

CHARACTERISTICS AND CONSTRUCTION OF LANDSCAPE ECOLOGY IN ARID REGIONS

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ABSTRACT: This paper analyzes the characteristics of the landscape structures and landscape ecological processes in arid regions of China. Landscape structure is simplicity and homogeneity with the pattern of desert oasis river and canal corridor. The spatial distribution of landscape heterogeneity mosaics is relatively dependent on water resources. In arid regions, the landscape changes rapidly and extensively because of the sensitive landscape ecosystems and fragile regional ecosystems. For the sustainable development of arid regions, the theories and methods for the eco-environmental construction and the strategies of ecological construction in the arid regions were proposed in the view of landscape ecology. Keynote subjects of landscape ecology were also discussed. The paper points out that protecting and increasing landscape diversity and heterogeneity are critical to control ecological safety in arid regions.

KEY WORDS: landscape ecology; arid regions; ecological construction; landscape planning

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Landscape ecology is a new interdisciplinary science dealing with the interactions between spatial patterns and ecological processes. The application of the landscape conception is generally based on the territories of human scale or regarded as the representative of spatial heterogeneity at stochastic scale. At the macroscopic scale the spatial heterogeneity and spatial patterns become the major topics in landscape ecology (PICKETL *et al.*, 1995; XIAO *et al.*, 1997a). The relations, such as landscape dynamics and evolution, landscape change and stability, landscape planning and construction, as well as landscape diversity and protection, are all the central issues of the theoretical system of landscape ecology in the present eco-environmental studies in arid regions (O'NELL, 198

9; XIAO *et al.*, 1997b). The eco-environmental problems in arid regions result from the strong disturbance of human activities to natural ecosystems, which lead to the unstable fluctuations and significant degradation of the eco-environmental systems as the amplitudes of the disturbance exceed the thresholds of the ecological safety. There are two distinct but closely related landscape pattern changes in arid regions. In the areas close to water sources, or the upper and middle streams of a watershed, agriculture is highly developed and forms the intensive and almost perfect irrigation systems and farmland landscape. In the areas far from water sources, or the downstreams, readily increasing over-exploitation of water resources has led to severely and irreversibly disturbed

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or damaged ecosystems, and the landscape is evolving from highly fragmentary natural vegetation towards desert environments. This process illustrates a typical regional shift in arid landscape types and patterns. How to control such an evolution and realize the symbiosis between natural ecosystems and human communities, i. e. the sustainable development, have always been the concerns in arid regions. In this regard, the theory and methods concerning the landscape ecology have an essential distinction as compared with those of traditional ecology. The landscape ecology highlights the environmental impacts of the anthropogenic activities on landscape patterns and processes (XIAO *et al.*, 1997a; XIAO *et al.*, 1997b), which provide a constructive and challenging tool for the environmental studies in the arid regions.

1 BASIC CHARACTERISTICS OF LANDSCAPE ECOLOGY IN ARID REGIONS

1.1 Characteristics of Landscape Structure

In arid regions, water is the driving force for various ecological processes. It is also the most active factor in the environmental systems. However, its spatial distribution is extremely uneven. Precipitation at an annual range of 300–700 mm is mainly concentrated in mountainous upper streams, and most of the rivers in inland arid regions originate from high mountains. In the vast arid desert and desert steppe, water resources are mainly distributed in the vicinity of the river systems, the annual precipitation is hardly greater than 200 mm and generally less than 100 mm, or even less, whereas the evaporation potential varies from 2000 to 3000 mm. This discrepancy in the water supply and consumption results in a distinct landscape structure in the arid regions, which is different from that in humid and semihumid regions. Their characteristics are as follows.

1.1.1 Landscape pattern of desert-oasis-river and canal corridor

In vast arid plains, water resources are concentratively distributed in the corridors encompassing the

river courses. Under an arid and extremely dry climate, such as the gobi climate, desert or desert steppe is formed in the piedmont plains out of the influence of the rivers, where the vegetation is dominated by the halophilic, xeric dwarf shrubs and bushes, and desert vegetation is developed in a considerable proportion. In the plains in Xinjiang, Hexi Corridor and Qaidam Basin, natural meadows, forests, shrubs, cultivated land and artificial waters account for 6.86%–25.3% of the region's total area, and gobi, desert, barren land, rocky lands and desertified land forming the desert landscape account for 33.1%–72.2% (FORMAN, 1995; CHEN *et al.*, 1992). As a result, the arid region's basic pattern is formed with the desert and desert steppe as the landscape matrix and the oases as the mosaic.

Generally, natural oases along rivers are distributed in stripes in the expanses of desert landscape, or with irrigation networks as the link from the patchy manmade oases. Farmlands with protective forest belts are built along the irrigation ditches. Roads extending between oases and leading to various districts within the oases, and forest belts stretching along the ditches form the main forest belts. Rivers, irrigation networks and roads between the oases constitute the major corridor landscape. The protective forest belts along the roads and ditches are integral parts of the forest network landscape. All these corridors have very important ecological functions in the formation and development of the oases, mass water-energy transfer and exchange, spatial spreading of the species, prevention of the invading and expanding of the desert landscape.

