of the subdivisions, even though formally platted, had not begun observable development by 2001. To resolve the gap in data availability, we predicted land-cover in the fully built subdivisions from the 1992 land-cover dataset.

The basis for the land-cover predictions was a map of predicted residentially developed areas representing built-out conditions based upon existing developments. Using the 1992 land-cover interpretations (Fig. 3a) as a starting point, the first step in creating the predicted residential class was to identify all platted parcel portions that contained agriculture (hereafter referred to as Ag) or Open land covers within a subdivision (Fig. 3b). To accomplish this, parcel boundaries (excluding right-of-ways) for all subdivisions were intersected with the 1992 land-cover Ag and Open classes (Fig. 3c). Because of the likelihood that areas within the boundary of newly platted residential areas, which were once used as Ag or Open, are not likely to continue their pre-existing use, we assumed all portions of the residential parcels that were previously Ag or Open would be fully developed as residentially maintained areas, which included lawns and vegetable gardens (Fig. 3d).

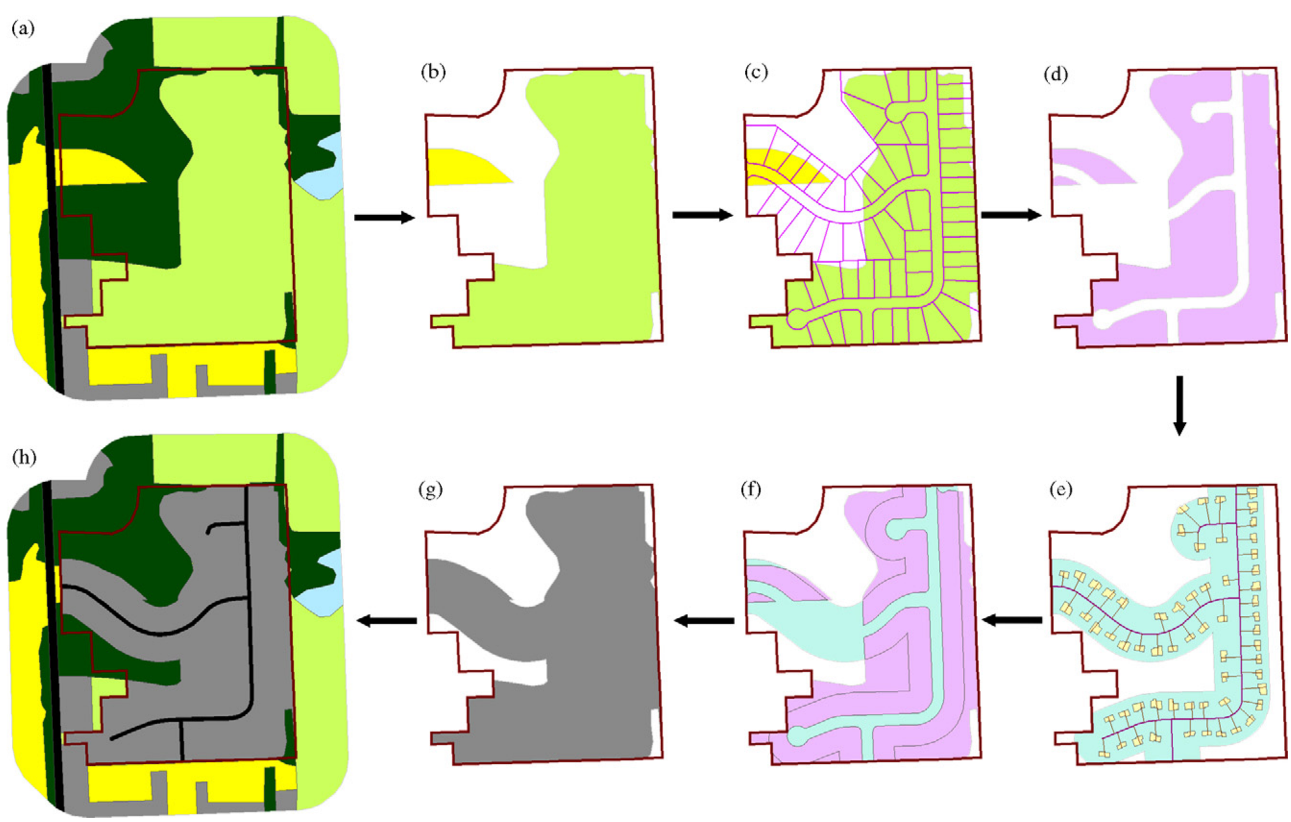

Fig. 3. Diagram of the residential prediction method for River Oaks Hollow subdivision. The illustrations represent: (a) the 1992 land cover; (b) the Ag and Open isolated patches; (c) the parcel intersection with the Ag and Open classes; (d) the parcel portions that are co-incident with the Ag and Open classes; (e) the buffer of the average distance to the rear of all structures; (f) the union of the Ag and Open patches with the distance buffer; (g) the creation of the predicted residential developed extent; and, (h) the final predicted built-out land cover. The legend for the land-cover classes is the same as that in Fig. 2.

To account for the location of housing structures, using previously built-out subdivisions, all areas from the road centerlines to the rear of the structures were enclosed in a polygon using 326 structures identified within the Township's GIS structures layer. The observed mean depth of the structures from the road centerline was 37.9 m, but to account for the likelihood of disturbance at the edge of the forest and mixed classes (i.e., removal of natural vegetation for structure and lawn establishment), an additional 10 m depth of impact was applied. As a result, a depth of 47.9 m was used to create an area surrounding the development's road network that incorporated the potential placement and effects of any structures within or adjacent to the forest or mixed classes (Fig. 3e). The final average effective extent of the residential class (AEERC), and therefore the predicted built-out residential class, was completed by combining the 47.9 m buffer area and the Ag and Open parcel portions (Fig. 3f).

The last step in predicting the built-out land-cover was to combine the AEERC with the 1992 land-cover classes. Prior to the integration step (Fig. 3h), the components of the AEERC were re-classified to residential (Fig. 3g). Additionally, because farming practices are not likely to occur within a residential development, and because potential forest re-growth will exhibit a lag, any Ag patches falling outside of the residential parcels but within the development boundary (i.e., within an open space and not part of the AEERC) were re-classified as Open.

2.5. *Evaluating the predictive method*

The validity of using our prediction method to create the built-out land-cover was evaluated using the three subdivisions (McCully Lake Estates, Orchard View, and River Oaks Hollow) that were most fully developed in the 2001 photographs. For these developments, a 2001 'actual' land-cover dataset was interpreted from the orthographically corrected, high resolution (0.15 m), black and white photographs using the same procedures and classes used in the creation of the 1992 land-cover.

For the three subdivisions to be evaluated, the 'predicted' 2001 built-out land-cover (created using the prediction method detailed above) and the 'actual' 2001 land-cover (digitized from the 2001 photography) were converted to raster form for comparative analysis. To simplify the evaluation, each of the land-cover datasets was re-classified into two categories, residential developed and non-developed. The goal of the evaluation was to quantify the agreement between the 'predicted' residential development map and the 'actual' residential development map. The re-classified images were processed to calculate cross-tabulation results identifying all combinations of the categories represented in each landscape cell (Fig. 4).

