4 Peri-urban dynamics: landscape ecology perspectives

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Through spatial pattern analysis, landscape ecology assesses the impact of human action on landscapes and on the ecosystems composing them. Peri-urban territories represent direct consequences of urbanization and can be considered as exogenous edge zones of urban patches. A decision tree is presented to define and identify the different parts of the urban-rural gradient. For the city of Kinshasa (Democratic Republic of the Congo), the width of the peri-urban zone is estimated to be ~10 km, based on a semi-circular model. The limited availability of space for human actions is proposed to be the central hypothesis of a new unifying discipline, named "choralogy".

Dynamiques périurbaines : perspectives de l'écologie du paysage

Par l'analyse de la structure spatiale, l'écologie du paysage étudie l'impact des activités anthropiques sur les paysages et les écosystèmes qui les composent. Les territoires périurbains sont une conséquence directe de l'urbanisation et peuvent être considérés comme des zones exogènes de lisière. Un arbre de décision est présenté pour permettre la définition et l'identification des différentes parties du gradient urbain-rural. Pour la ville de Kinshasa (République Démocratique du Congo) et sur base d'un modèle semi-circulaire, la largeur de la zone périurbaine a été estimée à ~10 km. La disponibilité limitée en espace pour les activités anthropiques est proposée comme hypothèse centrale d'une nouvelle discipline, appelée « choralogie ».

4.1. LANDSCAPE ECOLOGY AND GEOGRAPHICAL SPACE MANAGEMENT

Landscape ecology, a discipline with many links to other branches of science such as landscape architecture, physical geography or botany (Bogaert et al., 2013), singularizes itself in the realm of ecology by its focus on the spatial patterns and processes observed in landscapes (Fahrig, 2005). This approach is known as the pattern/process paradigm (Turner, 1989), which hypothesizes a strong influence of observed patterns on underlying processes, and *vice versa*. This paradigm justified the development of techniques to assess patterns in landscapes, such as landscape metrics (Bogaert et al., 2004a; Li et al., 2004), or neutral models (Turner et al., 2001). For landscape ecologists, a landscape corresponds to a particular scale level situated approximately in the center of the hierarchy of the biosphere (Allen et al., 1982; Urban et al., 1987) which can be divided in a top-down approach in different levels or stages of complexity or organization. These levels also correspond to different extents, from large (the biosphere itself) to small (atoms and their components). In the aforementioned hierarchy, the landscape level is situated below the regional level and above the ecosystem level, and landscapes are therefore often defined as "eco-complexes" or particular combinations of interacting ecosystems (Forman & Godron, 1986). These ecosystems, which consequently form the composing elements of landscapes, are considered internally homogeneous and called "patches". When they are characterized by a linear form and contribute to landscape connectivity, they can

Bogaert J. & Halleux J.-M., 2015. *Territoires périurbains. Développement, enjeux et perspectives dans les pays du Sud*. Gembloux, Belgique : Presses agronomiques de Gembloux.

be denoted as "corridors". The difference between patches and corridors is therefore mainly functional; nevertheless, since corridors distinguish themselves from other patches by their elongated shape, the difference can also be considered as configuration-based. Patches representing similar ecosystem types or land covers are called a "patch type", "landscape class" or "land cover class"; the dominant type is called "landscape matrix". In case of absence of a dominant class, the term "mosaic" is often used to characterize the overall landscape pattern (Forman, 1995).

The analysis of landscape patterns is often based on a two-step approach. Firstly, landscape composition is quantified. By means of heterogeneity metrics which describe the number and the relative abundance of patch types, the presence and dominance of particular patch types is quantified. Landscape and patch type stability as well as the underlying mechanisms of landscape dynamics can be derived from a transition matrix, which can form the starting point of landscape modelling, for example through an application of Markov models (Urban et al., 2002; Takada et al., 2010). In a second step, landscape configuration is analyzed, by means of the areas, shapes, spatial dispersion and density of the patches of the different types. Patch type juxtaposition can complete this analysis (Bogaert et al., 2014). For these patch and patch type characteristics, a large number of metrics have been proposed and tested. Some of them, such as fractal dimension (Krummel et al., 1987) or the index of disturbance (O'Neill et al., 1988) have been designed to study anthropogenic land cover change. In a diachronic analysis, the evolution of the landscape metric outcomes can be monitored. The determination of the landscape transformation process could be mentioned as a complementary analysis potentially enhancing the ecological interpretation of the observed dynamics (Bogaert et al., 2004b). It should be emphasized that pattern analysis should only be done when justified by relevant scientific hypotheses, *i.e.* the link between quantified patterns and ecological processes should be clear (Li et al., 2004).

