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Editorial

Corridors and Networks in Landscape: Structure, Functions and Ecological Effects

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Network is defined in GIS as a system composed of arcs and nodes (Cova and Goodchild, 2002). In real landscape, network corresponds to a complex of corridors in its early definition (Forman and Godron, 1986). Although not occupying a large percentage of area, network plays a dominant role in landscape functions through its high connectivity and intensive flows of organisms, materials, energy and information. Habitat within network is generally characterized by frequent disturbance and active dynamics (Collinge, 1996; Haddad, 1999).

The most significant corridor networks in natural landscape are undoubtedly the river systems. By connecting the erosion and deposition processes, river system acts as a major driver of landscape evolution on earth at multiple spatiotemporal scales (Poole, 2002). In the human-dominated landscape, the transportation networks, i.e., road and railway systems on the land, and the networks of shipping lines and flight lines in the seas and the sky, are recognized as the major regulating framework of the human society and modern landscape (Abry *et al*., 2002; Hulme, 2009). The fundamental function of corridor networks is facilitating the horizontal flows and connections across landscape (Bennett, 2003). However, both natural and human-made corridor networks also have barrier and isolation effects on some natural processes, such as fire spreading and animal migration, and the spatial distribution of almost all species of organisms, i.e., creating habitat fragmentation in a general sense (Tischendorf and Fahrig, 2000; Forman *et al*., 2003). This understanding provides a functional assessment of landscape connectivity beyond the viewpoint of human being, instead with a perspective of landscape from any species of organisms or ecological processes (Urban and Keitt, 2001; Bélisle, 2005). The definition of network in landscape is therefore broadened to include both corridors and patches irrespective of spatial shapes, but emphasizing the function or result of connectivity between the landscape elements of interest.

As the first analytical concept framework in landscape ecology, the ′patch-corridor-matrix′ paradigm (Forman and Gordon, 1986), and maybe also the theory of metapopulation dynamics (Hanski, 1998), helped to focus the landscape pattern analysis on patches for about 20 years (Turner and Gardner, 1991), partially facilitated by the free software for landscape pattern analysis, i.e., FRAGSTAT (McGarigal *et al*., 1995; 2002). Since the 1990s, Dean Urban and his cooperators pioneered the application of graph theory and methods to characterize the network structure in landscape, as an alternative (and complementary) approach that emphasize the spatial pattern of corridors and landscape connectivity (Keitt *et al*., 1997; Bunn *et al*., 2000; Urban and Keitt, 2001). The approach helps to discern the structural and functional connectivity, and appreciate the role of object-specific dispersal capacity in addition to spatial distance in estimate of landscape connectivity (Beier and

Noss, 1998). The progress in methodology is recognized critical in the ′post-FRAGSTAT′ development of landscape pattern analysis (Kupfer, 2012), and evidenced by the increasingly popular applications of addressing issues of biological conservation, urban planning and landscape management (Minor and Lookingbill, 2010; Fletcher *et al*., 2011; Saura *et al*., 2011; Theobald *et al*., 2012).

This special issue of 'Structure and Function of Network in Landscape' is based on the talks presented in the symposium of the same topic organized in September, 2012, for the Annual Conference of the Chinese Society of Ecology in Changchun City, China. As an effort to push the applications of the concepts and approaches of network analysis in landscape ecological studies, and integrate the studies of network characteristics, flows and spatial processes, as well as landscape functions and services, this collection of papers provides a window to three aspects of our contemporary state of understanding of the structure and function of landscape network in China:

(1) On the application of the general concept of network and landscape connectivity in natural resource estimate, landscape planning and management

Xu Weihua *et al*. apply the concept of patch network in combined with gap analysis to evaluate the efficiency of the natural reserve system in the Qinling Mountains, for its role of protecting the crucial habitat of Qiant Panda and other endangered species. This concept of landscape function of patch network is also applied by Zhen Nahui *et al*. in their estimate of ecosystem service for landscape planning. Wang Wenjie *et al.* combine the landscape connectivity with the concept of ecological zone planning, and develop an optimizing framework for key ecological areas, and corresponding policies of biological conservation.