To analyze the agreement between the predicted and actual maps, the accuracy of predictions for the location as well as the abundance of the 'developed' cells were necessary. Pontius (2000) developed statistics that divide the Kappa index of agreement into four components: Kstandard (equivalent to kappa—the proportion assigned correctly versus the proportion correct due to chance), Kno (measure of the proportion correctly classified versus the expected proportion classified under an assumption of no knowledge of quantity or location), Klocation (measure of the accuracy due to correct assignment of values spatially), and Kquantity (measure of the accuracy due to the correct assignment of quantities for each class). Using the com-

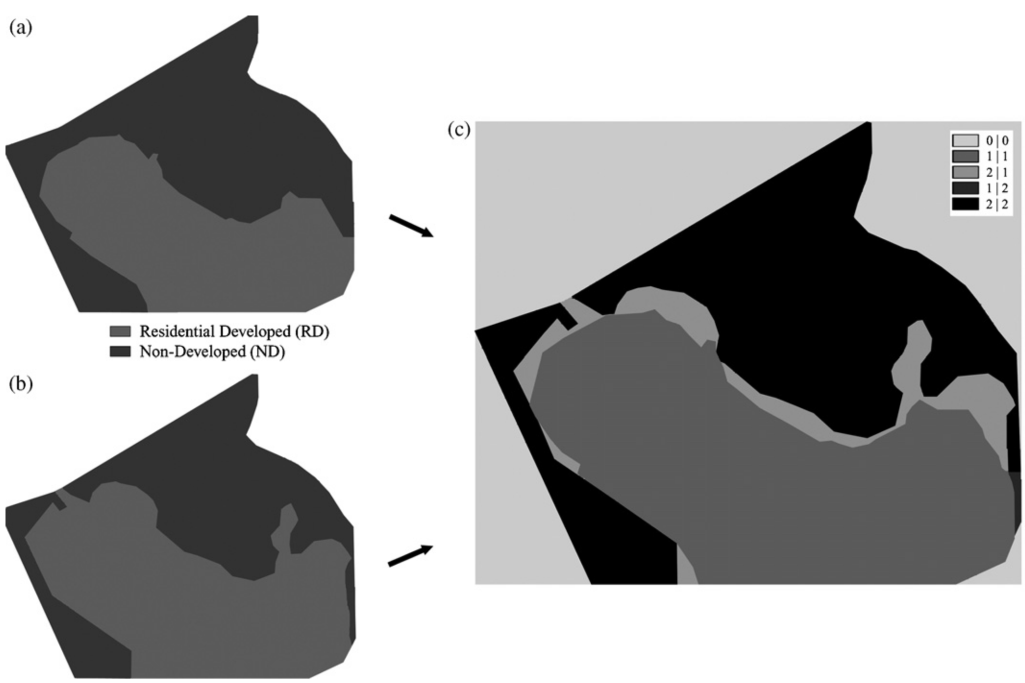

Fig. 4. Illustration of the cross-tabulation results for McCully Lake Estates subdivision. (a) The actual residential developed results compared to the (b) predicted results and (c) the cross-tabulation outcome. No Data (0|0), RD is correctly predicted (1|1), where ND was predicted as RD (2|1), where RD was predicted as ND (1|2), and where ND was correctly predicted (2|2). Note that within the cross-tabulation output the correctly predicted areas are black and medium gray.

bination of Kno, Klocation, and Kquantity for evaluation allows for a determination of an overall success rate while providing an understanding of the factors (i.e., location and quantity) that contribute to the strength or weakness of the results. Similar to standard Kappa, the Kappa components equal one for perfect agreement between simulation and reality, and zero when the simulation does no better representing reality than a guess with no knowledge of location and quantity.

The evaluations, producing Kno values of 0.808, 0.830, and 0.892 (Table 2), support that our prediction method, in all cases, is better than 80% more likely to produce the modeled outcome versus chance alone. These error assessment values, which are at, or above, commonly accepted Kappa values within the remote sensing community (Rosenfield, 1986; Congalton, 1991), are deemed satisfactory by the authors. By reviewing Klocation and Kquantity, the effectiveness of the prediction method is additionally supported with average values of 0.856 and 0.546, respectively. The comparably low Kquantity average can be explained by the Kquantity value for McCully lake estates (−0.295). In this case, the quantity of the residential development category was slightly over estimated (Fig. 4c) as many of the residents in this development chose not to fully develop the Open areas at the rear of their properties. However, the general

Table 2
Kappa component values comparing actual vs. predicted land covers for the sites used to evaluate the prediction method (Pontius, 2000)

Study site	Kno	Klocation	Kquantity
McCully Lake	0.808	0.983	−0.295
Orchard View	0.830	0.713	0.981
River Oaks	0.892	0.872	0.951

Table 3
Description, interpretation, and ecological significance of landscape metrics used to describe subdivision land-cover patterns

Metric	Description[a]	Value interpretation[a]	Ecological significance
Class-level			
PLAND	Percentage of landscape: provides the proportional abundance of each land-cover class within a landscape	PLAND = 0 when a land cover is absent and = 100 when a single land-cover class covers the entire landscape	Describes the composition of the landscape Addresses availability of habitats and, indirectly, land-cover heterogeneity
NP	No. of patches: returns the number of patches for each class within the landscape	Actual number of patches, NP = 1 when the landscape consists of a single patch (i.e., the entire landscape is homogenous)	Indicates the level of land-cover fragmentation
PD	Patch density: calculates the density of patches per land-cover class	PD = number of patches per 100 ha	An area-normalized measure of fragmentation
AREA_MN	Patch area-mean: quantifies the average size of all patches within each land-cover class	AREA_MN = actual mean area in ha	Related to NP, also indicates land-cover fragmentation
SHAPE_MN	Shape index-mean: computes an area-adjusted measure (to a square) of the average shape complexity for each class	SHAPE index value = 1 when a patch reaches its highest level of compaction—a square in this case, the value increases as the patch becomes more complex	Serves as a proxy for the amount of edge for a habitat patch, which relates to potential predation in avian species and altered core-area micro-climatic effects
TECI	Total edge contrast index: quantifies the total relative abundance of contrast present along the edges of a class	TECI = 100 when all edges between the land-cover classes are of greatest contrast, and nears 0 as the contrast between classes lessens	An indicator of the difference between patches at their edges, related to wildlife dispersal, avian parasitism, and core-area microclimatic effects
GYRATE_MN	Radius of gyration-mean: returns the average extent covered by the patches of a class, the extent is calculated using the mean distance from the parch centroid to each cell	GYRATE = 0 if the patch is a single cell, it increases as a patch includes more of the landscape	Related to geographic extent, or dispersion, of a patch, like area, affects the potential for supporting core-area species and services
ENN_MN	Euclidean nearest-neighbor distance-mean: provides a class mean of the straight-line distance to a nearest like-class neighbor	Actual straight-line distance (m) to the nearest like-class neighbor, ENN approaches 0 as the distance to a like patch lessens	Affects ability of wildlife to disperse and forage among multiple patches of the same type
PROX_MN	Proximity index-mean: calculates the class mean index value for the distance between a focal patch and all others within a specified search radius	PROX = 0 if no other like-class patches are present within the search radius, the value increases as more patches are present	Another indicator of dispersal capability and the possibility to support metapopulations
Landscape-level			
CONTAG	Contagion index: computes an index based on the interspersion (intermixing of different patches) and dispersion (spatial distribution of a patch class) of all land-cover classes present	CONTAG nears 0 with higher levels of dispersion and interspersion and = 100 with maximum aggregation – when the landscape is a single patch	Measures degree of intermixing among land-cover types and affects habitat quality and context
PR	Patch richness: provides the number of patches, of any class, within the landscape	PR = actual number of total patches present, regardless of class	Measure of land-cover heterogeneity (i.e., diversity) within a landscape, affecting diversity of habitats available

[a]Paraphrased from McGarigal et al. (2002).

pattern and spatial extent of the developed area was appropriately reproduced (illustrated by the high Kno and Klocation values). Overall, our method is effective for estimating near-future subdivision-scale, developed versus non-developed land-cover configurations in lieu of up-to-date aerial photography.