1.1.2 Simplicity and homogeneity in landscape structure and constituents

In arid regions, plant species are sparse, population structure and biological chains are comparatively simple, artificial oases are operated in local belts of such simple natural vegetation landscape, patches of cultivated lands form the artificial oasis heterogeneity in the vast desert steppe and gobi deserts, cities and other land heterogeneity are small in areal extent. All these reflect the features of land mosaics. The lands

affected by human activities, such as oases exhibit as the small heterogeneous mosaic, but the oases themselves generally form the relatively homogeneous and dense geographical entity, and the number of the patches in the spatial distribution is limited. As for the natural land types dominated by desert landscape, such as gobi, desert and sandy desert, their landscape matrices, fragmentation degrees are rather low and often form a homogeneous regional landscape background. Except for the heterogeneous mosaics, such as artificial and natural oases distributed along the rivers, there are hardly patches formed. Such a feature in landscape structure decrease the spatial patch numbers and density of the dry-land landscape and enlarge the areal extent of these patches.

1.1.3 High contrast of the landscape heterogeneity mosaics and dependence on water resources

Species, structure and functions of organisms of the arid desert matrix are quite simple, and their effects are weak. On the contrary, the oasis landscape mosaicked by heterogeneity, contains runoff-nourished intrazonal vegetation and agricultural landscape, its species and structure are diverse and complex, biological productivity is high, biological effect is strong, thus forming a sharp contrast. Such a contrast enables the oasis patches to have clear boundary (JIN, 1996). The high ecological performance and strong biological effect of the oasis landscape are attributed to the relatively abundant water resource conditions. The intrazonal vegetation in natural oases are the output of ecological flows directly effected by river corridors. Once the river corridors disappear, the intrazonal vegetation growing on the river terraces, river courses and wetlands will shrink and dry up, and the oasis landscape will be replaced by desert matrix landscape. Artificial oases and their size, stability as well as biological productivity are all dependent on the irrigation availability and water consumption. Highly effective irrigation systems and adequate water resources result in the large, stable and productive artificial oases. In arid regions, water is vital for the survival of the oases, and the desert will form without sufficient water; however, excessive water at

some locations can result in the land salinization.

1.2 Basic Characteristics of Landscape Ecological Processes

1.2.1 Sensitive landscape ecosystems and fragile regional ecosystems

Ecological stability of landscape depends upon the resistance and restoring capability of landscape spatial structure to the external disturbance. Stable landscape ecosystems reflects the disturbance received within the thresholds, the ecological types, structure and functions can not be changed easily, and transitional ecological types are rare in space and only distribute in the limited scope. As for the landscape ecosystems in arid regions, the desert vegetation formed under harsh natural environments, any small fluctuations in the eco- environments may cause profound changes of the ecosystems. The vegetation successions of aquatic plant community \rightarrow swamp plant community \rightarrow salinized meadow plant community \rightarrow halophytes \rightarrow desert vegetation \rightarrow barren lands or land desertification are common processes in arid regions and the transitional ecosystems also are quite common. The heterogeneously mosaicked oasis landscape only occupies a small proportion of the land types and is scattered in the desert matrix landscape in patches. Furthermore, its existence and development are strictly controlled by water availability. The vegetation succession processes described above reflect that as the water sources conditions change, the natural oasis landscape change into desert landscape correspondingly. Desert land has a large area and expands rapidly (0.6% – 5.0% per year) (ZHU *et al.*, 1994), desert ecosystem has a low stability and has a number of transitional types. All these result in the ecosystem fragility of the arid regions. the ecosystems in the arid regions are extremely sensitive to natural and anthropogenic disturbances, especially the over-exploitation of the water and land resources. This can be demonstrated by such a fact that the expansion of artificial oases in the upper streams of a watershed is achieved by sacrificing natural oases in the down-

streams.

1.2.2 Extensive and rapid landscape changes

The spatial patterns of arid regions landscapes are the combined results of the dry climate and human activities. Landscape patterns often show a rapid regional change under the influences of climatic fluctuation, river course evolution, land reclamation, irrigation and cultivation. In the past 50 years, the area of the irrigation oases in Xinjiang has increased 849 200 km², a considerable part of which was transformed from previous desert landscape. In the meantime, many ancient artificial or natural oases, such as some oases at the southern edge of the Taklimakan Desert and the delta of the downstream Tarim River have evolved into desert, gobi or aeolian landscapes (FAN, 1996). The lake water surface also has reduced by 3 495 km² in area, and many lakes have dried up gradually. The area of artificial oases in the Hexi Corridor has increased by 536 000 km² since the 1950s at the costs of a 2-7 km downstream moving of the spring overflowing belt and a 68%–80% areal reduction of the swamps and lowland meadows (CHEN, 1992). With the changes in the oasis landscape, desertification landscape has been developing at an alarming rate. For example, the annual rate of desertification was 0.76%–3.56% in the Tarim River basin in Xinjiang, and 2.6%–6.8% in the Heihe Watershed in Gansu and Inner Mongolia. These two areas represent the most serious desertification regions in China, even in the world.