(2) On the ecological effects of network in landscape

Tang Qian *et al*. define three types of corridor network in an agricultural landscape, and explore the impacts of network type and spatial configuration on the plant species composition and diversity in an intensively disturbed vegetation. Wang Cong *et al*. differentiate the road impacts into lateral disconnection effect and crossing effect, and explore the interaction between road, river and topographic features and the impact on soil erosion in a river landscape. Liang Jun *et al*. rethink the ecological impacts of roads of different levels, by combining the road length, regional distribution, and correlation with spatio-temporal patterns of land use and land cover change; and argue that the level-related road impacts need to relate the particular ecological process for a mechanistic and reasonable evaluation.

(3) On the network based method in landscape analysis and simulation

Liu Shiliang *et al*. introduce a landscape connectivity index (Probability of Connectivity) and least-cost modeling to evaluate the road impacts on the conservation of species of different dispersal capacity, and the scale property of road impact. Xiao He *et al*. apply the standard approach of network analysis, i.e., eco-profile method and least-cost distance model in optimizing an eco-network planning in Beijing, and explore the role of habitat requirement and dispersal capacity in developing the species-specific functional networks. Wen Qingchun *et al*. select a set of boundary and node-based indices to describe the spatial patterns of a landscape in the Upper Minjiang River, and compare the sensitivity of network related landscape indices with the patch-based indices to landscape dynamics. Ying Lingxiao *et al*. improve a kernel density estimate algorithm to quantify the effects of road network, and estimate the social and economical services of the network in the Three Parallel River Region, by taking the level-related intensity and extent of road effects into account. Sun Ranhao *et al*. proposed a new method to describe the landscape pattern in the 3-dimensional space, to provide a general model for understanding the complexity and diversity of mountain environment and landscape. Wang Kaiyong *et al*. introduced an optimized gravity model to characterize the spheres of urban influence, as a distinct approach of analyzing the spatial patterns of urban agglomerations in China.

In general, we can see that increasing attention have turned to the structural and functional characteristics of corridor and patch network in landscape ecological studies in China, and the connectivity concept have begun to be applied in landscape planning and management. However, the graph-based method is yet to be a common approach in these studies, and the direct measure or estimate of structural or functional connectivity of the landscape networks is still rarely applied. This invokes the necessity of more effort to be involved in the application of network approach and perspective in the landscape ecological studies in China.

By providing indicators and algorithms for describing and estimating the structure and function of landscape network, the graph-based approach is obviously a fast growing front in landscape ecology and related disciplines (Kindlmann and Burel, 2008; Galpern *et al*., 2011; Rayfield *et al*., 2011). This approach integrates the spatial pattern of corridors (edges) and patches (nods) with the dispersal capacity of the studied flows of materials, energy or information, sets up an explicit link between landscape patterns and ecological processes through functional estimate of landscape connectivity (Miller and Urban, 2000; Pascual-Hortal and Saura, 2006; Fall *et al*., 2007; Gascuel-Odoux *et al*., 2011). The predictive capacity and testability of its results with empirical observation render this approach a promising power in exploring scientific questions and practical concerns, with especially useful applications in biological conservation, natural resource management and land use planning in response to the impacts of climate change and human interferences at landscape scale (Urban and Keitt, 2001; Zetterberg *et al*., 2010).

Just as the role of the open software FRAGSTAT in the widespread (sometimes too much) applications of spatial pattern indices in landscape studies, many tools for the graph-based landscape analysis and simulation have emerged recently, such as Conefor Sensinode 2.2 (Saura and Torne, 2009), Circuitscape (McRae and Shah, 2011), UNICOR (Landguth *et al*., 2011) and Graphab1.0 (Foltête *et al*., 2012). Along with the discussion on the methodology issues regarding the consistency, redundancy and complementation between different graph-based network indices (Saura, 2010), the uncertainty, bias, and data availability for the graph-based connectivity estimates (Kindlmann and Burel, 2008; Kupfer, 2012), and the mechanistic link between the network features and ecological functions, the studies of ′post-FRAGSTAT landscape′ are probably experiencing a paradigm shift to the framework of ′network-dispersal-connectivity′, and the consciousness and catching up with this paradigm shift is critical to the development of Chinese landscape ecology.

