Journal of Environmental Sciences Vol.16, No.4, pp.610—615, 2004

ISSN 1001—0742
CN11—2629/X

Article ID: 1001-0742(2004)04-0610-06 **CLC number**: X22; Q149 **Document code**: A

Adopting an ecological view of metropolitan landscape: the case of "three circles" system for ecological construction and restoration in Beijing area

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Abstract: Ecological construction and restoration for sustainable development are now a driving paradigm. It is increasingly recognized that ecological principles, especially landscape ecology theory, are not only necessary but also essential to maintain the long-term sustainability worldwide. Key landscape ecology principles—element, structure and process, dynamics, heterogeneity, hierarchies, connectivity, place and time were reviewed, and use Beijing area as a case study to illustrate how these principles might be applied to ecological construction and restoration, to eventually achieve sustainability. An example to more effectively incorporate the ecological principles in sustainable planning in China was presented.

Keywords: landscape ecology; ecological principles; ecological benefits; Beijing

Introduction

Global changes induced by human activities include modification of the global climate system, reduction in stratospheric ozone, alteration of earth's biogeochemical cycles, changes in the distribution and abundance of biological resources, decreasing water quality(Meyer, 1994; IPCC, 1996; Vitousek, 1997; Mahlman, 1997) and so on. However, land cover changes have been identified as a primary, profound and pervasive effect of humans on natural systems (Vitousek, 1994; Dale, 2000; Zipperer, 2000). That is because the widespread changes of land cover affects so many of the planet's physical and biological systems, which maintain the ability of Earth to continue providing the goods and services for human being. Especially, the transformation of the urban and urbanizing landscape has profound social and ecological consequences, and has been highlighted by ecologists worldwide (Meyer, 1994; Flores, 1998; Zipperer, 2000). Therefore, ecological construction and restoration, related to land use planning and land use decisions for sustainable development are now a driving paradigm.

Unfortunately, potential ecological effects have not been put more emphasis on, when making land use decisions. Moreover, ecological theory or thinking is rarely incorporated in land use planning or management(Dale, 2000). To meet the challenge, an ecological framework and principles that are relevant to land use decisions are not only necessary but also essential to incorporating ecological principles in land use planning and management, in order to maintain the long-term sustainability of ecosystem benefits, services, and resources(Zipperer, 2000).

Many famous ecologists, for instance, Risser *et al.* (Risser, 1984), Forman and Godron (Forman, 1986), Risser(Risser, 1987), Forman(Forman, 1995a), Flores *et al.*(Flores, 1998), Dale *et al.*(Dale, 2000) and Zipperer *et al.*(Zipperer, 2000), presented many key ecological principles. These principles are not at odds with each other, and they, in different study fields, reflect different aspects. Furthermore, specifying ecological principles and understanding their implications for land-use and land-management decisions in concrete or special region, are essential not only to theory development, but also in the application of ecological theory in land use planning. Therefore, a major intent of this paper is to set forth landscape ecology principles relevant to land use and management and use Beijing area as a case study to illustrate how these principles might be applied to achieve sustainable ecological landscape.

1 Ecological conditions and problems of Beijing area

Beijing, as the capital of the People's Republic of China, has an area of 16807.8 km^2, with mountain area 10418 km^2, and plain area 6390 km^2, composed of 18 administrative districts or counties(BMPC, 1987).

The quality of Beijing's ecological environmental directly affects the sustainability of capital social-economic development, and has close relationship with appearance as international metropolitan. Currently, ecological environment of Beijing is fragile, and the quality of ecological environment is lower, which is follows: (1) In mountain region, vegetation devastation, water runoff and soil erosion are serious. Ecological benefits cannot function normally. There was about 15000 hm^2 wild land suitable to plantation need plantation and greening, where soil and water loss is serious.