Using our prediction method, the post-development (built-out) land-covers were created for all 20-study sites. The process was completed by using 2003 Fenton Township parcels and road centerlines, and by applying the prediction method presented above to the 1992 land-cover maps. Therefore, unlike Girling and Kellet (2002) we did not create new designs but instead assumed that future developments would maintain a character similar to existing developments.

2.6. Landscape metric analysis

The study sites formed two groups, before-policy and after-policy. For each site, two land-cover maps were created, *pre-development* (1992 actual land-cover digitized from the 1992 photos) and *post-development* (land-cover from the prediction method). All 40 vector land-cover maps were converted to raster format for spatial analysis.

We used spatial analysis of land-cover patterns to evaluate the observable effects of the policy change. The challenge in using spatial-pattern metrics is that the many varieties of metrics are at least partially redundant and tend to quantify similar aspects of landscape pattern (McGarigal et al., 2002). Using the research of Riitters et al. (1995) and others, Leitao and Ahern (2002) proposed a core set of metrics to "address the principle needs of applied landscape planning by describing landscape structure and its key associated spatial processes" (p. 75). Their objective was to provide a set of metrics related to several fundamental ecological processes to serve as a standard for the planning community. For this reason, their core set of metrics served as a basis in our study.

We calculated nine class-level and two landscape-level metrics (descriptions and ecological significance for each metrics can be found in Table 3). The metrics for percent of landscape (PLAND), number of patches (NP), patch density (PD), mean patch area (AREA_MN), mean radius of gyration (GYRATE_MN), mean Euclidean nearest-neighbor distance (ENN_MN), contagion index (CONTAG), and patch richness (PR) directly quantify the amount and geometric form of the land-cover patches. The mean shape index (SHAPE_MN), total edge contrast index (TECI), and mean proximity index (PROX_MN) adjust for the area of the patch, the relative contrast between patch edges, and the proximity of all patches with their center inside a specified search distance, respectively.

TECI and PROX_MN each required setting parameter values. TECI required a contrast weight file, which describes the differences in the content of patch types (i.e., their contrast). McGarigal et al. (2002) posited that in lieu of a strong experimental basis for constructing a weighting scheme, a sound estimation is likely an improvement over assuming all edges are similar. Contrast weights (Table 4) were composed by comparing the variability within the land-cover classes using the descriptive definitions for each class (Table 1). PROX_MN required a search radius from a focal patch to direct its calculations. Since no patches external to the landscape border could be considered, the longest diagonal distance (2000 m) for the largest subdivision was used as the search radius. This value was additionally selected to ensure the inclusion of all possible patches for all landscapes.

The described metrics were calculated for each of the pre- and post-development land-cover classes. The metrics were summarized for mean, standard deviation, and range. Differences in the amounts of change in the mean values, between the before- and after-policy groups, were evaluated to test the null hypothesis that the means of the two groups were equivalent ($\mu_1 = \mu_2$). Our analysis tests the effectiveness of a policy change in altering, in a positive way (i.e., less decrease or a greater increase in area), the effects of subdivision developments on natural land covers. The analysis was completed using a two-tailed Student's *t*-test at a significance level of 0.05.

3. Results

At a significance level of 0.05, there was no significant difference in the initial land-cover compositions of the before- and after-policy groups (Table 5) for any of the study sites. Though not significantly different, it should be noted that the before-policy group had a disproportionate number of tracts consisting primarily of open fields while the after-policy group had a large number of parcels with a large percentage of agriculture.

The results for a single metric at one site, presented for illustration purposes, indicate that the pre-development composition (PLAND) of Site 1 was 15.55% Forest, 80.83% Mixed, 1.81% Open, and 1.81% Wetlands with no Residential, Roads, Ag, or Lake. For the same site, post-development composition was 13.86% Forest, 25.46% Mixed, 1.81% Open, 1.81% Wetlands, 53.52% Residential, and 3.54% Roads with no Ag or Lake (Table 6 provides similar results for all study sites). In this case, classes registering a change from pre- to post-development

Table 4
Contrast weights used in the calculation of the total edge contrast index (TECI)

Class	AG	Forest	Lake	Mix	Open	Res	Roads	Wet
AG		(table is symmetrical)						
Forest	0.8							
Lake	1	1						
Mix	0.6	0.2	1					
Open	0.2	0.6	1	0.4				
Res	1	1	1	1	1			
Roads	1	1	1	1	1	0		
Wet	0.8	0.6	0.4	0.4	0.2	1	1	

No contrast - 0
Nearly similar - 0.2
Closer to similar - 0.4
Closer to different - 0.6
Nearly different - 0.8
Total contrast - 1

No contrast, 0; nearly similar, 0.2; closer to similar, 0.4; closer to different, 0.6; nearly different, 0.8; total contrast, 1.

Table 5
Pre-development percent of landscape class (PLAND) including *t*-test results comparing the means of the before- and after-policy groups

Class	Before mean	Before S.D.	Before range		After mean	After S.D.	After range		*P*-value (two-tailed)	$\mu_1 = \mu_2$
			Min	Max			Min	Max		
Ag	**28.2855**	30.8239	0.0000	65.7703	**52.3502**	37.1706	0.0000	92.5497	0.1330	Yes
Forest	**31.4433**	23.0084	0.6979	73.3330	**23.4033**	19.4610	3.6443	62.4139	0.4102	Yes
Lake	**0.2766**	0.4977	0.0000	1.4441	**0.7083**	2.2380	0.0000	7.0777	0.5649	Yes
Mix	**10.9608**	26.3624	0.0000	84.6737	**10.5354**	25.2093	0.0000	80.8281	0.9710	Yes
Open	**22.6597**	31.2344	0.0003	87.8730	**5.0386**	12.6375	0.0007	40.8869	0.1244	Yes
Res	**0.7726**	1.4930	0.0008	4.2805	**1.1461**	2.1053	0.0007	6.8223	0.6533	Yes
Roads	**0.0888**	0.2806	0.0004	0.8883	**0.1570**	0.4470	0.0001	1.4230	0.6894	Yes
Wet	**5.5126**	6.6977	0.0000	21.2947	**6.6610**	7.6511	0.0000	17.8583	0.7252	Yes

stages were Forest (−1.69%), Mixed (−55.37%), Residential (53.51%), and Roads (3.54%). Summarizing the change for a single metric (PLAND) and land cover (Forest) across all study sites, to continue illustrating the process, the mean changes in the percent of Forest from pre- to post-development for the before- and after-policy groups were −16.29 and −9.89, respectively (Table 7 provides similar results for all metrics at all study sites). Though the difference was not significant ($\alpha < 0.05$), it shows a tendency for after-policy subdivisions to have resulted in less forest clearing than the before-policy subdivisions.

Overall, the shift in local land-use policy for Fenton Township produced only a small number of observable and significant differences in the change of class- and landscape-level metric values between the before- and after-policy groups (Table 7).