References

Abry P, Baraniuk R, Flandrin P *et al*., 2002. The multiscale nature of network traffic: Discovery, analysis, and modelling. *IEEE Signal Processing Magazine*, 19(3): 28–46. doi: 10.1109/79.998080

Beier P, Noss R F, 1998. Do habitat corridors provide connectivity? *Conservation Biology*, 12(6): 1241–1252. doi: 10.1111/j.1523-1739.1998.98036.x

Bélisle M, 2005. Measuring landscape connectivity: The challenge of behavioral landscape ecology. *Ecology*, 86(8): 1988–1995. doi: 10.1890/04-0923

Bennett A F, 2003. *Linkages in the Landscape*: *The Role of Corridors and Connectivity in Wildlife Conservation*. Switzerland and Cambridge, U.K.: IUCN.

Bunn A G, Urban D L, Keitt T H, 2000. Landscape connectivity: A conservation application of graph theory. *Journal of Environmental Management*, 59: 265–278.

Collinge S K, 1996. Ecological consequences of habitat fragmentation: Implications for landscape architecture and planning. *Landscape and Urban Planning*, 36(1): 59–77. doi: 10.1016/S0169-2046(96)00341-6

Cova T J, Goodchild M F, 2002. Extending geographical representation to include fields of spatial objects. *International Journal of Geographical Information Science*, 16(6): 509–532. doi: 10.1080/13658810210137040

Fall A, Fortin M J, Manseau M *et al*., 2007. Spatial graphs: Principles and applications for habitat connectivity. *Ecosystems*, 10(3): 448–461. doi: 10.1007/s10021-007-9038-7

Fletcher J R, Acevedo M A, Reichert B E *et al*., 2011. Social network models predict movement and connectivity in ecological landscapes. *Proceedings of the National Academy of Sciences*, 108(48): 19282–19287. doi: 10.1073/pnas.1107549108

Foltête J C, Clauzel C, Vuide G, 2012. A software tool dedicated to the modeling of landscape networks. *Environmental Modelling & Software*, 38: 316–327. doi: 10.1016/j.envsoft.2012.07.002

Forman R T T, Gordon M, 1986. *Landscape Ecology*. New York: John Wiley & Sons.

Forman R T T, Sperling D, Bissonette J A *et al*., 2003. *Road Ecology*: *Science and Solutions*. Washington D.C.: Island Press.

Galpern P, Manseau M, Fall A, 2011. Patch-based graphs of landscape connectivity: A guide to construction, analysis and application for conservation. *Biological Conservation*, 144(1): 44–55. doi: 10.1016/j.biocon.2010.09.002

Gascuel-Odoux C, Aurousseau P, Doray T *et al*., 2011. Incorporating landscape features to obtain an object-oriented landscape drainage network representing the connectivity of surface flow pathways over rural catchments. *Hydrological Processes*, 25(23): 3625–3636. doi: 10.1002/hyp.8089

Haddad N M, 1999. Corridor use predicted from behaviors at habitat boundaries. *American Naturalist*, 153(2): 215–227. doi: 10.1086/303163

Hanksi I, 1998. Metapopulation dynamics. *Nature*, 396(6706): 41–49. doi: 10.1038/23876

Hulme P E, 2009. Trade, transport and trouble: Managing invasive species pathways in an era of globalization. *Journal of Applied Ecology*, 46(1): 10–18. doi: 10.1111/j.1365-2664.2008.01600.x

Keitt T H, Urban D L, Milne B T, 1997. Managing fragmented landscapes: A macroscopic Approach. *Conservation Ecology*,