Foundation item: State Key Basic Research and Development Plan of China(G2000018607); * Corresponding author

(2) In plain region, extensive agriculture activity and inappropriate agricultural structure, combined with sandy soil along rivers, there are 101000 hm^2 potential sand soil, and 240000 hm^2 sandy area, accounting for 14.4% of Beijing area and 38% of plain area, at the same time, water level of groundwater descended increasingly. (3) Urban heat island and environmental pollution still exist.

It is shown that Beijing current ecological conditions mismatch with its functional property and position of capital, at the same time, it can not meet the need of production and life for people in Beijing. Therefore, Beijing's ecological construction and restoration demand strengthening and consolidating, and what is more to incorporate ecological principles in land use planning and decisions. In this paper, the key landscape ecology principles—element, structure and process, dynamics, heterogeneity, hierarchies, connectivity, place and time are discussed, and then use Beijing as a case study to illustrate how ecological principles effectively incorporated in sustainable planning.

2 Landscape ecology principles

Ecology and planning have many common interests, ecology concerned with the functioning of resources, planning focusing on their appropriate use for human's benefit. Sound (short-and long-term) planning cannot be achieved without full consideration in the view of ecology(Leitão, 2002).

According to Forman and Godron (Forman, 1986), landscape ecology focuses on (1) the distribution patterns of landscape elements or ecosystems; (2) the flows of animals, plants, energy, mineral nutrients, and water across these elements; and (3) the ecological changes in the landscape mosaic over time. Therefore, structure, function and change are three fundamental landscape characteristics. Landscape introduced several aspects that were important in land use planning and decisions: (1) spatial heterogeneity; (2) time and spatial scales; (3) interaction of spatial pattern and ecological process; (4) hierarchy characteristics of ecological system; (5) dynamics of mosaics, identification of disturbance as organic parts of system; (6) close relationship between society, economy, people and ecological process(Wu, 2000).

2.1 Landscape element

Forman and Godron(Forman, 1986) defined "landscape as a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout". These ecosystems are called landscape elements, and they can be polygon, line, network and so on. According to Flores *et al*.(Flores, 1998), the concept of the ecosystem, as an ecological principle, is prime importance to planners. An ecosystem consists of organisms, a physical environment, and the interactions and exchanges among the organisms and the environment. All ecosystems have structure and function, structure refers to the physical arrangement of system components, and function means the interactions among components. Ecological function has close relationship with structure. Ecological system structure of natural or undisturbed by human, have highly environmental benefits(Table 1).

Table 1 Examples of environmental benefits sustained by urban greenspaces*

Biological benefits	Social benefits	Physical benefits
Refuge for threatened and endangered species	Recreational opportunities	Flood control
Increased biodiversity	Enhancement of property value	Reduction of erosion
Habitat for flora and fauna	Community cohesion	Modulation of temperature
Storage and cycling of nutrients	Aesthetic enhancement	Removal of air pollution
Ecosystem/community representativeness	Source of knowledge	Protection of water quality

Notes: * Quotation from Flores, 1998

Also, the organisms, for instance, particular species and networks of interacting species in ecosystem have key, broad-scale ecosystem-level effects (Dale, 2000). Dale (Dale, 2000) believe these focal species such as indicator species, keystone species, ecological engineers, umbrella species and so on, affect ecological system in diverse ways. Therefore, large regional reserves, with diverse ecosystem and rich species should be established to attain good environment benefits.

2.2 Landscape structure and process

Landscape structure consists mainly of the size, shape, composition, number, and position of different ecosystems within a landscape. Landscape structure influences processes such as the flow of energy, materials, and species between the ecosystems within a landscape. It was the core of landscape ecology.

