Emerging Relationships Between Structure and Ecological Function in the Landscape

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The concepts of landscape ecology are theoretically applicable to landscapes anywhere in the world. Much information has been generated relating sizes, shapes, and composition of patches and corridors in the landscape to their ecological function. Many patterns related to ecological processes are emerging that can be applied with increasing confidence in landscape planning and design. In this context, we developed a comprehensive approach that makes use of three-dimensional (3-D) models to describe visually the structural properties of landscape elements. This approach may be used by landscape architects so that the patterns they create also have an appropriate ecological function.

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INTRODUCTION

THERE IS INCREASING evidence suggesting that the explicit composition and the spatial form of a landscape mosaic affect ecological processes, including species persistence and dispersal (Wiens, 1995: Turner *et al*, 2001). Landscape ecology provides the theory to deal with this *structure-to-function* interaction under different spatial and temporal scales: landscape elements, like green corridors and stepping-stones, are thought to facilitate the exchange of individuals between habitat patches, promoting genetic variations and reducing population fluctuations (Forman, 1995). Although empirical data supporting this theory are still lacking, recent studies revealed significant influences of patch/corridor size, shape and spatial arrangement of species composition, pollination and seed dispersal (Tewksbury *et al*, 2002). In two major field experiments, Collinge (1998) directly tested positive effects of fragment size, connectivity and spatial configuration on insect-species richness. Results from these studies provide encouraging clues for incorporating the effects of spatial patterns on ecological processes in landscape architectural planning and design. In an effort to incorporate these insights into practical solutions for landscape architects, we developed a comprehensive approach that makes use of 3-D models to describe visually the structural properties of patches and corridors. Such an approach integrates the well-known pattern language introduced by Dramstad *et al* (1996) with other findings as seen in literature. Specifically, we adopted a model from Laurance and Yensen (1991) to represent mutual relations among size, shape, edge-distance and core-area of patches and corridors (Lafortezza and Brown, 2003). All of these attributes are closely intertwined and require 3-D schemes to be analysed as a whole. Landscape architects can take advantage of this integrated approach when designing new green patches and corridors (for example, in the context of periurban parks, greenway systems and so on) so that the patterns they create also have an appropriate ecological function. Although this approach is globally applicable, it must be applied and tested within local contexts such as socio-cultural patterns and microclimatic constraints. This paper illustrates how the model is able to predict core-areas of small fragments of vegetation interspersed in the Mediterranean rural landscape of Apulia, Southern Italy.

MODELLING PATCH/CORRIDOR STRUCTURAL ATTRIBUTES

The idea to integrate landscape ecology into landscape architectural planning and design is not new. Various frameworks and conceptual models shown in literature stress this integration by combining current theory in landscape ecology with practice (Bissonette, 2003). Relevant to this topic is the pattern language introduced by Dramstad *et al* (1996) that still remains a milestone for the expanding field of landscape ecology. Using simple diagrams, these authors illustrated more than 50 principles, grouped in four main categories such as: patches, edge/boundaries, corridor/connectivity and mosaic. Diagrams are two dimensional (2-D) representations of landscape elements and each one accounts for a single attribute or dimension at a time (for example, the ecological effect of size for the patch category). This may constitute a limit for achieving a holistic vision of landscape elements and their *structural-to-functional* interactions (Naveh, 2000). A more comprehensive approach to this issue is certainly required and may become a point of discussion for landscape ecologists. In this perspective, we attempted to arrange 3-D structural models for patches and corridors that may represent a first step towards this integrated vision. These models are based on a 'molecular analogy', which is a metaphoric interpretation of the stereo-chemical structure of molecules (see Figure 1, model M0). The basic elements of each model, represented by a tetrahedral figure, are four attributes that typically characterise the structure of patches and corridors: size (*TA*), shape (*SI*), edge-distance (d_e), and core-area (CA), *plus* one attribute that conveys the generic idea of ecological function (*EF*) (for example, the establishment of species in the internal part of landscape elements). In terms of theoretical background, our approach refers consistently to the Core-Area Model (CAM) as proposed in Laurance and Yensen (1991). According to these authors, the CAM is able to generate a priori predictions of the core-area (interior habitat) of any specific landscape element combining its size, shape and the estimated value for edge-distance. The core-area 'CA' for a patch/corridor with size area '*TA*' and perimeter '*P*' and for an edge-distance 'd_e' (perpendicular distance inside the elements at which the edge-effect becomes ameliorated), can be predicted by the following expressions: $CA = TA - AA$; where: AA (affected area) = $[3.55\, d_e\, SI\, (TA/10{,}000)^{0.5}]$ and SI (shape index) = $P/\,[200\, (\eth\, TA)^{0.5}]$. The authors also provided some mathematical adjustments that minimise the estimation error of core-area: AA_{adj} = (adjusted affected area) = $AA\,[1\text{-}(0.265(AA/TA))/SI^{1.5}]$. The CAM makes explicit the inter-relationship among the structural attributes of patches/corridors: for landscape elements of any given size, irregularly shaped elements lose more core-area as d_e increases than do more circular elements. This model has found applications in the context of large fragments of forest (*TA*>100ha) where predictions were highly accurate (Laurance and Yensen, 1991, Sharma *et al*, 2000). When applied to the planning and design of small landscape elements, this model, as part of the 'molecular analogy' approach, may support landscape architects in recommending size, shape and core-area of patches and corridors that have the potential to support ecological function (Figure 1, models M1–M3).

