The Effectiveness of Landscape Pattern Indices for Judging the Ecological Consequences of Regional- and Local-scale Design and Planning

ROBERT CORRY

Robert C Corry, PhD,
Assistant Professor, Environmental Design and Rural Development,
University of Guelph, Guelph, Ontario,
Canada N1G 2W1.
Email: rcorry@uoguelph.ca

KEY WORDS
FRAGSTATS
Metrics
Data resolution
Scale effects

INTRODUCTION

LANDSCAPE PLANNING AND DESIGN affects humans and others by manipulating land covers, ecosystems and entire regions. Increasingly, ecology is emphasised in planning and design, yet planners and designers lack adequate tools to evaluate alternatives for ecological consequences.

Landscape ecology encompasses the structure and function of ecosystems across broad areas, emphasising energy, materials, and species flows (Forman, 1995). Landscape ecologists link patterns and processes with a goal of inferring processes by understanding patterns. Landscape pattern indices (LPI) quantify landscape composition and configuration (Gustafson, 1998) and have commonly been applied to coarse-resolution data covering broad areas – that is, regional scales (O'Neill *et al*, 1999). The performance of LPI for local-scale design and planning is only beginning to be investigated.

Landscape pattern indices have quantified parts of the United States of America (O'Neill *et al*, 1988), Honduras (Southworth *et al*, 2002), Australia (Hobbs, 1993), Poland (Ryszkowski and Karg, 1992), and The Netherlands (Vos and Zonneveld, 1993). In most investigations the largest ecosystems dominate analyses and fine-scaled features and local conditions are overlooked. Data resolution in the above-mentioned studies is as coarse as 1,000 metres – any ecosystems smaller than the minimum mapping unit are not represented. While LPI may be acceptable tools for regional characterisation, LPI's value for local-scale applications is largely unknown.

Landscape pattern indices are suitable for comparing landscape alternatives (Gustafson, 1998). The inferential value of LPI has been investigated, including ecological specificity (Vos *et al*, 2001)and LPI are described as applicable for evaluating the ecological consequences of plans and designs (Jongman, 1999; Opdam *et al*, 2001; Botequilha Leitão and Ahern, 2002). Yet LPI continue to be applied at broad scales or coarse data resolutions, while design and planning decisions include fine scales.

Planners and designers now have substantial capacity to measure landscapes with LPI – at both regional and local scales – but lack adequate guidance for interpreting index values, especially at local scales (Gustafson, 1998; Turner *et al*, 2001). Landscape pattern indices are not a consistently valid way to infer ecological consequences of local-scale landscape plans, but could be useful for characterising changes in patterns (Corry and Nassauer, Accepted). Animal species have multiscale habitat responses that may not be detected when LPI are applied at a single scale (Lawler and Edwards, 2002; Thompson and McGarigal, 2002). That is, species that respond to a continuum of landscape elements – from regional patterns to local features such as water holes, roads, or perch trees – may be difficult to infer from the application of LPI to a single scale or data resolution.

Advice for planners and designers using LPI to evaluate alternative landscapes has implicated fine-resolution data and linear features as potentially complicating LPI measurement (Corry and Nassauer, Accepted). Yet planners and designers effect changes at resolutions of a few metres, data are increasingly available at sub-metre resolutions, and linear features such as hedgerows, roadsides, and powerline corridors are common to most fragmented landscapes. It is at these local scales that LPI are most necessary yet least understood. In this paper, I analyse the sensitivity of LPI to different data resolutions to investigate the implications of local-scale LPI applications.

METHODS

I calculated LPI at different resolutions for eight alternative landscapes that were created as part of a research project for Iowa, USA, agricultural watersheds (Santelmann *et al*, 2001; Nassauer *et al*, 2002). The watersheds have many attributes common to urban and suburban landscapes, with large expanses of relatively poor habitats (for example, corn fields), and small, infrequent better-quality habitats (for example, woodlots, field boundaries, roadsides).

I used *ArcView* GIS to vary data resolutions from 3 metres to 6 metres, and *FRAGSTATS* (McGarigal and Marks, 1995) to calculate the following LPI: proportion of habitat; mean patch size; aggregation index; interspersion and juxtaposition index; and mean nearest neighbour distance. To compare LPI values I transformed values to percentage of change from baseline. I compared the 3 metre and 6 metre LPI results using a paired t-test (two-tailed) and I operationalised habitat in several different ways to increase my sample: that is, I compared results across two guilds and two habitat types, separately and together. Results show whether local (3 metre) and coarser (6 metre) scale analyses lead to significantly different LPI values, and whether LPI have variable inferential value for judging alternative landscapes depending on issues of scale.

