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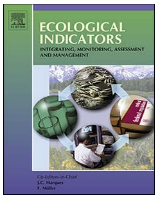

Interpreting multiscale domains of tree cover disturbance patterns in North America

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ABSTRACT

Spatial patterns at multiple observation scales provide a framework to improve understanding of pattern-related phenomena. However, the metrics that are most sensitive to local patterns are least likely to exhibit consistent scaling relations with increasing extent (observation scale). A conceptual framework based on multiscale domains (i.e., geographic locations exhibiting similar scaling relations) allows the use of sensitive pattern metrics, but more work is needed to understand the actual patterns represented by multiscale domains. The objective of this study was to improve the interpretation of scale-dependent patterns represented by multiscale domains. Using maps of tree cover disturbance covering North American forest biomes from 2000 to 2012, each 0.09-ha location was described by the proportion and contagion of disturbance in its neighborhood, for 10 neighborhood extents from 0.81 ha to 180 km^2. A *k*-means analysis identified 13 disturbance profiles based on the similarity of disturbance proportion and contagion across neighborhood extent. A wall to wall map of multiscale domains was produced by assigning each location (disturbed and undisturbed) to its nearest disturbance profile in multiscale pattern space. The multiscale domains were interpreted as representing two aspects of local patterns – the proximity of a location to disturbance, and the interior-exterior relationship of a location relative to nearby disturbed areas.

1. Introduction

A central question in landscape ecology is how patterns and processes change with the scale of observation (Wu, 2013). A “scale domain” has been defined (Wiens, 1989) as an interval in scale space within which landscape patterns and/or pattern-process relationships are stable or predictable. Knowledge of scale domains is important because inferences made within one domain do not necessarily apply in another domain (O’Neill et al., 1986). Furthermore, if pattern regulates process, then scale domains in pattern space define constraint envelopes that regulate landscape processes occurring in those domains (O’Neill et al., 1989). Thus, knowledge of scale domains in pattern scale space is a powerful tool for describing and understanding the scaling of pattern-dependent ecological processes in complex systems (Milne, 1998; Tscharntke et al., 2006; Zurlini et al., 2006; Wheatley 2010; Zhao et al., 2016).

Progress has been limited by a tradeoff between accurate measurement of local patterns and the ability to identify scale domains. Wu et al. (2002) and Wu (2004) evaluated several pattern metrics with respect to scale domains in univariate (i.e., one metric at a time) pattern spaces. The evaluations were done at both the landscape level (Wu et al., 2002) and the focal class level (Wu 2004). Those studies concluded that if scale domains existed, they were contingent upon the choice of metric because different metrics measure different aspects of pattern. Furthermore, the metrics that were most sensitive to local patterns did not exhibit consistent scaling relations with respect to changing extent because of geographic variation of local patterns. In other words, the best metrics for measuring patterns were also the worst metrics for understanding how those patterns scaled with changing extent. That logical dilemma implied a trade-off between having a good description of patterns versus having a consistent description of how patterns changed with spatial extent.

To alleviate that trade-off, Zurlini et al. (2006, 2007) proposed a conceptual model to evaluate scaling with respect to extent while using pattern metrics that were sensitive to local patterns. By analogy to scale domains in pattern space, they considered the possibility of multiscale domains in geographic space. They demonstrated the model using binary maps of disturbed and undisturbed areas. The spatial scaling of disturbance patterns is of particular interest as a driver of complex ecological phenomena (Milne 1998). Disturbance patterns are complex

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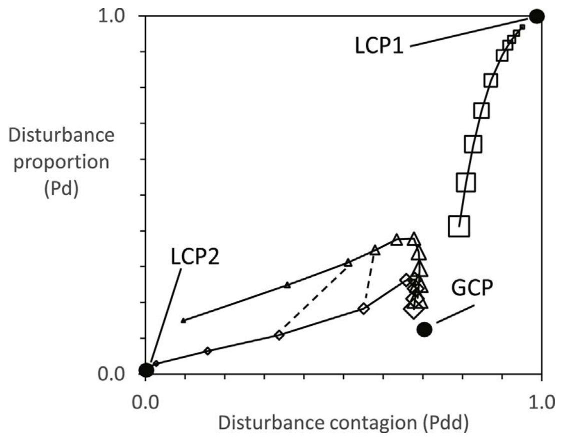

Fig. 1. The conceptual model is illustrated by three disturbance profiles in a pattern space defined by the local proportion and contagion of disturbance. Each disturbance profile connects the observed patterns across measurement extent (scale), and the size of the symbols indicates the relative extent. In addition to the global convergence point (GCP), there are two local convergence points for an extent equal to the size of one pixel that is either disturbed (LCP1) or undisturbed (LCP2). The dotted lines illustrate a "cross-scale mismatch" (Zaccarelli et al., 2008).

because disturbances have multiple causes operating over a range of spatial scales (Turner, 2005). Alternatives to the classical equilibrium paradigm must be able to define stability in terms of disturbance at multiple scales (Wu and Loucks, 1995). The conceptual model considers a pattern space defined by the proportion (Pd) and contagion (Pdd) of disturbance (Fig. 1). In that pattern space, there is a global convergence point (GCP) which is the [Pd, Pdd] value for the extent (scale) that is exactly the extent of the entire study area. For smaller extents, the observed [Pd, Pdd] departs from the GCP if the local pattern is different from the global pattern, where "local" is defined by a particular location and extent. At a given location, the trajectory away from the GCP is the "disturbance profile" which describes the scaling of pattern at that location. A "multiscale domain" is a set of geographic locations with similar disturbance profiles. Whereas classical scale domains are identified by local invariance of pattern in pattern space, multiscale domains are identified by local invariance of the scaling of pattern in geographic space. This conceptual model made it possible to exploit the local sensitivity of pattern metrics such as proportion and contagion, by incorporating their geographic variance into the definition of a multiscale domain.