TESTING ATTRIBUTES RELATIONS FOR SMALL LANDSCAPE ELEMENTS

To demonstrate the ability of this approach in predicting core-areas of relative small landscape elements and therefore its capacity to support landscape architects, we performed a statistical analysis of data coming from a major case study located in the Apulia region, Southern Italy. We computed *TA* and *SI* for 122 fragments of Mediterranean-type vegetation, covering an area of 311.85 hectares and then used *TA* and *SI* to estimate *CA* for incremental values of d_e. Data were analysed using a multi-regression method: $CA = a\,(TA) + b\,(SI) + c$; where the parameters '*a*', '*b*', and '*c*' are the regression coefficients to be estimated.

Results in Table 1 indicate that there was not a significant difference ($p<0.001$) between regression scores and data resulting from the model application: the model is able to predict core-areas of relative small landscape elements. The fitness of the regression decreases as d_e increases. The reason has to do with the relationship between core-area and d_e that becomes curvilinear when the core area becomes small (high value of d_e). The 'molecular analogy' approach on the basis of the CAM model can be used to predict the relative amount of interior-edge habitat for small fragments of vegetation. Landscape architects can benefit from this approach when implementing patches and corridors of relative small size (for example, new green areas) into the landscape.

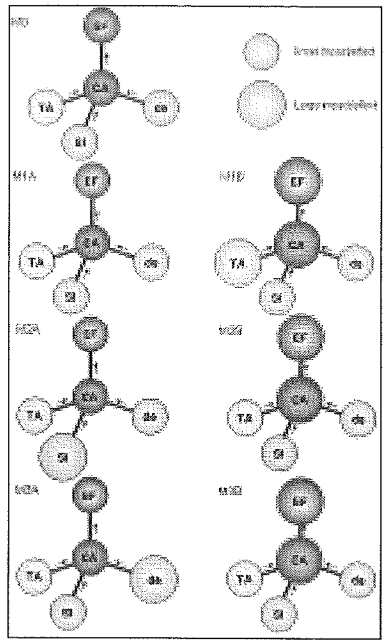

Figure 1: 3-D structural models for patches and corridors (TA = total area; SI = shaper index; d_e = edge-distance; EF = ecological function). From the models, the following assumptions can be made: (1) for a given SI *and d_e, model M1A reveals a lower* CA *than M1B; (2) for a given* TA *and d_e, model M2A reveals a lower CA than M2B; (3) for a given* TA *and* SI, *model M3A reveals a lower* CA *than M3B.*

CONCLUSION

In this paper, we introduce a landscape ecological approach that may support landscape architects when designing new landscape elements such as habitat patches

Table 1: Multi-regression analysis for estimating *CA* of sample fragments
(Statistical significance of coefficients: ** $p<0.001$)

d_e (m)	a	b	c	Statistical significance of regression R^2	significance of F
10	0.85**	-0.13**	-0.04	1.00	$p<0.001$
20	0.70**	-0.25**	-0.03	0.98	$p<0.001$
30	0.55**	-0.34**	0.04	0.94	$p<0.001$
40	0.40**	-0.41**	0.15	0.81	$p<0.001$
50	0.25**	-0.47**	0.31	0.52	$p<0.001$

and green corridors. Three-dimensional models have been used to represent mutual relationships among critical attributes characterising the structure of these elements and therefore their attitude to accommodate ecological functions, like the establishment of species with interior habitat requirements (Peck, 1998). It is worth noting that this approach represents a mere oversimplification of the complex field of landscape ecology, which makes use of sophisticated methods to deal with the structure and the function of landscape elements (Turner *et al*, 2001). Such an approach, therefore, requires an adequate knowledge of landscape ecology (or cooperation between landscape architects and landscape ecologists) to be properly applied in the landscape. Finally, 3-D models have been conceived to be globally applicable, but must be applied within local contexts such as socio-cultural and ecological patterns and microclimatic constraints.

REFERENCES

Bissonette, JA (2003) Linking landscape patterns to biological reality, in Bissonette, A and Storch, I (eds) *Landscape Ecology and Resource Management*,. Washington, DC: Island Press, pp 15–30.

Collinge, SK (1998) Spatial arrangement of habitat patches and corridors: clues from ecological field experiments, *Landscape and Urban Planning*, 42, pp 157–168.

Dramstad, WE; Olson, JD and Forman, RTT (1996) *Landscape Ecological Principles in Landscape Architecture and Land-use Planning*, Washington, DC: Island Press.

Forman, RTT (1995) *Land Mosaic: the Ecology of Landscapes and Regions*, New York: Cambridge University Press.

Lafortezza R and Brown, RD (2003) (In Press) A framework for landscape ecological design of new patches in the rural landscape, *Environmental Management*.

Laurance, WF and Yensen, E (1991) Predicting the impacts of edge effects in fragmented habitats, *Biological Conservation*, 55, pp 77–92.

Naveh, Z (2000) What is holistic landscape ecology? A conceptual introduction, *Landscape and Urban Planning*, 50, pp 7–26.

Peck, S (1998) *Planning for Biodiversity: Issues and Examples*, Washington, DC: Island Press.

Sharma, S; Palni, LMS; Roy, PS (2000) Analysis of fragmentation and anthropogenic disturbances in the Himalayan forests: use of remote sensing and GIS, *GIS Development*, online journal: <http:/ /gisdevelopment.net/aars/acrs/2000/ts6/fore0004pf.htm> (last accessed 8 June 2004).

Tewksbury, JJ; Levey, DJ; Haddad, NM; Sargent, S; Orrock, JL; Weldon, A; Danielson, BJ; Brinkerhoff, J; Damschen, EI and Townsend, P (2002) Corridors affect plants, animals, and their interactions in fragmented landscapes, *PNAS*, 99 (20), pp 12923–12926.

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

Wiens, JA (1995) Landscape mosaics and ecological theory, in Hansson, L; Fahrig, L and Merriam, G (eds) *Mosaic Landscapes and Ecological Processes*, London: Chapman & Hall, pp 1–26.