Landscape ecologists have proposed that landscape structure, especially the size, number, and isolation of habitat patches, can influence local population density, extinction of local populations, and the movement of organisms between potentially suitable habitats. For instance, fragmentation of habitats including loss of the original habitats, reduction in habitat patch size, and increasing isolation of habitat patches will lead to loss of biodiversity or extinction of species (Leitão, 2002). Similarly, the size, shape, and spatial relationships of land cover types influence the dynamics of populations, communities, and ecosystems. Structure and function of a land unit is often strongly influenced by those land units adjacent to it, at the same time, other land units within its neighborhood significantly influenced it(Flores, 1998). For another example, a land unit with a high edge to interior ratio (circumference/area) may be considerably more sensitive to external factors than one with a smaller ratio sharing a similar ecological context (Forman, 1995b).

Human land use has influenced most landscape,

resulting in a landscape mosaic of natural and human-managed patches that vary in size, shape and arrangement (Burgess, 1981; Forman, 1986; Krummel, 1987; Turner, 1988). Since spatial pattern strongly influences the ecological processes, then our goal is to thriving for an optimal spatial arrangement or structure of landscape mosaic to attain the best ecological benefits.

2.3 Landscape dynamics

Ecological systems are dynamic, and their structure and function are in constant flux. Landscapes are structured and change in response to geological processes, climate, activities of organisms, and disturbance. The patterns of landscape development in time and space result from complex interactions of physical biological and social forces (Urban, 1987; Turner, 1988). (1) The geological features or function such as volcanism, sedimentation, and erosion interact with climate provide a primary source of landscape structure. Climate is also a major determinant of landscape structure, because it determines whether the potential ecosystem in area will be temperate forest, tundra, or desert, and it also sets the baseline for aquatic ecosystem. As climate changes, landscapes change. (2) Human activities dramatically alter natural landscape. It is estimated that, between 1700 and 1980, the area of forests and woodlands decreased globally by 19% and grasslands and pastures diminished by 8% while world croplands increased by 466% (Dale, 2000). Furthermore, the pace of change has accelerated, with greater loss of forests and grasslands during the 30 years from 1950 to 1980 than in the 150 years between 1700 and 1850. Also, the type, intensity, and duration of disturbance shape the characteristics of populations, communities, and ecosystems. Disturbance may be natural factors(wildfires, storms of floods) or human activities such as transformation of land use, building roads or urban development.

2.4 Landscape heterogeneity

A landscape is a heterogeneous area composed of several ecosystems. Heterogeneity is crucial to the functioning and maintenance of natural systems to provide environmental benefits. Heterogeneous region maintains more types of organisms and more diversity of ecosystem process than does a large area of homogeneous habitat (Wilson, 1997). The spatial heterogeneity in ecological system at various scales often influences important functions, ranging from population structure through community composition to ecosystem processes. Increasing species diversity and ecosystem diversity are necessary to generate the genetic, biological, and biogeochemical capacity to adapt and respond to a changing environment. This is the essence and foundation of sustainability.

2.5 Landscape hierarchies

Landscape ecology focus on an organizational scale above that addressed by community and ecosystem ecology. And ecological dynamics and heterogeneity are manifested at different nested hierarchical levels(Flores, 1998). Hierarchy theory is concerned with systems that have a certain type of organized complexity. Hierarchically organized systems can be divided, or decomposed into discrete functional components operating at different scales (Urban, 1987). Natural phenomena often are complex and not perfectly decomposable: spatial boundaries may be difficult to define precisely and components may interact. Yet components of a hierarchical system are often organized into levels according to functional scale or conceptualized as hierarchical systems. Each of these function hierarchies is more than a convenient way to organize spatial heterogeneity. The most important is that hierarchy system is help to analyze which factors influence the patterns and processes observed at each scale and functional relationships within and between scales (Pickett, 1997; Zipperer, 2000). Therefore, dividing the metropolitan areas into functional components, and then different structure of each function component will be analyzed, at the same time, different ecological restoration measures will be carried out.