Landscape ecology not only aims at analyzing and understanding landscapes through their patterns, but also at improving the management and use of the (spatial) resources present. A landscape corresponds to a geographical space with a delimited extent. Each areal unit corresponds to a particular patch type and when natural land covers are replaced with anthropogenic ones, this process is often irreversible. This concept of "space consumption", *i.e.* the consideration of space as a limited resource, is crucial when developing policies for sustainable landscape development. Considering the increasing demographic pressure on lands (Cole, 1996), a rather conservative approach with regard to the transformation of natural land covers should be applied, as illustrated in table 4.1. Data for Central Africa show that available land *per capita* decreases dramatically when the 2025 projections are considered. Arable lands, essential to food production, and ecosystem services delivered by forests are critically endangered while demographic pressure continues to increase. Land restoration and conservation should be considered as key instruments to preserve sufficient spatial resources for all necessary ecosystem functions. Suboptimal use or waste of space should be avoided at any price; for every anthropogenic land cover change, an analysis should be made with regard to its opportunity, cost, reversibility, and to the type of (natural) land cover replaced.

Table 4.1. Approximate trends of space limitation for nine countries situated in Central Africa. Data and projections are based on the World Development Indicators (The World Bank, 2014).

Country	Total land area ha per capita			Arable land area* ha per capita			Forest area** ha per capita		
	2000	2012	2025	2000	2012	2015	2000	2012	2025
Burundi	0.38	0.26	0.18	0.14	0.10	0.07	0.03	0.02	0.01
Cameroon	2.97	2.18	1.60	0.37	0.27	0.20	1.39	1.02	0.75
Central African Republic	17.31	13.84	10.74	0.53	0.42	0.33	6.37	5.09	3.95
Chad	15.17	10.15	6.92	0.43	0.29	0.20	1.49	1.00	0.68
Congo, Democratic Republic	4.83	3.45	2.46	0.14	0.10	0.07	3.35	2.39	1.71
Congo, Republic	11.02	7.94	5.69	0.16	0.12	0.08	7.28	5.25	3.76
Equatorial Guinea	5.62	4.01	2.81	0.25	0.18	0.13	3.49	2.49	1.75
Gabon	21.48	16.11	11.71	0.27	0.20	0.15	18.34	13.75	10.00
Rwanda	0.29	0.21	0.16	0.11	0.08	0.06	0.04	0.03	0.02

*Arable land area estimates for 2012 and 2025 based on estimated arable land area for 2000. **Forest area estimates for 2012 and 2025 based on estimated forest areas for 2000. Table concept based on Cole (1996).

4.2. ANTHROPOGENIC EFFECTS AND PERI-URBANIZATION

It can be accepted that anthropogenic effects in landscapes have been observed since the invention of agriculture, *i.e*. at the start of the Neolithic era (Bogaert et al., 2014). During the Paleolithic era, Man acquired food by gathering fruit and hunting game and lived according to the rhythms of the surrounding ecosystems, which were determined by natural cycles such as the sequence of favorable and less favorable seasons, life cycles of fruit-producing plants or game migration. Human population density was very low, which resulted in non-significant impacts on land cover, although this thesis remains subject to debate (Lecomte, 2005). After the start of agricultural production, Man became sedentary and started to modify systematically his environment: agricultural fields were installed and replaced the original natural vegetation; villages were founded to enable the primitive farmers to live next to their production sites. Increased agricultural productivity (per farmer, through the use of animal energy) enabled these villages to evolve towards communities in which different professional activities were developed; further evolution led to the development of cities, with different social classes and in which architectural design became more important (Mazoyer et al., 2006; Bogaert et al., 2014).