Table 6
Pre- and post-development percentage of landscape (PLAND) for each study site indicated as before- (B) and after-policy (A) changes

Site #	Policy	Pre-AG	Post-AG	Pre-Forest	Post-Forest	Pre-Lake	Post-Lake	Pre-Mix	Post-Mix
1	A	0.00	0.00	15.55	13.86	0.00	0.00	80.83	25.46
2	B	0.00	0.00	15.04	6.45	0.00	0.00	84.67	4.93
3	B	0.00	0.00	55.16	22.26	0.00	0.00	0.22	0.22
4	A	0.09	0.00	62.41	23.26	7.08	6.72	16.52	5.68
5	A	72.11	0.00	5.10	1.99	0.00	0.00	4.27	0.25
6	B	0.00	0.00	1.07	0.78	0.00	0.00	11.06	0.07
7	A	60.80	0.00	38.20	11.57	0.00	0.00	1.00	1.00
8	A	87.80	0.00	9.52	9.52	0.00	0.00	0.00	0.00
9	A	76.84	0.00	16.82	10.99	0.01	0.01	1.76	0.42
10	A	70.91	0.00	8.60	4.08	0.00	0.00	0.98	0.83
11	B	59.82	0.00	32.73	16.13	0.02	0.02	0.87	0.55
12	B	54.00	0.00	37.24	20.41	0.07	0.07	0.00	0.00
13	B	65.77	0.00	23.28	11.43	0.34	0.34	0.00	0.00
14	A	61.11	0.00	32.03	18.02	0.00	0.00	0.00	0.00
15	B	0.00	0.00	0.70	0.70	0.89	0.89	12.79	12.74
16	B	37.49	0.00	45.81	14.71	0.00	0.00	0.00	0.00
17	B	0.00	0.00	73.33	38.14	1.44	1.44	0.00	0.00
18	B	65.77	0.00	30.07	20.48	0.00	0.00	0.00	0.00
19	A	1.28	0.00	42.14	39.34	0.00	0.00	0.00	0.00
20	A	92.55	0.00	3.64	2.49	0.00	0.00	0.00	0.00

Site #	Policy	Pre-Open	Post-Open	Pre-Res	Post-Res	Pre-Roads	Post-Roads	Pre-Wet	Post-Wet
1	A	1.81	1.81	0.00	53.52	0.00	3.54	1.81	1.81
2	B	0.09	0.09	0.19	80.78	0.00	7.74	0.00	0.00
3	B	39.99	0.00	2.75	70.25	0.00	5.43	1.88	1.84
4	A	3.13	0.79	0.47	50.79	0.00	4.53	10.29	8.23
5	A	0.34	13.09	0.17	61.80	0.15	5.66	17.86	17.20
6	B	87.87	0.00	0.00	91.93	0.00	7.22	0.00	0.00
7	A	0.00	8.47	0.00	70.83	0.00	8.14	0.00	0.00
8	A	0.00	30.43	1.44	56.37	0.00	3.65	1.24	0.03
9	A	1.56	36.93	0.22	45.55	0.00	3.31	2.80	2.80
10	A	0.85	10.30	0.10	60.64	1.42	7.02	17.14	17.14
11	B	0.00	1.01	0.00	70.76	0.00	4.98	6.56	6.56
12	B	0.00	0.09	0.29	67.13	0.89	5.09	7.50	7.21
13	B	0.64	0.00	0.00	73.65	0.00	4.60	9.98	9.98
14	A	0.03	15.27	6.82	61.27	0.00	5.43	0.00	0.00
15	B	64.33	7.74	0.00	53.88	0.00	2.76	21.29	21.29
16	B	15.72	0.00	0.21	78.87	0.00	5.66	0.76	0.76
17	B	13.79	0.00	4.28	50.16	0.00	3.89	7.15	6.37
18	B	4.16	0.11	0.01	74.35	0.00	5.06	0.00	0.00
19	A	40.89	0.69	0.22	40.52	0.00	3.99	15.46	15.46
20	A	1.79	45.36	2.01	48.54	0.00	3.61	0.00	0.00

Table 7
Summary of comparisons between before- and after-policy groups

	Ag	Forest	Lake	Mix	Open	Res	Roads	Wet
Class-level metrics								
PLAND								
B-policy	−28.29	−16.29	0.00	−9.11	−21.76	70.40	5.15	−0.11
A-policy	−52.35	−9.89	−0.04	−7.17	11.27	53.84	4.73	−0.39
Direction of difference	−	+	−	+	+	−	−	−
p-Value	0.13	0.28	0.34	0.84	0.01	0.00	0.53	0.27
$\mu_1 = \mu_2$	Yes	Yes	Yes	Yes	**No**	**No**	Yes	Yes
NP								
B-policy	−1.90	2.40	0.00	0.70	0.50	0.80	1.00	0.00
A-policy	−2.20	2.70	0.00	1.00	5.30	1.80	0.90	0.20
Direction of difference	−	+	0	+	+	+	−	+
p-Value	0.83	0.85	n.a.	0.80	0.00	0.24	0.68	0.34
$\mu_1 = \mu_2$	Yes	Yes	Yes	Yes	**No**	Yes	Yes	Yes
PD								
B-policy	−8.76	15.04	0.00	11.92	−1.62	8.19	8.77	0.00
A-policy	−9.72	10.12	0.00	4.43	28.11	7.40	7.47	0.27
Direction of difference	−	−	0	−	+	−	−	+
p-Value	0.84	0.43	n.a.	0.56	0.01	0.90	0.71	0.34
$\mu_1 = \mu_2$	Yes	Yes	Yes	Yes	**No**	Yes	Yes	Yes
AREA_MN								
B-policy	−2.46	−2.38	0.00	−0.60	−1.63	6.22	0.63	<−0.0l
A-policy	−13.80	−2.11	−0.03	−0.56	0.33	3.74	1.11	−0.11
Direction of difference	−	+	−	+	+	−	+	−
p-Value	0.18	0.85	0.34	0.95	0.02	0.27	0.26	0.24
$\mu_1 = \mu_2$	Yes	Yes	Yes	Yes	**No**	Yes	Yes	Yes
SHAPB_MN								
B-policy	−0.95	−0.07	0.00	0.52	−0.42	1.53	5.98	−0.01
A-policy	−1.50	−0.05	0.00	−0.05	0.43	0.97	7.07	−0.06
Direction of difference	−	+	0	−	+	−	+	−
p-Value	0.18	0.94	0.34	0.12	0.06	0.31	0.54	0.33
$\mu_1 = \mu_2$	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TECI								
B-policy	−25.29	16.15	0.00	14.42	−9.21	12.30	−8.10	2.60
A-policy	−46.06	6.65	−0.02	6.13	41.15	−1.70	−7.57	−0.80
Direction of difference	−	−	−	−	+	−	+	−
p-Value	0.07	0.08	0.34	0.33	0.02	0.37	0.96	0.27
$\mu_1 = \mu_2$	Yes	Yes	Yes	Yes	**No**	Yes	Yes	Yes
GYRATE_MN								
B-policy	−40.76	−31.12	0.00	−14.29	−31.65	106.16	113.56	−0.38
A-policy	−115.32	−32.34	−0.11	−12.81	8.58	84.95	153.56	−5.08
Direction of difference	−	−	−	+	+	−	+	−
p-Value	0.10	0.94	0.34	0.89	0.03	0.34	0.35	0.21
$\mu_1 = \mu_2$	Yes	Yes	Yes	Yes	**No**	Yes	Yes	Yes
ENN_MN								
B-policy	−3.40	17.65	0.00	3.63	11.42	−19.98	5.61	1.13
A-policy	−30.07	6.51	0.00	17.23	35.70	−32.41	3.31	−3.22
Direction of difference	−	−	0	+	+	−	−	−
p-Value	0.08	0.48	n.a.	0.29	0.48	0.68	0.71	0.23
$\mu_1 = \mu_2$	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PROX_MN								
B-policy	−94.49	−43.84	0.00	0.10	−7.79	662.81	0.29	−5.54
A-policy	−44.26	−13.92	−0.36	−0.95	107.75	1167.64	−0.57	0.10
Direction of difference	+	+	−	−	+	+	−	+
p-Value	0.43	0.71	0.30	0.37	0.12	0.35	0.16	0.34
$\mu_1 = \mu_2$	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 7 (*Continued*)

Landscape-level metrics	
CONTAG	
B-policy	1.48
A-policy	−7.91
Direction of difference	−
p-Value	0.01
$\mu_1 = \mu_2$	**No**
PR	
B-policy	0.50
A-policy	0.30
Direction of difference	−
p-Value	0.67
$\mu_1 = \mu_2$	Yes

Mean group-changes are indicated as before- (B) and after-policy (A) changes. Direction of the differences for the means are indicated as (+) for a positive difference. (−) for a negative difference, (0) for no difference. $\mu_1 = \mu_2$ is No (bold font) for study sites with a significant difference (at 0.05) in the metric values.