RESULTS

Examples of the LPI values for the different data resolutions are presented in Table 1 (note: this table shows only the LPI values comparing two alternative landscapes for 'good' quality habitat classes in one of the study watersheds; values were also calculated for comparison of other alternative landscapes, 'poor' habitat, and the other watershed).

Notably, re-sampling data from 3 metres to 6 metres resolution did not substantially change the PLAND values, thereby maintaining the distribution of area among habitat types. However, measures of landscape configuration (AI, IJI, MNN) show that LPI values differ in both direction and magnitude for these data resolutions. Mean patch sizes varied up to ten-fold for different data resolutions.

Table 2 reports results of the t-tests. I tested for differences among LPI and ways of operationalising habitat (for example, by habitat class or guild). Two of the indices of landscape configuration have significant ($p<0.01$) differences for 3 metre

Table 1: Landscape pattern index values for two different data resolutions applied to 'good' habitat for at-ground-nesting and below-ground-nesting small mammals in Walnut Creek watershed, Iowa, USA (values are percentage change from baseline conditions)

	At-ground-nesting habitats		Below-ground-nesting habitats	
Landscape pattern index	3 metre data	6 metre data	3 metre data	6 metre data
Proportion of landscape (PLAND)	907	909	35	35
Mean patch size (MPS)	1,124	3,123	14	157
Aggregation index (AI)	20	32	5	1
Interspersion and juxtaposition index (IJI)	53	-57	150	164
Mean nearest neighbour distance (MNN)	-27	-40	9	-28

Table 2: Paired t-test (two-tailed) results for comparisons of 3 metre and 6 metre resolution data effects on landscape pattern index values

Landscape pattern index	***p* value**	**Degrees of freedom**
Proportion of landscape index	0.6643	23
Mean patch size index	0.1734	23
Aggregation index	0.0059*	23
Interspersion and juxtaposition index	0.0039*	23
Mean nearest neighbour distance index	0.4976	23
Method of operationalising habitat patterns		
All 'poor' habitats	0.7272	71
All 'good' habitats	0.1579	71
All at-ground-nesting habitats	0.3784	71
All below-ground-nesting habitats	0.0052*	71
At-ground-nesting, 'poor' habitats	0.0008*	35
At-ground-nesting, 'good' habitats	0.2090	35
Below-ground-nesting, 'good' habitats	0.4376	35
Below-ground-nesting, 'poor' habitats	0.1189	35

**significant at $p<0.01$*

and 6 metre data. The other indices, including MNN (another configuration index) did not have significant differences. For two of eight ways of operationalising habitat there were significant differences in LPI values, but the differences were not consistent for nesting-based guilds, nor for habitat types. While the LPI values in Table 1 appear to be quite different, in six of the eight tests the differences are not significant.

DISCUSSION

If data resolution changes could overcome some of the limitations of LPI (Corry and Nassauer, Accepted), resolution changes might lead to more valid inferences from LPI values. For example, linear habitats that can complicate landscape pattern analysis are generally less apparent at coarser resolution. If LPI do not significantly change for different resolutions, LPI values might be capable of valid results when applied at more than one data resolution (even if design and planning decisions were made at a single resolution).

Landscape pattern indices applied to different resolutions *can* have significant changes in value, and those changes do not consistently apply to indices or ways of operationalising land-cover types. While small changes in data resolution could make landscape pattern analysis faster without significantly changing outcomes in some cases, in others the changes in LPI values can be significant. In this investigation I found no consistently significant LPI responses, making it difficult to know when a resolution change will affect LPI values.

These findings are limited in scope. An analysis of more extensive data-resolution changes and validation of LPI values is required to learn if LPI are useful tools for planners and designers. Without further analysis of the validity of LPI values, there should be considerable caution in how LPI are applied and how the values are interpreted to judge alternative landscapes for ecological consequences (Turner *et al*, 2001). In this analysis data resolution was doubled, but both 3 and 6 metre data are relatively fine and appropriate for local-scale design. With increasingly fine data resolution, designers and planners will be tempted to use highly specific information. Yet there remains an unanswered question about the resolution of data that might best implicate ecological consequences. Thus, while high-resolution data may be excellent for design and planning decisions, more than one data resolution may be required for LPI application. Following the advice of Corry and Nassauer (Accepted), I recommend that planners and designers be exceedingly cautious in making inferences from LPI values, especially if those values are significantly different when data resolutions are only mildly altered.