Theoretically, two transformation phases are expected when landscapes evolve from natural to anthropogenic (Bogaert et al., 2014). Initially, the natural matrix is replaced with an agricultural one, often composed of different land covers or land uses, such as crop fields, fallows, pasture lands or lands with (primitive) agricultural buildings. Secondly, a growing importance of urban land covers and uses is observed, such as buildings, road infrastructure, or parks. The speed at which these transformations take place, the moment they start, and the relative dominance of particular anthropogenic effects depend on local environmental, economic, social and demographical conditions. For example, areas with a high demographic pressure and with many, easily accessible, fertile soils can be expected to have rapidly developed a highly dominant agricultural matrix. Consequently, this anthropogenic transformation of landscapes on a global scale presents itself as a mosaic, where intensively transformed landscapes and regions are found next to landscapes with few or no anthropogenic features. Industrial development is often cited as the third type of anthropogenic effect (Comin, 2010). Morphologically and geographically, it is often related to urban development (buildings, roads, impervious soil cover). Cross-fertilization of industry and agriculture has led to production activities in which the emphasis is mainly put on increasing benefits (commercial instead of subsistence agriculture; transformation of the primary products), large-scale uniformity (of production techniques and cultures to increase efficiency), increased fossil energy use, animal production (meat consumption is related to economic progress), and world-wide exchanges.

Urbanization has undoubtedly characterized the dynamics of northern hemisphere landscapes in the 19th and 20th century, and is currently dominating landscape dynamics in developing countries. Due to migratory fluxes from rural to urban areas, and to the intrinsic demographic evolution of the urban population itself, urban expansion is observed, leading to land cover changes in the external peripheral part of the urban zone by means of the introduction of urban elements in rural areas (Figure 4.1). This transforming zone is generally denoted as the "peri-urban area" of the city; the interaction of urban and rural elements confers it unique traits, the frequency and dynamics of which are considered crucial for the functioning of these future urban zones; peri-urban areas therefore form a challenge for urban and landscape scientists. The integration of peri-urban zones as well as their hybrid and dynamic characteristics in urban and rural development programs is consequently crucial to optimize essential activities for the (peri-) urban population such as mobility, food production, or water distribution.

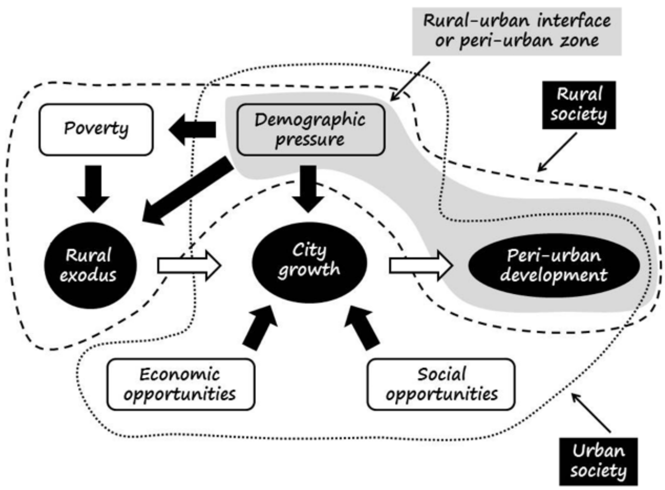

Figure 4.1. Conceptual view on peri-urban development, which is observed at the interface of rural and urban societies. Rural societies are characterized by an exodus of their population, mainly driven by demographic pressure and the absence of economic and/or social opportunities. City growth is mainly driven by the increase of its population, a consequence of the aforementioned influx from rural areas and of the endogenous dynamics of the city population, including a disequilibrium between urban economic opportunities and massive population increase (Delcourt, 2007). The result is an interaction between rural and urban societies, the understanding of which is considered a key issue for urban and landscape management, planning and ecology.