Positive directions of difference (Table 7) indicate that the after-policy group experienced a larger increase from pre- to post-development, a smaller decrease, or a change to increasing from decreasing values in relation to the before-policy group. For example, from pre- to post-development, the number of Forest patches (NP) in the after-policy group (+2.70) increased more as compared to the before-policy group (+2.40); the proportion of Forest (PLAND) in the after-policy group (−9.89) decreased less than the before-policy group (−16.29); and, the mean patch size (AREA_MN) of the Open patches in the after-policy group (+0.33) changed to increasing from decreasing values as compared to the before-policy group (−1.63). Negative directions of difference indicate that the after-policy group had a larger decrease, a smaller increase, or a change to decreasing from increasing values as compared with the before-policy group. For example, from pre- to post-development, the mean Euclidean nearest neighbor (ENN_MN) distance of the Residential patches in the after-policy group (−32.41) decreased more than that of the before-policy group (−19.98); the total edge contrast index (TECI) of the Mixed patches in the after-policy group (+6.13) increased less than the before-policy group (+14.42); and, the mean shape index (SHAPE_MN) of the Mixed patches in the after-policy group (−0.05) changed to decreasing from increasing values as compared to the before-policy group (+0.52).

Four of eleven metrics (SHAPE_MN, ENN_MN, PROX_MN, and PR) exhibited no significant difference in pre- to post-development change between the before- and after-policy groups for any of the land-cover classes (Table 7). The Open class (composed of the non-residential portions of developments including open fields, areas of 0–20% tree cover, and recreation areas) demonstrated the most notable changes between group means. For this class, six of nine class-level metrics (PLAND, NP, PD, AREA_MN, TECI, and GYRATE_MN) exhibited significant differences. The associated Open-class differences between the before- and after-policy groups, in terms of changes from the pre- to post-development stages, included: PLAND (+33.03), NP (+4.80), PD (+29.74), AREA_MN (+1.96), TECI (+50.36), and GYRATE_MN (+40.23). The mean values of change for the after-policy group were increasing compared with decreasing values in the before-policy group for: the proportions of Open land present within the landscape (PLAND); the density of Open patches (PD); the mean area of Open patches (AREA_MN); the contrast of Open patches with neighboring patches (TECI); and the mean patch extent (GYRATE_MN). The number of Open-land patches (NP) for the after-policy group experienced a greater increase from pre- to post-development as compared to the before-policy group. Class area proportion (PLAND) for the Residential land-cover class also experienced a significant difference (−16.57), demonstrating that the after-policy group exhibited a smaller increase in residential land area from pre- to post-development than the before-policy group.

One of two landscape-level metrics evaluated demonstrated a significant difference. The CONTAG metric exhibited a difference of −9.39 as a result of decreasing values in the after-policy group compared with increasing values for the before-policy group. This difference indicates that, on average, the after-policy landscapes became more dispersed and interspersed from pre- to post-development (i.e., the land-cover classes have become more fragmented) as compared to the before-policy landscapes.

4. Discussion

The 1999 open-space policy in Fenton Township was intended to preserve unique natural features and the township's rural character. On the basis of land-cover change and according to our analysis of the data, the policy's objectives were not achieved.

In Fenton Township Article 3.i, the Township wishes "to encourage the preservation of unique natural features and the township's rural character," but has not defined natural features. In lieu of any formal definition provided by the Township, we defined natural features as forest, wetlands, and open fields and additionally assumed that these natural landscape features also define 'rural character.' Although there are certainly other considerations that go into the issue of preserving natural features and rural character, land cover is a reasonable starting point to evaluate the policy relative to these two primary goals. Accordingly, preservation should have resulted in new developments that provided an increase, or lessened the decrease, in the amounts of the land-covers that are indicative of rural character, as compared to developments established prior to the new pol-

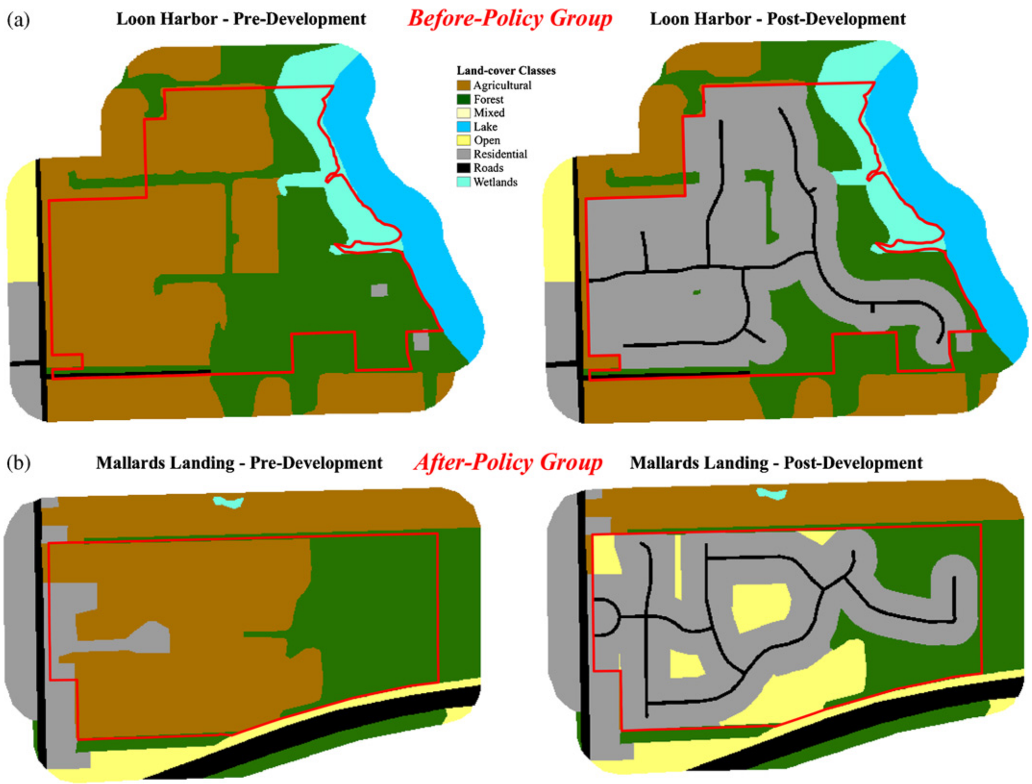

Fig. 5. Examples of pre-development and predicted post-development conditions for (a) before-policy (Loon Harbor; 36 ha) and (b) after-policy (Mallards Landing; 30 ha) subdivisions. After-policy developments, on average, have an increase in the number of open spaces and relatively less land converted to residential, as compared to before-policy developments. The platted development boundaries are outlines in red.

icy. The results show that the shift in land-use policy produced only a small number of observable and significant changes in the land-cover effects of development. Those changes that were significant paralleled the only clearly defined function of the 1999 open-space policy—to increase open or non-developed land.

