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Modelling potential conservation easement locations using physical and socio-economic factors: A case-study from south-east Michigan

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ABSTRACT

Conservation easements are an important tool for land stewardship by managing existing land use on private lands while allowing for continued private ownership and management. Conservation easements have been used to address a variety of conservation goals such as preserving wetlands for wildlife or constraining urban growth to conserve agricultural landscapes. Since conservation easements serve not just environmental but also social goals, understanding the pattern-process relationships of conservation easement placement can help illustrate current landscapes compared to future scenarios potential by linking current locations across the social and physical landscape. This paper examines the relationships of two types of conservation easements (i.e. environmental and farm) and projects similar potential locations based on just the physical landscape compared to both physical and social landscape by adapting the ecological model, Maxent, to land use modelling. Our results found that current conservation easement locations are modelled equally well using only environmental variables as social and environmental variables together. However, a comparison between projected potential conservation easement locations based on environmental versus socio-economic and environmental factors revealed little difference for environmental conservation easement, but a substantially different distribution for open space conservation easements. These results indicate potential areas to expand open space conservation easements that will serve different socio-economic groups than current locations and demonstrate the potential utility of this methodology for modelling current and future landscapes using the Maxent approach.

1. Introduction

Conservation easement programs are tools that incentivize certain forms of land-use to achieve local and regional planning objectives (Fairfax, Gwin, King, Raymond, & Walt, 2005). Through conservation easements, both governmental and non-governmental groups work with private landowners to protect and restore their lands for ecological services and aesthetic purposes. These include, but are not necessarily limited to, conservation of wildlife habitats, flood mitigation, maintaining agricultural systems, and preserving scenic viewsheds (Mittal, 2011). Owing to their growing popularity, as of October, 2014 there are over 100,000 conservation easements in the United States covering more than 22 million acres of land (NCED, 2014).

Understanding factors related to land use patterns can help identify the processes of land use change and provide better information on land use change objectives to stakeholders. Land use change is a complicated process involving many factors including physical, economic, and social such as climate, hydrology, soils, market access, and labor availability (Walsh et al. 2013). Describing and quantifying these complex relationships can be challenging. One approach adapted from ecology is to model the likelihood of land use projected across the landscape based on relationships of current land use locations and environmental and social landscape factors (Heumann, Walsh, Verdery, McDaniel, & Rindfuss, 2013).

This paper seeks to both understand the relationship of current conservation easement locations to the physical and social environment and to illustrate how future landscape might look based on these factors to help inform future conservation easement placement that considers both environmental and social factors.

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Specifically, this research examines the relationships of two types of conservation easements (i.e. environmental and farm) based on current locations and projects likely potential locations based on landscape factors by adapting the ecological model, Maxent to land use modelling, using Southeast Michigan as a case study.

2. Background

2.1. Conservation easement frameworks

Conservation easements limit future land development in exchange for ecological, development, and aesthetic goals. Although land trusts date back to 1891, they did not become common land preservation tools until the latter half of the 20th Century (Walker, 2007). Urban sprawl blossomed during the 1950s and 1960s, inspiring an open space movement whose members championed the ecological, aesthetic, and social values found in conserving open space in and around preexisting developments (Rome, 1998; 2001).

Just as citizens have created conservation easements over time in scattered places, conservation easement policy also has evolved in piecemeal fashion. Added incentives and calls for oversight have served as catalysts for deepening the legal frameworks for conservation easements (Morris, 2008; The Nature Conservancy, 2004). The customary approach for protecting land was simple acquisition by governmental and non-governmental groups (Walker, 2007). However, conservation easements are an increasingly popular tool to protect a wide range of resources including land with agricultural, environmental, cultural, or historical values because conservation easements involve a voluntary legal contract that allows a landowner to limit the type of development on their property while retaining ownership, the right to continue preexisting land uses within that space, and generally the right to disallow public access to the easement land (Dana & Ramsey, 1989; Fishburn, Kareiva, Gaston, & Armsworth, 2009). Conservation easements are also attractive for their financial incentives. For instance, farmers in suburban areas can enter into a conservation easement agreement where the farmers are compensated for keeping up agricultural land use instead of selling their lands to developers. These advantages include a federal income tax deduction for limiting the amount of development on their lands.