REFERENCES

Botequilha Leitão, A and Ahern, J (2002) Applying landscape ecological concepts and metrics in sustainable landscape planning, *Landscape and Urban Planning*, 59, pp 65–93.

Corry, RC and Nassauer, JI (Accepted) Limitations of using landscape pattern indices to evaluate the ecological consequences of alternative plans and designs, *Landscape and Urban Planning*.

Forman, RTT (1995) *Land Mosaics*, Cambridge, Massachusetts: Cambridge University Press.

Gustafson, EJ (1998) Quantifying landscape spatial pattern: What is the state of the art?, *Ecosystems*, 1, pp 143–156.

Hobbs, R J (1993) Effects of landscape fragmentation on ecosystem processes in the western Australian Wheatbelt, *Biological Conservation*, 64, pp 193–201.

Jongman, RHG (1999) Landscape Ecology in Land Use Planning, in Wiens, JA and Moss, MR (eds) *Issues in Landscape Ecology*, Guelph, Ontario: The International Association for Landscape Ecology, pp 112–118.

Lawler, JJ and Edwards, TC (2002) Landscape patterns as habitat predictors: Building and testing models for cavity-nesting birds in the Uinta Mountains of Utah, USA, *Landscape Ecology*, 17, pp 233–245.

McGarigal, K and Marks, BJ (1995) *FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure*, General Technical Report, USDA Forest Service Pacific Northwest Research Station. Number: PNW-GTR-351.

Nassauer, JI; Corry, RC and Cruse, RM (2002) The landscape in 2025, *Journal of Soil and Water Conservation*, 57, pp 44A–53A.

O'Neill, RV; Krummel, JR; Gardner, RH; Sugihara, G; Jackson, B; DeAngelis, DL; Milne, BT; Turner, MG; Zygmunt, B; Christensen, SW; Dale, VH and Graham, RL (1988) Indices of landscape pattern, *Landscape Ecology*, 1, pp 153–162.

O'Neill, RV; Riitters, KH; Wickham, JD and Jones, KB (1999) Landscape pattern metrics and regional assessment, *Ecosystem Health*, 5, pp 225–233.

Opdam, P; Foppen, R and Vos, C (2001) Bridging the gap between ecology and spatial planning in landscape ecology, *Landscape Ecology*, 16, pp 767–779.

Ryszkowski, L and Karg, J (1992) The effect of the structure of agricultural landscape on biomass of insects of the above-ground fauna, *Ekologia Polska*, 39, pp 171–179.

Santelmann, M; Freemark, K; White, D; Nassauer, J; Clark, M; Danielson, B; Eilers, J; Cruse, R; Galatowitsch, S; Polasky, S; Vaché, K and Wu, J (2001) Applying Ecological Principles to Land-use Decision-making in Agricultural Watersheds, in Dale, VH and Haeuber, RA (eds) *Applying Ecological Principles to Land Management*, New York: Springer-Verlag, pp 226–252.

Southworth, J; Nagendra, H and Tucker, C (2002) Fragmentation of a landscape: Incorporating landscape metrics into satellite analyses of land-cover change, *Landscape Research*, 27, pp 253–269.

Thompson, CM and McGarigal, K (2002) The influence of research scale on bald eagle habitat selection along the lower Hudson River, New York (USA), *Landscape Ecology*, 17, pp 569–586.

Turner, MG; Gardner, RH and O'Neill, RV (2001) *Landscape Ecology in Theory and Practice: Pattern and Process*, New York: Springer-Verlag.

Vos, CC; Verboom, J; Opdam, PFM and Ter Braak, CJF (2001) Toward ecologically scaled landscape indices, *American Naturalist*, 157, pp 24–41.

Vos, CC and Zonneveld, JIS (1993) Patterns and process in a landscape under stress: The study area, in Vos, CC and Opdam, P (eds) *Landscape Ecology of a Stressed Environment*, New York: Chapman and Hall, pp 1–27.