4.3. PERI-URBAN ZONES

4.3.1 Definition and identification

A review has recently been conducted on the denominations, definitions and characteristics of the different zones composing the urban-rural gradient (André et al., 2014); it highlighted the lack of uniformity among authors with regard to the criteria applied to subdivide this gradient as well as to the nomenclature applied to label the different zones. Such a diversity of definitions prevents a rigorous comparison between scientific studies (Forstall et al., 2009; MacGregor-Fors, 2011) and hampers an appropriate analysis, planning and integration of peri-urban zones in landscape management.

In the aforementioned review, the characteristics which were most frequently cited in the scientific literature to characterize the different zones in the gradient were identified in order to develop a decision tree leading to easily applicable definitions and identifications of the different components of the gradient, based upon quantitative-based, integrative, consensual, and discriminative criteria or principles (Figure 4.2). In the decision tree model, every component or zone is defined by its discriminative characteristics based on the choices made when applying the model.

Consequently, a peri-urban zone could be defined as a zone where (i) built surfaces are not dominant or where building areas are discontinuous, (ii) no explicit zonation of land use is observed, and, (iii) land covers and land uses are not (almost) exclusively related to agricultu-

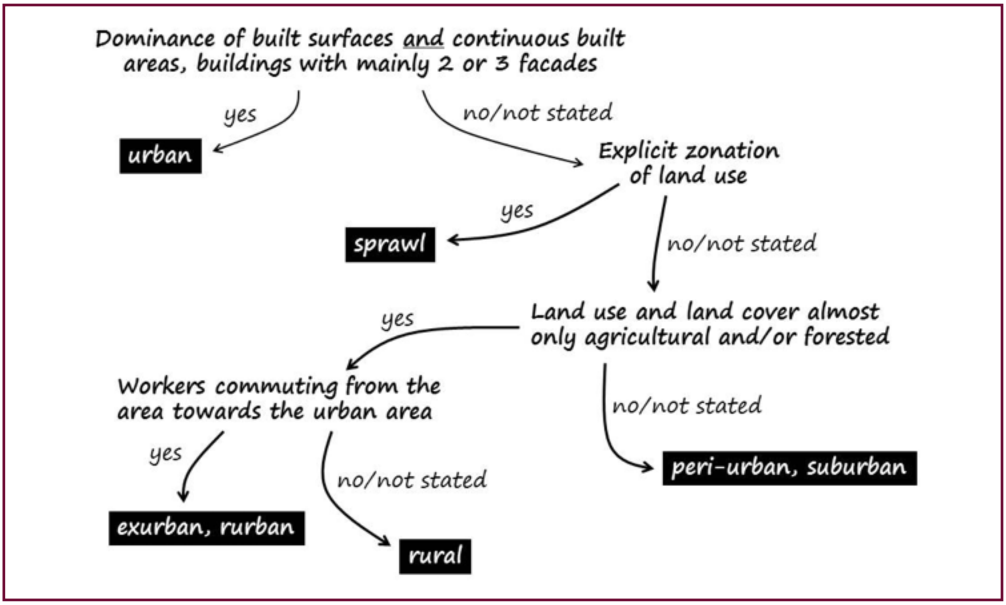

Figure 4.2. Decision tree for the definition of the zones present in the urban-rural gradient (adapted from André et al. (2014)). The decision tree is to be read from the top to the bottom, and by answering "yes" or "no/not stated" to each of the proposals. In francophone countries, peri-urban zones are also referred to as suburban zones.

ral activities or forest areas. An urban zone is then defined as a zone where the built surfaces are dominant or where buildings are present as contiguous pattern elements. Considering the rural, “exurban” and “rurban” zones, they distinguish themselves from peri-urban zones by their land uses and covers which are (almost) exclusively related to agriculture or to forest areas. Only mobility characteristics enable a distinction between rural zones on the one hand and “exurban” and “rurban” zones on the other hand. To identify peri-urban territories by means of a pattern analysis, landscape metrics were suggested that are based on the proportion of built area or on the spatial dispersion of the patches representing these built areas.