1(1): 4.
Kindlmann P, Burel F, 2008. Connectivity measures: A review. *Landscape Ecology*, 23(8): 879–890. doi: 10.1007/s10980-008-9245-4
Kupfer J A, 2012. Landscape ecology and biogeography: Rethinking landscape metrics in a post- FRAGSTATS landscape. *Progress in Physical Geography*, 36(3): 400–420. doi: 10.1177/0309133312439594
Landguth E L, Hand B K, Glassy J *et al*., 2011. UNICOR: A species connectivity and corridor network simulator. *Ecography*, 34: 1–6.
McGarigal K, Cushman S A, Neel M C *et al*., 2002. FRAGSTATS: Spatial pattern analysis program for categorical maps. Available at: www.umass.edu/landeco/research/fragstats/fragstats.html.
McGarigal K, Marks B J, 1995. Fragstats: Spatial pattern analysis program for quantifying structure. PNW-GTR-351, Oregon.
McRae B H, Shah V B, 2011. *Circuitscape User Guide. The University of California*, *Santa Barbara*. Available at: http://www.circuitscape.org.
Miller C, Urban D L, 2000. Connectivity of forest fuels and surface fire regimes. *Landscape Ecology*, 15(2): 145–154. doi: 10.1023/A:1008181313360
Minor E S, Lookingbill T R, 2010. A multiscale network analysis of protected-area connectivity for mammals in the United States. *Conservation Biology*, 24(6): 1549–1558. doi: 10.1111/j.1523-1739.2010.01558.x
Pascual-Hortal L, Saura S, 2006. Comparison and development of new graph-based landscape connectivity indices: Towards the priorization of habitat patches and corridors for conservation. *Landscape Ecology*, 21(7): 959–967. doi: 10.1007/s10980-006-0013-z
Poole G C, 2002. Fluvial landscape ecology: Addressing uniqueness within the river discontinuum. *Freshwater Biology*, 47(4): 641–660. doi: 10.1046/j.1365-2427.2002.00922.x
Rayfield B, Fortin M-J, Fall A, 2011. Connectivity for conservation: A framework to classify network measures. *Ecology*, 92(4): 847–858. doi: 10.1890/09-2190.1
Saura S, 2010. Measuring connectivity in habitat mosaics: The equivalence of two existing network indices and progress beyond them. *Community Ecology*, 11(2): 217–222. doi: 10.1556/ComEc.11.2010.2.10
Saura S, Estreguil C, Mouton C *et al*., 2011. Network analysis to assess landscape connectivity trends: Application to European forests (1990–2000). *Ecological Indicators*, 11(2): 407–416. doi: 10.1016/j.ecolind.2010.06.011
Saura S, Torne J, 2009. Conefor Sensinode 2.2: A software package for quantifying the importance of habitat patches for landscape connectivity. *Environmental Modelling & Software*, 24(1): 135–139. doi: 10.1016/j.envsoft.2008.05.005
Theobald D M, Reed S E, Fields K *et al*., 2012. Connecting natural landscapes using a landscape permeability model to prioritize conservation activities in the United States. *Conservation Letters*, 5(2): 123–133. doi: 10.1111/j.1755-263X.2011.00218.x
Tischendorf L, Fahrig L, 2000. On the use and measurement of landscape connectivity. *Oikos*, 90(1): 7–19. doi: 10.1034/j.1600-0706.2000.900102.x
Turner M G, Gardner R, 1991. *Quantitative Methods in Landscape Ecology*: *The Analysis and Interpretation of Landscape Heterogeneity*. New York: Springer-Verlag.
Urban D, Keitt T, 2001. Landscape connectivity: A graph-theoretic perspective. *Ecology*, 82(5): 1205–1218. doi: 10.1890/0012-9658(2001)082[1205:LCAGTP]2.0.CO;2
Zetterberg A, Mörtberg U M, Balfors B, 2010. Making graph theory operational for landscape ecological assessments, planning, and design. *Landscape and Urban Planning*, 95(4): 181–191. doi: 10.1016/j.landurbplan.2010.01.002