The policy achieved an increase in the average percentage of open-space compared to sites developed before the policy (Fig. 5). A consequent decrease in the amount of land converted to residential area followed the increase in open-space. The increased amount of open-space can be attributed to an increase in the number, density, and average size of the patches in the after-policy landscapes, compared to the before-policy landscapes. While the increase in total area and size of open-space patches may seem unquestionably positive, associated increases in the number and density paint a picture of a fragmenting landscape. This notion is further supported by an increase in edge contrast between Open areas and adjacent land-cover types (i.e., adjacent land covers are becoming less similar) and an increase in the geographic extent to which land-cover patches spread out across a site (i.e., with patch area fixed, an increase in the average, potential distance of travel before reaching a patch boundary, while remaining within a given patch; McGarigal et al. (2002)), in the after-policy group as compared to decreases in the before-policy group (Table 7). Both increased contrast and linearization of habitat patches can increase the edge effects associated with fragmentation.

While the metrics confirmed that the policy resulted in landscape changes that increased open-space, the policy did not specify the types of land covers that should be preserved or created within those spaces. Collectively, the open-space areas generated by the policy consisted of Forest, Mixed, Wetlands, and Open patches. Of these classes, we hypothesized that the wetlands would remain constant as they are federally protected and by definition in the township policy were not considered as developable land. Additionally, we hypothesized that an increased percentage of Forest, Mixed, and Open areas would be generated by the policy. The data indicate that, while the after-policy developments resulted in increased Open areas, the rate of loss of the Forest and Mixed classes that resulted from the after-policy developments was not significantly reduced compared to the before-policy developments.

In several instances, Forest patches were selected by developers as part of the areas to be developed (i.e., not as a portion of the set-aside open-space) even if other, more easily developable, land covers (e.g., Ag) were available. Example developments where this occurred include Stoneybrook and Mallards Landing (Fig. 6). Stoneybrook, an 88 ha site, was 93% Ag prior to development; a 2 ha Forest patch located in the extreme southwest corner of the property had 13 residential lots platted within or directly adjacent to its boundary. Mallards Landing, a 30 ha site, was over 60% Ag prior to development; an 11 ha Forest patch located on the rear half of the property received 26 residential lots totaling 5 ha. At the same time, seven patches totaling 9 ha were designated as open-space and established within the Ag portions of the property. In both instances, large Ag areas were designated as open-spaces while development occurred within or adjacent

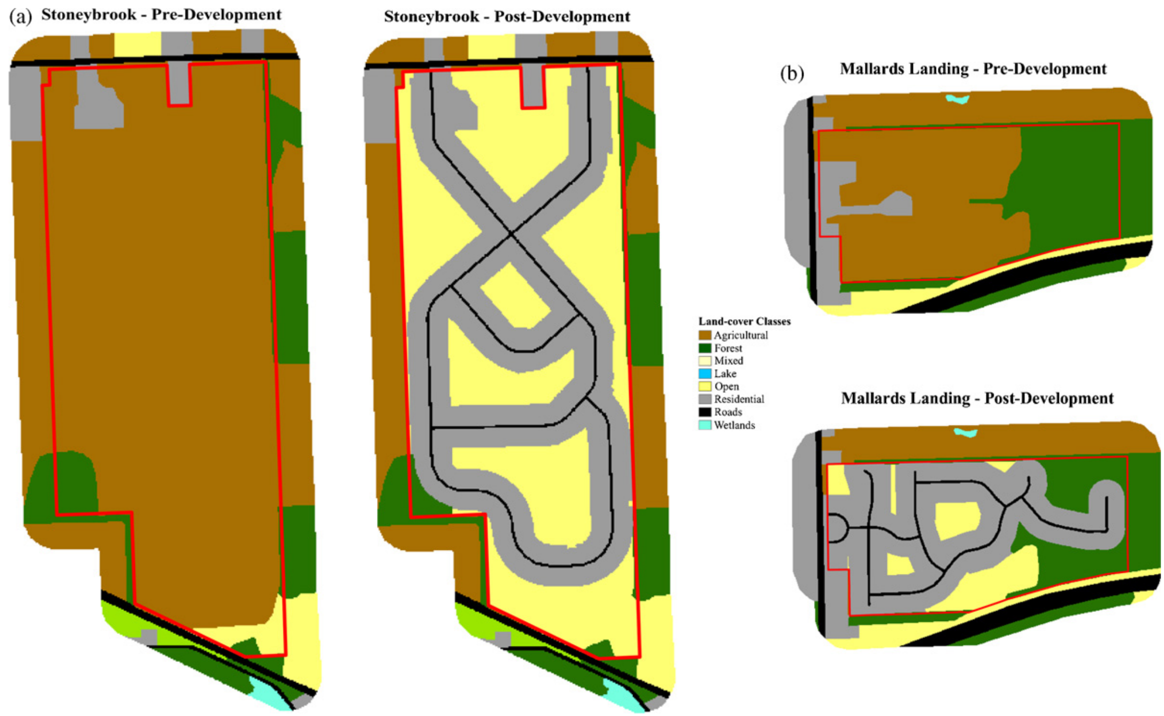

Fig. 6. Stoneybrook (88 ha) and Mallards Landings (30 ha) are examples of sites where large agricultural areas are designated as open-space while development occurred within or adjacent to natural areas. Note that the platted development boundaries are outlines in red.

to the natural areas the policy intended to preserve. Such examples illustrate that land-covers with specific ecological value, like forest, must be explicitly defined as non-developable in order to guarantee their preservation.

Even though the Open land-cover class was primarily composed of agricultural remnants that seemed to be arbitrarily designated, these open-spaces do provide a palette from which future beneficial land-covers could be introduced. Potential future land-covers could include prairies or open fields (which may undergo a process of secondary succession with no additional influence), re-planting of forests or other native vegetation, or natural recreation areas. Depending on the selected design decisions, the open spaces have the potential to re-introduce or increase the ecosystem values (Forman, 1995; Nassauer, 1997) provided by natural land covers.

To achieve the original objective of preserving natural features, a suggested policy direction for the Township includes the incorporation of a pro-active spatial planning method into their open-space policy. In doing so, the Township would provide, or at least critically review, a suggested configuration (pattern) of land covers and land uses appropriate, for each site to be developed. Spatially based planning solutions have the potential to preserve not only open-space, but spaces within the landscape that have the highest ecological value. One such method is presented by Forman and Collinge (1997), where a spatial solution is used to conserve the majority of the most important attributes of biodiversity and natural processes within portions of or within whole landscapes in a region. By comparing modeled patterns of random land conversion versus conversion directed with a spatial solution, they demonstrated that a spatial planning process that identifies 'first removals' (i.e., society designated areas prime for development) and 'last stands' (i.e., the large and medium areas of most ecological importance to be protected) preserved five times more of the areas with high ecological value. Specifically, a spatial solution is highly effective for conserving ecologically important landscape features if the planning commences prior to the removal of the first 40% of the natural vegetation (Forman and Collinge, 1997). From a regionally specific design perspective, large areas of agriculture (i.e., first removals) are to be developed first, avoiding last stands (e.g., large to medium patches of natural cover and streams). In addition, major corridors between smaller patches and last stands are to be conserved. Our suggestion is to integrate such a method into the Township's current open-space policy. Based on Forman and Collinge's scale, a development designating 40% open space would be required to preserve the majority of the areas of highest ecological value.