2.6 Landscape connectivity

Landscape connectivity refers how spatially or functionally continuous a patch, corridor, network or matrix of concern is. It includes not only continuity spatially; but also more important functionally (Wu, 2000). Connectivity spatially means continuity in spatial, and connectivity functionally refers landscape connectivity identified by the characteristics of ecological objectivity or ecological process. In the study of ecology, avoid of ecological process, it is no meaning only to consider superficial and structural connectivity.

Connectivity provides a good example for the application of landscape ecological principles to land use decision. A growing body of literature suggested that habitat connectivity is important to the persistence of both plant and animal populations in fragmented landscapes (Forman, 1986; 1995b). Connectivity is the fundamental landscape concept to support sustainable land use planning and conservation strategies, such as the ecological network concept(van Lier, 1998). The greenways movement has been advocating and implementing ecological networks internationally. The European Ecological Network, an important goal of the European Community's Habitat Directive, is also based largely on the concept of connectivity. In addition, a network of ecological corridors to connect the entire Australian continent has been proposed(Leitão, 2002).

2.7 Place and time principles

Place and time principles can make us accurately analyze ecological phenomena or characteristics at landscape or regional scales. As it was described in landscape dynamics, local climatic, hydrologic, edaphic, and geomorphologic factors as well as biotic interactions strongly

affect ecological processes and the abundance and distribution of species at any one place. Local environmental conditions reflect location along gradients of elevation, longitude, and latitude and the multitude of micro-scale physical, chemical and edaphic factors that vary within these gradients. These factors constrain the locations of agriculture, forestry, and other land uses, as well as provide the ecosystem with a particular appearance. For instance, the alluvial deposits along a river valley provide growing conditions different from those on thin, well-rained soils on nearby hills.

Ecological processes function at many time scales, some long, some short; and ecosystems change through time. The time principle has several important implications for land-use: first, the current composition, structure, and function of an ecological system are, in part, a consequence of historical events or conditions that occurred decades to centuries before; second, the full ecological effects of human activities often are not seen for many years because of the time it takes for a given action to propagate through components of the system; third, the ecological influences of current land use pattern may persist on the landscape for a long time, constraining future land use for decades or centuries; finally, the long-term effects of land use or management may be difficult to predict, just because of the variation and the change of characterizing ecosystem structure and process(Dale, 2000).

We discussed several key landscape ecology principles—element, structure and process, dynamics, heterogeneity, hierarchies, connectivity, place and time. These ecological principles are often interdependent and related, and in general, ecological characteristics and process can be interpreted by several principles. Furthermore, we use the Beijing City Metropolitan Area as a case study to illustrate how these principles might be applied to achieve sustainable planning goals. We additionally set an example to more effectively incorporate the modern ecological principles in other planning in our country.

3 The use of modern ecological principles in ecological restoration for Beijing City region

Hierarchy theory is concerned with systems that have a certain type of organized complexity. Hierarchically organized systems can be divided, or decomposed, into discrete functional components operating at different scales (Urban, 1987). We develop three circles hierarchy system to study ecological construction and restoration of Beijing City region according to functional scale. At the same time, the functional components are in agreement with place principle, different components have different physical environment feature. The "three circles" system mean mountain region, plain region and urban area, and their objectives are that: (1) mountain region should play a critical role in providing ecological benefits such as water and soil conservation, water source protection; (2) creating heterogeneous mosaics of cropland, forestry, and pasture, and a network of greenways to connect and nurture our cities, suburbs, and protected landscapes; (3) urban area should focus on greening, including urban parks, public spaces, natural resources green belt along roads, streets, railway, river and irrigation and so on, to improve the environmental quality of our cities.

Given that ecological interactions are often intricate, inconspicuous, and involve temporal and spatial lags, the task of protecting and restoring environmental benefits for a Metropolitan area is a challenging one (Flores, 1998). Therefore, the proposal of three-circle conservation theory provides a useful framework for approaching this challenge by addressing three key landscape features of Beijing area: (1) conservation and restoration of mountain area; (2) optimal arrangement of cropland, forestry and pasture; (3) greening of urban area.