4.3.2 Peri-urban areas are exogenous edge zones of urban patches

In landscape ecology, edge effects are among the most debated topics. Edge effects are a direct consequence of the patch-corridor-matrix landscape model and are inextricably linked to patch definition itself, which is based on the contrast concept, *i.e.* the magnitude of the difference between two patch types with regard to an ecologically significant characteristic (Forman, 1995; Farina, 2000; Bogaert et al., 2014). Edge effects are observed where two contrasting land covers meet and adjacent patches influence each other. The result is a hybrid contact zone, with intermediate characteristics, which can be considered reducing the actual patch area (Farina, 2000). This reduction could be characterized by an interior-to-edge ratio (Bogaert et al., 1999; Bogaert et al., 2001). Edge zones formed in this way can be considered endogenous edges, *i.e.* they correspond to the peripheral part of the original patch.

Peri-urban zones can also be considered as edge zones, reflecting intermediate conditions between urban areas and rural areas. Both types are here considered as homogeneous. A difference with the aforementioned approach is that these edges are to be considered as exogenous to the urban area, as the city is expanding and is influencing the surrounding rural areas. For the rural matrix, the edge zone could be considered endogenous, since it is occupying an area formerly characterized by only rural traits. These peri-urban environments can therefore be considered the glue that link core cities in extended urbanized regions (Grimm et al., 2008): the edges of the city are then expanding into the surrounding rural landscapes, including changes in soils, built structures, markets, and informal human settlements, all of which exert pressure on fringe ecosystems.

Consider the case of an urban zone with a circular shape with radius r, surrounded by a ring-shaped peri-urban zone with a width equal to d (Figure 4.3). This model of city development assumes an isotropic concentric expansion of the city (Forman, 2008). The area of the peri-urban zone is in this case given by $\pi d\,(d + 2r)$. However, many cities, such as Kinshasa (4°19’54” S; 15°18’50” E), the capital of the Democratic Republic of the Congo, are not characterized by this type of isotropic development; for Kinshasa, the Congo River forms a physical barrier and the city model is more close to the development of a semicircle expanding towards the eastern adjacent rural territories[1]. A semicircular approach, although simplifying the urbanization process, could be accepted as a first proxy. For a semicircular urban zone

[1] Two cities are situated at both sides of the Congo River: Kinshasa and Brazzaville, capital of the Republic of the Congo, also known as Congo-Brazzaville. Both cities could also be considered parts of the same urban zone, a point of view not followed in this contribution.

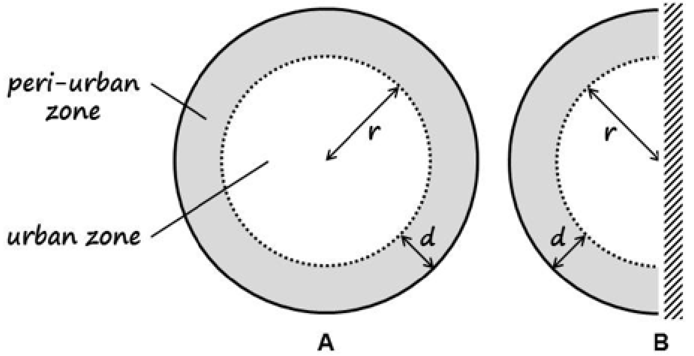

Figure 4.3. Circular models of city development. A. Circular model of city growth. B. Semicircular model of city growth; *r* is the radius of the urban zone; *d* is the width of the peri-urban zone. The semicircular model seems more appropriate when an analysis of Kinshasa (Democratic Republic of the Congo) is targeted, since the Congo River could be considered a physical barrier for urban expansion.