2.2. Land use modelling

Land use modelling offers scholars a glimpse into future land-use possibilities given a set of assumptions regarding human and biophysical changes for defined time periods (Chen & Pontius, 2010). GIS-based processes use spatial data to derive rules that quantitatively evaluate the suitability for a given land use at a location (Murphy, 2005). Inputs of suitability analysis include wide range of different variables such as environmental and socioeconomic factors. One of the chief methodological challenges inherent in land use modelling is the procedure of creating rules to determine how land use is related to variables under study. Multiple Criteria Evaluation (MCE) is a well-known GIS tool applied for land use modelling but often relies on assumption of linear rules (Pereira & Duckstein, 1993). The assumption is limited in that the pattern-process relationships of land use is often described as complicated human-environmental interactions in which multiple factors interact to build complex non-linear relationships in nature (Malanson et al., 2014; Walsh & McGinnis, 2008).

Land use change models rely on a set of rules to drive the models. For instance, cellular automata and agent-based models utilize principles of small-scale procedures to test larger scale patterns. Devising modelling rules is critically important since the assumption of the principle and simplifications can cause unexpected errors. As Heumann et al. (2013, pp.766) states, "although assuming linear relationships can greatly simplify a model, the assumption is that the linear relationship is a justified approximation of reality. However, in many cases, the data and relationships are messy (e.g., the data are not normally distributed or uni-modal, the relationships are interactive and non-linear and may exhibit different patterns at different areas of the parameter space)." Thus, the capability to distinguish and look at complicated non-direct associations between land use patterns and the environmental and socioeconomic landscape is critical to comprehend these pattern-process relationships.

2.3. Niche-based modelling of land use

Niche-based models can explain complicated environmental-species interactions based on environmental variables and species locations. The development of novel machine-learning species distribution models (SDMs) such as Maxent (Phillips & Dudik, 2008) that utilize presence-only data provides opportunities for land use modelling where many potential land use types are possible, even if not currently realized and non-linear relationships are likely. The Maxent model uses a machine learning algorithm to identify non-linear relationships between known locations and then projects those relationships geographically to map other similar locations based on those relationships. This method has been adapted to the land use modelling by adapting the niche theory to a human-managed landscape using physical landscape and social factors (Heumann, Walsh, & McDaniel, 2011, 2013). These studies found that this approach can examine non-linear relationships between land use types and the physical and social landscape. Additionally, Heumann et al. (2013) found that depending on the land use type, either physical environmental or socio-economic factor were dominant.

3. Aims and scope

3.1. Research questions and objectives

The aim of this research is to understand the associated environmental and socioeconomic factors of conservation easement placement, the relative importance of each factor, and how this informs potential conservation easement locations, using Southeast Michigan as a case study to demonstrate the potential of this modelling approach. Specifically, we ask the following questions from the main objective of this research: (1) How are different types of current conservation easements (i.e. environmental and farm) related to the physical and socio-economic landscape? (2) What is the projection of potential locations of conservation easements based on just the physical landscape versus both physical and social landscape?

3.2. Study area

Fig. 1 illustrates the study area that is encapsulated by the Southeast Michigan Council of Governments [hereafter SEMCOG] counties. Over 4.8 million people live within the 4630 km^2 territory of Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties within southeast Michigan (U.S. Census Bureau, Population Division 2014).

The study area is representative of other United States metropolitan areas through its history of land use. Much of the study area's remaining open space sits atop former glacial lakebeds, sometimes drained for farming. In the northwest quadrant of the study area, an interlobate moraine provides undulating topography, irregular drainage, and droughty soils challenging to farmers.