Incorporation of a spatial solution into Fenton Township's open-space policy would additionally provide a simple and effective method for addressing all of the conditions that Arendt (2004) states are necessary to implement effective conservation planning policies: i.e., specification of quantity, quality, and configuration of open spaces that developers are allowed to create. These conditions alleviate the "hit-or-miss" conservation efforts practiced by most developers (Arendt, 2004). The first condition was met when the Township formally established an open-space policy, but the latter two were not.

Another possible method to preserve open spaces with the highest ecological value is outlined as a four-step approach by Arendt (2004). These steps include: (1) the identification of primary (e.g., designated as 'unbuildable') and secondary (e.g., prime soils, woodlands, etc.) potential conservation lands; (2)

the placing of house sites at a 'respectful' distance from the natural areas; (3) the placement of streets and trails; and (4) the establishment of lot lines. Such a method has been applied near Fenton Township, in Hamburg Township in Livingston County, Michigan. This method for conserving open-space contrasts with that of Fenton Township, in that, the Hamburg Township Zoning Ordinance provides a definition of the composition and configuration of allowable open-space. The open-space shall provide the benefits of: the preservation of significant natural assets (e.g., woodlands, individual trees over 12 in. in diameter, significant views, etc.); the creation of recreation facilities or parklands if the site lacks natural features; or, the establishment of natural features if the site lacks existing natural features (Hamburg Township, 2000, Article 14.3). Furthermore, "the development(s) shall be designed to promote the preservation of natural features. If animal or plant habitats of significant value exist on the site, the Planning Commission. . .may require the open-space community plan preserve these areas in a natural state and adequately protect them. . ." (Hamburg Township, 2000, Article 14.4.15). Using this clearer conservation subdivision definition, Hamburg Township has protected over 530 ha (2 mile^2) of open-space since 1992. Spatial specificity will require increased planning capacity (the commitment of more time and labor) in Fenton Township and this realistic challenge for small municipalities may be a larger impediment to its incorporation than anticipated resistance from the development community.

4.1. Strengths and weaknesses of study

In designing a test for the effectiveness of the policy, we attempted to control for factors that might produce differences in land-cover effects within the developments other than the policy change, but it is possible for circumstances external to the policy change to have influenced our results. Steps taken to minimize external influences included ensuring that all sites were within the same community, had similar land covers, and were developed within a similar time frame, such that housing preferences were likely to be similar.

Our results and discussion are dependent on a method to predict near-future landscape changes using datasets representing platted residential development and pre-development land covers. This method is limited, like any, by its assumptions. One important assumption relates to the classification of non-developed agricultural areas within the newly created subdivisions. We assumed that these patches would transition to Open (i.e., grassland), but because there is a 10-year span between the pre-development photos and post-development predictions, the possibility exists that these locations could have become Mixed and/or fragmented Forest, either naturally or through planting. Also, the possibility exists that newly created open spaces resulting from the updated policy, which are not currently conserving more natural features, may conserve more natural features in the future as open spaces transition to forest or other natural areas in say, 20–30 years. We could have limited the necessary assumptions if up-to-date aerial photographs were available for the fully built-out, post-development, subdivisions. The issue here is that for many developments, the time frame from initial design and platting to built-out stages, may take several decades. Over such an extended period, housing, and more generally, public preferences, are likely to change increasing the uncertainty about the influences of the policy on land development patterns, versus other external forces.

The ability to analyze patterns of development related to a policy change, in the absence of up-to-date aerial photography, is a major strength of our approach. We used high-resolution (3 m) historical imagery for land-cover interpretation and future built-out conditions. The high-resolution imagery provides a superior level of detail as compared to many other landscape studies using 30-m (e.g., Landsat) imagery. Furthermore, the level of detail attainable from our photographs, combined with the prediction method, allowed for a high-level of accuracy when comparing cross-tabulation results to actual built-out landscapes (i.e., based on aerial photographs). A final strength of our approach is that it leverages tools (e.g., GIS) and data (e.g., parcel plats and historical photography) commonly available to many local governments. Therefore, our methods for predicting built-out, residential development conditions are reproducible by local governments with as intermediate level of technological infrastructure.

While the primary intent of our study was not to develop a new method for evaluating land-use policies, we had to create one in order to perform the spatial analysis that supported testing our hypotheses. Our case-study approach provides the fine-grained, context-specific analysis called for by Brody et al. (2006) by using spatial landscape pattern-metrics to evaluate land-use policy outcomes at multiple sites within one jurisdiction. A possible ancillary benefit of this method is that land-use planners have the potential to evaluate the influences of prospective policy changes and determine if proposed development plans adhere to the intended objectives (e.g., preservation of natural features) of previously enacted policies.

5. Conclusions

An analysis was completed to empirically evaluate the influences that an updated local land-use policy had on land-cover change at the urban–rural fringe in Fenton Township, Michigan. The policy's effectiveness for maintaining natural features within the community was evaluated by comparing changes in class- and landscape-level spatial metrics from pre- to post-development stages for developments initiated both before and after the policy implementation. According to our analysis of the data, the policy's objectives were not achieved. It should be noted, however, that fully understanding the changes in ecological integrity that result from the measured land-cover changes requires additional information about ecological processes extant on a site (e.g., fecundity of avian species). Our analysis focused on spatial-pattern metrics as indicators of ecological pattern, and evaluating the effect on specific ecological processes was outside the scope of our paper.

This research culminated in a presentation of observations and recommendations to the Fenton Township Planning Commission (FTPC). Observations included: (1) the open-space ordinance had a positive but limited (not statistically significant) effect on the development of the landscape, compared to the previous policy (supported by 89% of the metrics). Accordingly, the policy's objectives of preserving natural features and rural character were not achieved. (2) The results were logically consistent with the only explicitly detailed function of the ordinance, i.e., to increase open-space within new developments (33% more versus the previous policy). (3) Based on the changes in spatial-pattern metrics for Open areas (e.g., increases in the number of patches and patch density), landscapes within the township have become, on average, more fragmented. Based on our analysis, we made three primary recommendations to the Township Planning Commission; the ordinance should: (a) define natural features; (b) explicitly state that the defined natural features shall be preserved (i.e., not developed within or directly adjacent to); and (c) provide a spatial context for design decisions; that is, define a configuration (pattern) of land covers and land uses appropriate for each site to be developed.

Modifications were made to the open-space ordinance, following our research and additional Township debate. While the newest amendments to the policy were not based on any specific set of conservation principles, the updates did intend to: maintain the community's rural character; add a layer of residential privacy through larger, less fragmented open spaces; and, to increase the level of run-off protection for the Township's many lakes and wetlands. While not an explicitly defined policy objective, maintenance of wildlife habitat and corridors within the residential areas are anticipated (personal communication, Township staff). Specific amendments to the policy included: (i) "Any proposed open space must be a minimum of fifty (50) feet wide in order to be considered open space..."; (ii) "No individual areas less than one-half (1/2) acre may be counted in calculating open space"; (iii) "In considering the appropriate portions of a proposed site to be preserved as open space, the Planning Commission will give priority to land with one or more of these characteristics...", e.g., protects a woodlot; (iv) "In considering the size and shape of a proposed open space...(a) the open space is divided into the minimum number of sites feasible; (b) the open space connects to existing designated open space areas on adjacent parcels; [and,] (c) the open space, where possible, is relatively equal in width and depth, rather than long and narrow." The items described above (in Section 4) were further spatially described, by the addition of a figure detailing specifics related to the number, connectivity, and shape of open-space patches. Lastly, existing natural features were explicitly defined, e.g., streams, marshes, and woodlots.