with radius r surrounded by a peri-urban zone of width d , the area of the peri-urban zone a is given by

$$a_p = \pi d \left(\frac{d}{2} + r\right)$$

Applying the latter model to Kinshasa is appealing to estimate the width of its peri-urban zone. In an administrative way, the city-province of Kinshasa is composed of 24 municipalities with a cumulative area of ~9,950 km², which can be categorized in 12 urban municipalities with a cumulative area of ~80 km², 6 peri-urban municipalities with a cumulative area of ~375 km² and 6 rural municipalities with a cumulative area of ~9,500 km² (Table 4.2). In 2004, the urban, peri-urban and rural zones harbored a population of respectively ~2.3, ~2.7 and ~2.2 million inhabitants with respective densities of ~29,300, ~7,200 and ~250 inhabitants by km² (Lelo Nzuzi, 2008; Fumunzanza Muketa, 2011). The decreasing trend of the population density along the urban-rural gradient could be used as a first proxy for land use interpretation. The classification of the municipalities in three zones is however not always unequivocally confirmed by literature (*e.g.*, De Deken et al., 2005; Biloso & Lejoly, 2006; Sumbu et al., 2009; Maketa et al., 2013). Using the aforementioned semicircular city model and the areas of the urban and peri-urban parts of Kinshasa, the width of the peri-urban zone is estimated as $d \approx 10$ km, since $r \approx 7$ km. This estimation should be confirmed by field observations along the urban-rural gradient of objective (morphological) variables such as housing and population density, or the presence of non-built-up areas. An application of the decision tree of André et al. (2014) is consequently recommended.

Table 4.2. Summary statistics of the 24 municipalities forming the city-province of Kinshasa, Democratic Republic of the Congo, their area and their situation in the urban-rural gradient (P: peri-urban municipality; R: rural municipality; U: urban municipality). Sources: Lelo Nzuzi (2008); Fumunzanza Muketa (2011).

Municipality	Area (km²)	Zone	Municipality	Area (km²)	Zone
Bandalungwa	6.9	U	Lingwala	2.9	U
Barumbu	4.7	U	Makala	5.6	P
Bumbu	5.3	U	Maluku	7,948.8	R
Gombe	29.3	U	Masina	69.7	P
Kalamu	6.6	U	Matete	4.9	U
Kasa-Vubu	5.0	U	Mont Ngafula	358.9	R
Kimbanseke	273.8	R	Ndjili	11.4	R
Kinshasa	2.9	U	Nsele	898.8	R
Kintambo	2.7	U	Ngaba	4.0	U
Kisenso	16.6	R	Ngaliema	224.3	P
Lemba	23.7	P	Ngiri-Ngiri	3.4	U
Limete	27.6	P	Selembao	23.2	P

4.4. CONCLUDING CONSIDERATIONS

After a period of maturation and development of intrinsic concepts and methods in the 1980s and 1990s, landscape ecology can nowadays be considered a mature discipline (Farina, 2014), adapted and equipped to disentangle the complexity of late 20th and early 21st environmental issues at the landscape scale. Understanding landscape change and the dominant role of Man herein is currently becoming a central issue for landscape scientists; semi-natural, or anthropogenically modified landscapes form the core of current landscape ecology, or will do so in the near future. Urbanization, related to spatial transformation processes such as perforation, dissection, fragmentation, shrinkage and attrition when natural land covers are considered (Bogaert et al., 2004b), is nowadays responsible for profound landscape transformations in the southern hemisphere, as it was during the preceeding century in its northern counterpart. The understanding of peri-urban territories forms consequently a cornerstone in this analysis of the urbanization process, due to their dynamic and ephemeral nature.

The aforementioned integration of human actions in the hypotheses of an ecological discipline can be considered an element singularizing landscape ecology from its germane disciplines (Fahrig, 2005). It also explains the current focus of many landscape ecologists on bio-cultural landscapes, which are blends of human activities with the expression of biodiversity (Bridgewater & Arico, 2002). A direct relationship between landscape pattern and culture is accepted: culture changes landscapes and culture is embodied by landscapes (Nassauer, 1995). Bio-cultural diversity can be defined as the diversity of life in all of its manifestations (biological, cultural and linguistic) which are interrelated (and likely co-evolved) within a complex socio-ecological adaptive system (Maffi, 2010). The study of bio-cultural landscapes, in which both components are considered as well as their interactions, announces itself as a promising new field in landscape ecology (Maffi & Woodley, 2010; Hong et al., 2014). It should be noted that this relationship between biology, ecology and culture is not an entirely novel concept, since it has already been considered in anthropological literature in the 1970s, when "biocultural ecology" was mentioned as a potential discipline ideally seeking to transcend the separation of culture, human biology, and environment/ecology (Bennett et al., 1975).