3.1 Mountain region: ecological benefits function

The mountain region locates in the east and the north of Beijing area, and the upper portion of Haihe drainage area, the total area of which is 10400 km^2, accounting for 62%. Based on mountain vertical vegetation zone system, mountain region were divided into middle mountain belt, low mountain belt, Piedmont zone and inter-mountain basin(BMB, 1987). Different belt have different topography, landform and climate conditions(Table 2), thus they have different development direction and ecological conservation measures:

(1) Middle mountain belt: The function of this region is mainly ecological benefits, such as water runoff and soil erosion control, conservation of water supply and provision of wildlife habitat.

(2) Low mountain belt: Deterioration of vegetation and soil and water loss is more serious. Therefore, forestry and biological measures for soil and water should been pervasively applied.

(3) Piedmont zone and inter-mountain basin: This region is mainly for mountain residential area and agriculture activity. Because of good thermal conditions, this region pervasively develops forestry and orchard, and transforms sloped dry land into forestry or pasture.

The mountain region is the water source of Beijing. If there is high quality ecological environment, Beijing area will have high quality and supply water without water run off or soil erosion. But at present, the mountain vegetation is seriously destroyed, and ecological function cannot do normally. Therefore, the main direction of mountain region must focus on large regional reserves, construction of water source conservation forest and soil and water conservation forest, at the same time, forestry and biological measures should be combined, to strengthen ecological construction. Creating high quality ecological environment, controlling water runoff and soil erosion, breaking wind and fixing sand are long-term goals. This is the first conservation circle of

Beijing area, where ecological benefit should fully function.

Table 2 Climate characteristics in Beijing area*

Type	Elevation, m	MAT, ℃	ACT≥0, ℃	ACT≥10, ℃	AP, mm
Middle mountain belt	> 800	< 7	< 3300	3200—3400	450—550
Low mountain belt	600—800	7.0—8.0	3100—3600	2720—3245	550—600
Piedmont zone and inter-mountain basin	100—600	8.0—10.0	3500—4400	—	500—700
Piedmont plain	< 100	11.5—12.3	4550—4650	—	650—700
Low plain	20—50	11.2—11.5	4500—4580	—	600

Notes: * : Quotation from BMB, 1987; MAT: mean annual temperature; ACT≥0℃: annual cumulated temperature≥0℃; ACT≥10℃: annual cumulated temperature ≥10℃; AP: annual precipitation

3.2 Plain region: creating heterogeneous mosaics of cropland, forestry, and pasture, and a network of greenways

Within the highly fragmented landscapes of a metropolitan region, maintaining connectivity among green paces is paramount in that it may ensure the flow of energy, species and matter. Without connectivity, sites become isolated and their ability to sustain themselves and to produce environmental benefit may diminish.

The region consists of alluvial plains, many rivers through it. Based on humidity and moisture, topographic factor and soil, the region was divided into two subsets: piedmont plain and low plain(Table 2; BMB, 1987).

In piedmont plain, geomorphologic landscape is floodplain and alluvial plain, and soils are cinnamon soil, coastal soil and so on. Yongding River, Wenyu River, Chaobai River and Jingmi Irrigation Channel are all through this region. Annual precipitation ranges from 650 mm to 700 mm, but precipitation variation is larger, and distribution of it among seasons is uneven. In this region, drought in spring, water logging in summer, and wind-sandy damage along rivers brought out serious results to local agriculture production.

In this region, extensive agriculture activity and inappropriate agricultural structure, combined with sandy soil along rivers, there are 240000 hm^2, accounting for 14.4% of Beijing area and 38% of plain area, and 101000 hm^2 potential sand soil. Therefore, the goal of this region should been strengthen the construction of green ways, farmland shelter forest, greening of town and rural themselves. At the same time, optimal agriculture structure should be set up. At last, the plain region should create heterogeneous mosaics of cropland, forestry, and pasture, and a network of greenways to connect and nurture our cities, suburbs, and protected landscapes.