By amending the open-space ordinance to include: a definition of natural features; a statement of priority to development plans which explicitly preserve natural features; and, providing a spatial context for design decisions, the FTPC has made an effort to achieve the intended objectives of its open-space ordinance—to preserve unique natural features and the township's rural character. Furthermore, they expressed interest in reviewing the effects of these policy changes in 5 years (2010). This adaptive management approach to policy updating provides policy-makers with feedback directly from the system which the policy influences. In the context of a sustainable society (ecologically, socially, and economically), empirical documentation and assessment of the 'real world' effects of established and proposed land-use policies is essential for successful 'management' of the landscape. The presented research describes an effort to understand landscape changes resulting from a local land-use policy update and informs future policy updates by integrating science-based empirical evaluation with public policy formation.

Acknowledgements

We would like to acknowledge the staff of the Charter Township of Fenton, Michigan, specifically Valerie McDonald, Penelope Sharich, and Carl Gabrielson for their assistance with gathering background information and interpretations related to their open-space ordinance, as well as for original permission to use Township GIS data in our analysis. Furthermore, we express gratitude to the members of the Planning Commission, and Township Officials, for their interest and response to our research. The material in this manuscript is based on the work of Jason J. Taylor in partial fulfillment of a Master of Science degree at the School of Natural Resources and Environment at the University of Michigan.

References

Alig, R.J., Kline, J.D., Lichtenstein, M., 2004. Urbanization on the US landscape: looking ahead in the 21st century. Landsc. Urban Plan. 69, 219–234.

Arendt, R., 1997. Growing Greener: A Conservation Planning Workbook for Municipal Officials in Pennsylvania. Natural Lands Trust, Media, PA.

Arendt, R., 2004. Linked landscapes: Creating greenway corridors through conservation subdivision design strategies in the Northeastern and Central United States. Landsc. Urban Plan. 68, 241–269.

Bengston, D.N., Fletcher, J.O., Nelson, K.C., 2004. Public policies for managing urban growth and protecting open space: policy instruments and lessons learned in the United States. Landsc. Urban Plan. 69, 271–286.

Brody, S.D., Carrasco, V., Highfield, W.E., 2006. Measuring the adoption of local sprawl—reduction planning policies in Florida. J. Plan. Educ. Res. 25, 294–310.

Brown, D.G., Pijanowski, B.C., Duh, J.D., 2000. Modeling the relationship between land use and land cover change on private lands in the Upper Midwest, USA. J. Environ. Manage. 59, 247–263.

Collinge, S.K., 1996. Ecological consequences of habitat fragmentation: implications for landscape architecture and planning. Landsc. Urban Plan. 36, 59–77.

Congalton, R., 1991. A review of assessing the accuracy of classification of remotely sensed data. Remote Sensing Environ. 37, 35–46.

Costanza, R., dArge, R., deGroot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., Oneill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., vandenBelt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.

Dwyer, J.F., Childs, G.M., 2004. Movement of people across the landscape: a blurring of distinctions between areas, interests, and issues affecting natural resources management. Landsc. Urban Plan. 69, 153–164.

Fenton Charter Township, 1999. The Charter Township of Fenton Zoning Ordinance. Fenton Charter Township, Fenton, MI.

Forman, R.T.T., 1995. Land Mosaics: The Ecology of Landscapes and Regions. Cambridge University Press, Cambridge.

Forman, R.T.T., Collinge, S.K., 1997. Nature conserved in changing landscapes with and without spatial planning. Landsc. Urban Plan. 37, 129–135.

Girling, C., Kellet, R., 2002. Comparing stormwater impacts and costs on three neighborhood plan types. Landsc. J. 21, 100–109.

Guo, Z.W., Xiao, X.M., Gan, Y.L., Zheng, Y.J., 2001. Ecosystem functions, services and their values—a case study in Xingshan County of China. Ecol. Econ. 38, 141–154.

Gustafson, E.J., 1998. Quantifying landscape spatial pattern: what is the state of the art? Ecosystems 1, 143–156.

Hamburg Township, 2000. Hamburg Township Zoning Ordinance. Hamburg Township, Hamburg, MI.

Hollis, L.E., Fulton, W., 2002. Open Space Protection: Conservation Meets Growth Management. The Brookings Institute, Center on Urban and Metropolitan Policy, Washington, DC.

Jun, M.J., 2004. The effects of Portland's urban growth boundary on urban development patterns and commuting. Urban Stud. 41, 1333–1348.

Knaap, G., Nelson, A.C., 1992. The Regulated Landscape: Lessons from State Land Use Planning. Oregon, Cambridge, MA.

Leitao, A.B., Ahern, J., 2002. Applying landscape ecological concepts and metrics in sustainable landscape planning. Landsc. Urban Plan. 59, 65–93.

McGarigal, K., Cushman, S.A., Neel, M.C., Ene, E., 2002. FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. Pages Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site: http://www.umass.edu/landeco/research/fragstats/fragstats.html.

Michigan Townships Association, 1998. The Township Guide to Planning & Zoning. Michigan Townships Association, Lansing, MI (revised July 2001).

Mitsch, W.J., Gosselink, J.G., 1993. Wetlands. John Wiley and Sons, Inc., New York, NY.

Nassauer, J.I., 1995. Culture and changing landscape structure. Landsc. Ecol. 10, 229–239.

Nassauer, J.I., 1997. Cultural sustainability: aligning aesthetics and ecology. In: Nassauer, J.I. (Ed.), Placing Nature Culture and Landscape Ecology. Island Press, Washington, DC, pp. 65–83.

Nelson, A.C., 2001. Exclusionary practices and urban sprawl in metropolitan Atlanta. (Urban sprawl: local and comparative perspectives on managing Atlanta's growth). Georgia State University Law Review 17 (4), 1087–1102.

Nelson, A.C., Moore, T., 1996. Assessing growth management policy implementation—case study of the United States' leading growth management state. Land Use Policy 13, 241–259.

Pontius, R.G., 2000. Quantification error versus location error in comparison of categorical maps. Photogrammetr. Eng. Remote Sensing 66, 1011–1016.

Riitters, K.H., Oneill, R.V., Hunsaker, C.T., Wickham, J.D., Yankee, D.H., Timmins, S.P., Jones, K.B., Jackson, B.L., 1995. A factor-analysis of landscape pattern and structure metrics. Landsc. Ecol. 10, 23–39.

Robinson, L., Newell, J.P., Marzluff, J.M., 2005. Twenty-five years of sprawl in the Seattle region: growth management responses and implications for conservation. Landsc. Urban Plan. 71, 51–72.

Rosenfield, G.H., 1986. A coefficient of agreement as a measure of thematic classification accuracy. Photogrammetr. Eng. Remote Sensing 52, 223–227.

Southeastern Michigan Council of Governments, 2004. Land Use in Southeast Michigan, Regional Summary, 1999–2000. Southeastern Michigan Council of Governments.

Turner, M.G., Gardner, R.H., O'neill, R.V., 2001. Landscape Ecology in Theory and Practice. Springer-Verlag New York, Inc., New York, NY.

United States Department of Agriculture, Natural Resources Conservation Service, and Iowa State University Statistical Laboratory, 1997. Summary Report 1997. National Resources Inventory (revised December 2002).

VanLier, H.N., 1998. The role of land use planning in sustainable rural systems. Landsc. Urban Plan. 41, 83–91.

Vitousek, P.M., Mooney, H.A., Lubchenco, J., Melillo, J.M., 1997. Human domination of Earth's ecosystems. Science 277, 494–499.

Weitz, J., 1999. From quiet revolution to smart growth: state growth management programs, 1960–1999. J. Plan. Lit. 14, 266–337.