Although this cross-fertilization of culture and nature can be beneficial, landscape transformation by Man emphasizes the importance of landscape conservation and confirms the status of geographical space as a non-renewable resource. We therefore propose to coin the term "choralogy" for the study of the patterns, values and services of land areas (landscapes, geographical spaces) while recognizing their limitedness. The term is derived from the Greek words *χώρα* (land, rural area) and *λόγος* (word, study); the novel discipline aims to unify scientists and practitioners dealing with rural, urban or peri-urban systems to converge their visions on the use of land areas in order to meet the requirements of Man, Society and Nature. In a first step, this new discipline is expected to mainly infer from existing ones, such as landscape ecology, urban planning, landscape architecture, or environmental management (Figure 4.4). Later on, proper methods, theorems and paradigms can or will be developed. The limitedness of land imposes a sustainable use of the aforementioned areas and the concomitant values and services, which can be of divergent nature, such as biomass production, prevention of erosion, climate regulation, cultural heritage or scenic beauty.

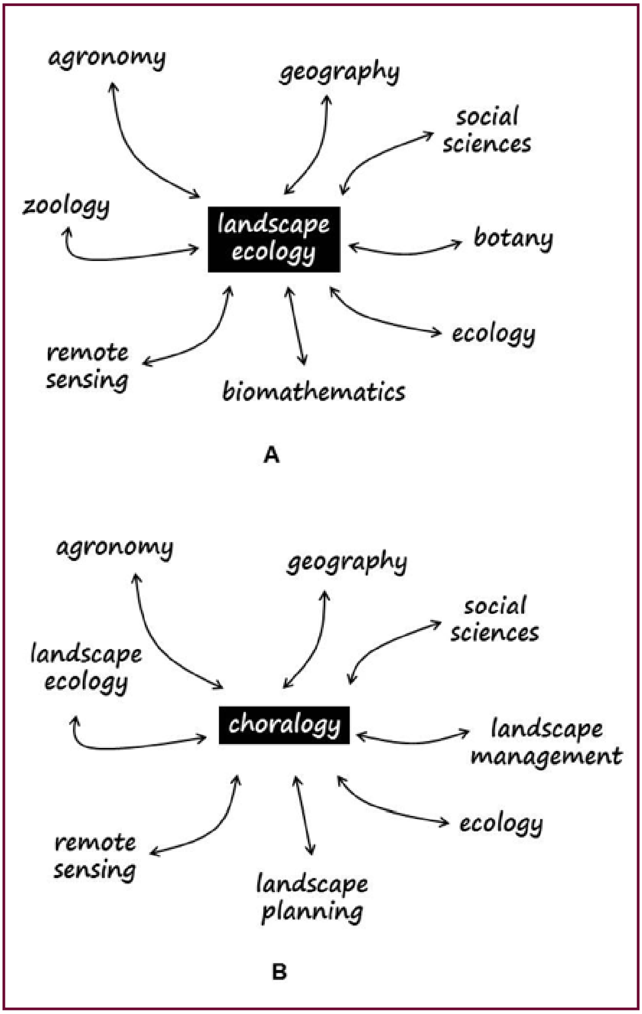

Figure 4.4. Landscape ecology and choralogy. (A). Initially, landscape ecology was considered a synthesis or integration of other disciplines, without proper concepts. As a new discipline, it took over existing concepts and through their application at the landscape scale, the source disciplines were influenced. (B) Nowadays, landscape ecology has become a mature discipline, still sharing concepts with other branches but also characterized by proper concepts. It now contributes to the discipline of choralogy, the science of the limited resource called geographical space. Top figure adapted from Wiens (1999).

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