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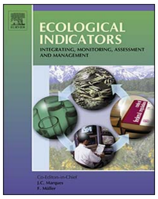

Original articles

# Modeling landscape condition for biodiversity assessment—Application in temperate North America

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## ARTICLE INFO

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## ABSTRACT

Conservation decisions are well supported by predictive spatial models that indicate the relative ecological condition of a given place. The intent of this 90 m pixel landscape condition model is to use nationally available spatial data from the USA, Mexico, and Canada to express assumptions regarding the relative ecological effects of land uses on terrestrial natural communities and species. This approach emphasizes and updateable and transparent design which takes advantage of empirical biodiversity data from the USA to both calibrate and validate the model. Map layers depicting infrastructure, land use, and modified vegetation were each scored for site impact and distance decay, and then combined into one map surface. Field observations from Natural Heritage Programs, each scored for relative ecological condition (in categories A = excellent to D = poor), were used to calibrate distance decay parameters. Some 90,000 observations for at-risk species, invasive plant species, and natural communities were used for model validation. Statistically significant distinctions in ecological condition among validation samples were predicted by the resultant spatial model. Variation in landscape condition was then summarized by regional U.S. Landscape Conservation Cooperatives (LCCs) in terms of areas approximating A–D condition. Montane and desert LCCs scored on average much higher in area approximating "A" and "B" landscape condition, while LCCs with more substantial agricultural and urban footprints scored overwhelmingly within the "D" range of condition. Similar analyses illustrated range-wide scoring of landscape condition for major vegetation types across temperate North America.

## 1. Introduction

Ecological condition commonly refers to the state of the physical, chemical, and biological characteristics of natural ecosystems, and their interacting processes (Stoddard et al., 2006). Ecological condition is often equated with ecological integrity, which has been defined as the ability of an ecological system to support and maintain a community of organisms with the composition, diversity, and functional organization comparable to those of natural habitats within the region (Parrish et al., 2003). Many human land uses affect ecological condition, through vegetation removal or alteration, hydrologic alteration, and introduction of invasive species, resulting in stress to ecosystems. These human-induced stressors in turn fragment landscapes by disrupting species dispersal and other ecological processes that require contiguous natural conditions (Lindenmayer and Fischer, 2013). Therefore, if one seeks to understand ecological condition, one should consider condition both at local sites of interest and at broader spatial and temporal scales.

Since human land uses, such as built infrastructure for transportation, urban development, industry, agriculture and other vegetation alterations, are depicted in maps that are periodically updated (Turner et al., 2015), they can be used in spatial models to make inferences about the status and trends in human-induced stress and ecological condition of landscapes at regional to global scales (Sanderson et al., 2002; Theobald, 2013; Venter et al., 2016). Maps of this nature can be particularly helpful for identifying relatively unaltered landscape patches. These patches can be subsequently analyzed using a variety of fragmentation statistics aiming to quantify patch area, shape, isolation, and edge to area ratio (Nagendra et al., 2004). They can be used for screening ecological reference sites; i.e., a set of sites occurring in landscapes that vary from low to high landscape fragmentation (Comer and Faber-Langendoen, 2013). If they express a continuum of ecological condition, they could be overlain on ecosystem type distributions to indicate the relative extent and intensity of biotic disruption, as is desired for scoring range-wide at-risk status for natural communities or habitat types (Keith et al., 2013). If repeated over time, these maps can be used to understand overall trends in ecological

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*Abbreviations:* LANDFIRE, Landscape Fire and Resource Management Planning Tools Project; US-EPA, U.S. Environmental Protection Agency; USGS, U.S. Geological Survey; ReGAP, Regional Gap Analysis Project part of USGS Gap Analysis Program

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**Table 1**
Date inputs and final parameters used for the NatureServe Landscape Condition Model. Site Impact Scores are derived from Brown and Vivas (2005) and NatureServe expert knowledge, Distance Decay values represent the mean value of Good-to-Excellent Ranked Element Occurrences*.

| Data Theme | Data Sources | | | Site Impact Score | Impact Approaches Negligible (meters) |
|---|---|---|---|---|---|
| | USA | CAN | MEX | | |
| **Transportation** | | | | | |
| Primary Highways with limited access (vector) | 1 | 7 | | 0.172 | 4500 |
| Primary Highways without limited access (vector) | 1 | 7 | 8 | 0.172 | 2700 |
| Secondary and connecting roads (vector) | 1 | 7 | 8 | 0.219 | 3000 |
| Local, neighborhood and connecting roads (vector) | 1 | 7 | | 0.5 | 420 |
| Minor and Dirt roads (vector) | 1 | 7 | 8 | 0.7 | 3800 |
| **Urban and Industrial Development** | | | | | |
| Mines (vector) | 10 | | | 0.05 | 500 |
| High Intensity Developed (raster) | 2 | 7 | 9 | 0.058 | 3450 |
| Transmission Lines (vector) | * | 7 | 9 | 0.168 | 100 |
| Oil and Gas Wells (vector) | * | 7 | | 0.168 | 500 |
| Transmission and Utility Towers (vector) | | 7 | | 0.168 | 500 |
| Pipelines (vector) | | 7 | 9 | 0.168 | 200 |
| Medium Intensity Development (raster) | 2 | | | 0.25 | 2450 |
| Open Space (raster) | 2 | | | 0.308 | 900 |
| Low Intensity Development (raster) | 2 | | | 0.31 | 2400 |
| **Managed and Modified Land Cover** | | | | | |
| Agriculture (raster) | 3,4 | 5,6,7 | 5,6 | 0.3 | 2500 |
| Introduced Upland grass & forb (raster) | 3,4 | | | 0.5 | 2300 |
| Introduced Wetland (raster) | 3,4 | | | 0.626 | 2500 |
| Pasture (raster) | 3,4 | 5,6,7 | 5,6 | 0.723 | 1950 |
| Managed Tree Plantations (raster) | 3,4 | | | 0.842 | 1200 |
| Recently Logged (raster) | 3,4 | | | 0.9 | 1500 |