3.3 Urban area: greening system of urban itself

The characteristics of urban area are intensive population density, frequent social economic activities and lack of natural spaces. In this region, function of green spaces should mainly be ecological, beautiful and recreational benefits, for instance, removing air pollution, creating opportunities for creation, fostering community cohesion, reducing noise, and providing wildlife habitat, to improve the quality of life in urban areas. Urban area should focus on greening, including urban parks, public spaces, natural resources and green belt along roads, streets, railway, river and irrigation and so on, to improve the environmental quality of our cities.

Beijing urban area, as famous ancient capital of four dynasties, its ecological environment is highly altered from its pre-development state. Therefore, greening should rule by ecological principles. (1) Creating heterogeneous landscape to increase the complexity of ecosystem structure and ecosystem diversity, for instance, in a park, there should be forestry, shrub, grass, flowers, water and birds. (2) Based on landscape connectivity principle, urban area is also creating a network of greenways, and increase the width of corridors along roads, streets, water irrigation, railways, residents and so on. Because the ecological benefits of green spaces to human outweigh the costs of corridors and increased connectivity.

4 Discussion and conclusions

Based on analysis of ecological principles mentioned above and application of ecological principles in Beijing's ecological construction and ecological restoration, some guidelines were provided to more effectively incorporation the modern ecological framework in other sustainable planning in our country.

4.1 Ecological suitability assessment

Place principle is paramount. Local climatic, hydrologic, edaphic, and geomorphologic factors as well as biotic interactions strongly affect ecological processes and the abundance and distribution of species at any one place. Therefore, to appropriate planning, firstly ecological suitability assessment should be accomplished. Only certain patterns of land use, settlement and development, building construction, or landscape design are compatible with local and regional hydrology and geomorphic conditions, as well as biogeochemical cycles. Then social-economic development is sustainable.

4.2 Analyze land use current pattern, land use dynamics, and land use development prediction at regional level

To comply with the heterogeneity of regional geographic environmental characteristics(geology, geomorphologic,

climate, hydrology, soil, vegetation and so on), it must be based on the comprehensive analysis of current land use pattern. Landscape patterns observed today are the result of the interaction of human activities and natural processes (Forman, 1995b). Physical attributes mentioned above play the main role in determining development of the patterns of land use. However, human also can develop specific land-uses having no relationship with natural attributes. Thus we must analyze current land use patterns, find negatively ecological effects determined by inappropriate land use patterns, analyze the main factors affecting the patterns of distribution of each land use type.

According to time principle, current composition, structure, and function of an ecological system are, in part, a consequence of historical events or conditions that occurred decades to centuries before (Dale, 2000). It is necessary to study the historical dynamics of land use, because it can contribute to understanding the formation of current land use pattern, analyzing the main factors influencing land use pattern. At last, based on land use dynamics and current pattern analyze, to certain degree, development of land use in the future, combined with social development plan, will be predicted.

4.3 Sustainable landscape ecological planning

Based on the analysis of natural environmental, current land use pattern and land use dynamic in a region. The next step is to conduct sustainable and ecological planning, according to the demand of human being. The underlying and fundamental goal of landscape ecological planning is sustainability. To pursue this goal, various advanced methods tools such as GIS, remote-sensing and spatial statistics, the use of ecological models and simulation techniques are needed. Ecological principles are the fundamental scientific basis to plan and manage for sustainable systems, and landscape is an appropriate unit for sustainable planning. At the same time, human activities have been considered as integral parts of ecological systems.

Eventually, human being will believe, only through the incorporation of ecological principles into the decision-making process can environment benefits be maintained for future generations. And we also believe, sustainable landscape ecological planning will make our urban areas a more livable place for current and future generations to come.

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(Received for review June 11, 2003. Accepted October 8, 2003)