The conceptual model has a high potential for the prediction and management of disturbance-related processes such as the spread of invasive species across landscapes (Otte et al., 2007). But additional testing is needed because the model has been tested with only one disturbance map in the Apulia region of southeast Italy, for which the choice of eight disturbance profiles was arbitrary (Zurlini et al., 2006). Furthermore, the patterns represented by those disturbance profiles have been interpreted only by comparisons with profiles derived from neutral (random, hierarchical, multifractal) disturbance maps (Zurlini et al., 2007). There has not been a systematic interpretation of disturbance profiles in terms of actual disturbance patterns, and it is not clear that eight disturbance profiles are optimum for another study area large enough to contain many more types of disturbance profiles (e.g., large fires in contiguous boreal forests versus dispersed forest cutting in fragmented temperate forests). Because reliable interpretations of patterns are pre-requisite to reliable interpretation of pattern-process relationships (Bogaert, 2003), the objective of this study was to improve the interpretation of multiscale domains with respect to actual patterns using maps of tree cover disturbance from 2000 to 2012 in North American forest biomes.

2. Methods

Maps of tree cover disturbance were derived from the Global Forest Change Database (GFCD) (Hansen et al., 2013). We defined forest disturbance from the GFCD map of tree cover loss which represents stand-replacement disturbances during the period 2000–2012. The GFCD consists of a set of 10° × 10° map tiles in a geographic projection. Following procedures detailed by Riitters et al. (2016), the 55 GFCD map tiles covering North America from 20 to 80° north latitude and 50–180 ° west longitude were mosaicked. To ensure that the neighborhoods used in later analyses were the same size everywhere, the mosaicked map was projected to a Lambert azimuthal equal-area geographic projection with a target pixel area of 0.09 ha (to match the nominal resolution of the Thematic Mapper data that were used to

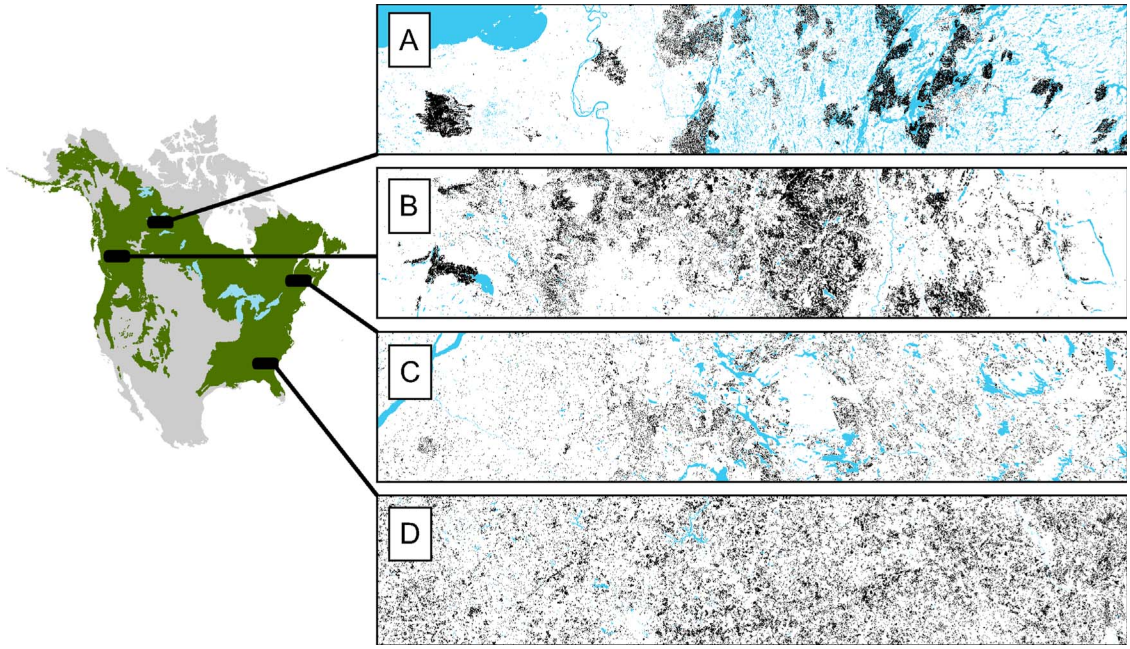

Fig. 2. Left: the study area included North American forest biomes. Right: examples of disturbed (black) and undisturbed (white) areas in (A) Northwest Territories, (B) British Columbia, (C) Maine, and (D) Georgia (water is shown in blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)