1-TIGER roads (https://www.census.gov/geo/maps-data/data/tiger.html); 2-USGS National Land Cover (http://www.mrlc.gov/nlcd2011.php); 3-USGS Gap land cover (http://gapanalysis.usgs.gov/); 4-NatureServe ecological systems and land cover (http://www.natureserve.org/conservation-tools/terrestrial-ecological-systems-united-states); 5-GlobCov global land cover (http://due.esrin.esa.int/page_globcover.php); 6-ChinaCov global land cover (http://glc30.tianditu.com/); 7-CanVec Canadian land cover (http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/-/(urn:iso:series)canvec); 8-OpenStreetMap (https://www.openstreetmap.org/#map=5/51.500/-0.100); 9-CONABIO Mexican land cover (http://www.conabio.gob.mx/informacion/gis/?vns=gis_root/biodiv/monmang/manglegw); 10-USGS/MRDS mine location (http://mrdata.usgs.gov/mrds/)
*Proprietary data, available under license in USA; see www.NatureServe.org for more information.

condition of landscapes and the relative contributions of different land uses to landscape change (Griffith et al., 2003; Comer et al., 2013).

However, both conceptual and practical issues complicate development of these spatial models. Most studies documenting ecological effects of land use features on ecosystems are quite context-specific, aiming to document selected species responses to either habitat loss or fragmentation (Knick and Rotenberry, 1995; Gelbard and Belnap, 2003; Fischer and Lindenmayer, 2007; Reino et al., 2013); thus limiting their generalized applicability. This reflects in part a strong tendency among researchers to presume minimal interdependence among individual species in their responses to these factors (Didham et al., 2012).

As a result, some researchers have approached this problem by developing generalized spatial models with less context-specific inputs and applications in mind. That is, they use broad generalizations about the relative ecological effects of human land uses to then transparently construct the spatial model. Some then use field-based observations of land use effects to validate the model relative to their intended use. For example, Brown and Vivas (2005) scored 25 common land use classes along a continuum of estimates for energy input for their development and maintenance; from lowest-intensity "pine plantations" to highest-intensity "central business district (average 4 stories)." This scoring enabled development of a "Landscape Development Index" varying from 1.00 to 10.00 which was then translated as an area-weighted index to individual watersheds. Model results were evaluated using samples from field-based assessments of wetland function, but was not evaluated for its utility for predicting other aspects of ecological condition.

Theobald (2013) provided a generalized model of human modification for the conterminous USA using a series of "intensity" and "footprint" values. Intensity is the degree to which an activity at a location modifies a natural ecological system. Footprint is the aerial extent of the activity. Using a "fuzzy sum" algorithm, the combination of these values provides a (0.0–1.0) human modification score per raster cell. That is, as multiple stressors occur in a given raster cell, their combined values will always approach, but not exceed, 1.0. In that model, intensity values were taken directly from Brown and Vivas (2005) or from expert opinion, and applied to fourteen nationally-available map data sets for infrastructure and land use. The footprint was calculated for each of several hundred land cover classes derived from the U.S. National Gap Analysis land cover map. Through aerial photo interpretation of some 6000 random locations, the proportional overlap of each land use class with each land cover class was recorded. These combined intensity/footprint values were then applied to the regional distribution of each land cover class.

While the model was evaluated for its predictive power using the US-EPA Wadeable Streams Assessment database, a concern remains for the potential effect of applying footprint values to natural land cover classes that vary considerably in their natural extent and distribution; i.e., in a well-justified desire to incorporate empirical data into the model, this particular component of model design could cause distortions in the result, where natural land cover classes located far from sources of ecological stress are still scored for some level of human modification. This could occur where the spatial juxtaposition of land uses to a given natural land cover type is highly skewed. No specific evaluation of this issue was provided by Theobald (2013).

The spatial model discussed in this paper builds on this growing body of published methods for ecological effects assessment and spatial modeling to characterize relative ecological condition of landscapes (Andreasen et al., 2001; Sanderson et al., 2002; Hansen, et al., 2005; Leu et al., 2008; Woolmer et al., 2008; Theobald, 2013; Venter et al., 2016). The intent of this Landscape Condition Model (LCM) is to use nationally available, moderate to high-resolution spatial data from the USA, Mexico, and Canada to transparently express assumptions regarding the relative effects of land uses on a broad cross-section of terrestrial natural communities and species. Both empirical data and expert knowledge were used in stressor selection and in model