The dynamic changes of arid regions landscape are characterized by large spatial scale but small temporal scale. Hence, for the effective studies of the eco environmental problems, comparatively large spatial scales such as the scales of several tens, hundreds or even thousands of kilometers should be considered; whereas the temporal scales should be from several years to decades.

2 CONSTRUCTION OF LANDSCAPE ECOLOGY IN THE ARID REGIONS

In arid regions, in particular the plain region of

inland watersheds, the formation and changes of landscape patterns are closely related to human activities. This is well manifested by that the unstable components of the landscape: vegetation was transformed, native species were managed and harvested; in the meantime, the stable components of the landscape: soils were also transformed. The widely distributed protective forest networks-grasslands-cultivated land mosaic patterns and complex ecosystems in the agricultural regions of the arid northern China (JING, 1991) are typical construction patterns of the landscape ecology, which are created by people in the long-term production and practice processes and used to control wind and sand damages, enhance ecosystem productivity and stabilize or develop artificial oases.

Regulation and reconstruction of spatial structures of landscape units are the basic ways of landscape ecological construction, including regulating original landscape patterns and introducing new landscape components. Their purposes are to improve the function of the threatened and damaged ecosystems, greatly enhance the overall productivity and stability of landscape systems and make the anthropogenic interventions on landscape evolution feedback positively (XIAO *et al.*, 1998). The main construction contents of landscape ecology in arid regions can be divided into three aspects: regional green landscape construction, oasis ecosystem construction and regional sustainable landscape ecological construction.

2.1 Construction Project of Green Landscape

The purpose of this construction project is to establish a new landscape pattern, with enhanced cover as its core, to increase the heterogeneity and stability of the landscapes, to form a new, highly effective and harmonious man-made natural landscape. In this respect, the green corridor construction is the most common one and also has the most practical significance. In arid regions, the desert and oasis interlacing belt and the gully belt in low mountains and hilly regions are the key zones for controlling desertification and soil erosion. In addition, the greening cor-

struction of the roads, river and canal corridors also has very important ecological significance. The purpose of green corridor construction in arid regions is to set up the safe and stable ecosystems, to control hazardous ecological flows, to increase new, positive feedback chains and loops, to enhance biodiversity and visual aesthetic perception of human living environments by green mosaics. The green corridors should be constructed on the bases of the patches, either connected or isolated. The former is better since the connection can maintain a high and stable ecological function of the green corridors. The selection of plant species is very important for the construction of the green corridors, the green landscape constructed under high cost protective conditions has no sustainability and stability, and has poor resistance to disturbances. Special attention should be paid to the ecological suitability, select the plant species with strong self-surviving ability in accordance with ecological laws; plant grasses, shrubs and trees simultaneously; artificial vegetation should be established according to the principle, "using irrigation to ensure their establishment and relying on collected rainwater to ensure their survival chance". In the low mountains, hilly and gully areas, green cover should be established "along and upstream the river courses", thus forming a stable green mosaic landscape with high self-regulation and restoration functions.

2.2 Oasis Construction Projects

In arid regions, both natural and artificial irrigation oases are the major landscapes on which the regional social and economic development are based, stable and adequate water resources are the prerequisites for these landscapes sustainable existence and development. As for the agricultural ecological landscape, developing water saving and highly effective agriculture should be placed on the central position, so as to establish an intensive and three-dimensional agricultural ecosystem, minimize non-effective water consumption should be considered as a permanent task of the oasis construction project in the arid regions.

The protective forest is an important component of agricultural oases. On the landscape scale, such indexes as forest belt and the areal ratio of forest belt to protected farmlands, forest network superiority, connectivity and circle size should be used as the quantitative criteria of the oasis construction projects. How to use minimum land and water resources to generate high agricultural output and how to use minimum afforested land area to obtain the maximum protective effects are two key problems to be solved in the farmland landscape ecological construction. As for the natural oases in the desert regions, how to stabilize oases, enhance their loading capacity and resistance to disturbances should be viewed as the heart of the matters. The key points are the ecological flow control within the landscape, and maintaining the safety and stability of landscape ecological processes through introducing or altering landscape patches.

2.3 Construction Planning of Regional Landscape Ecology and Ecological Safety Control

Maintaining ecological safety, controlling and improving landscape evolution in the fragile ecological regions, enhancing ecosystem stability, constructing sustainable landscape patterns suitable for human societies are the objectives of the landscape ecological construction in the arid regions. The construction planning of regional landscape ecology should take the ecological safety as its basis and conduct in accordance with the following principles.

2.3.1 Concordance of human adjustment and ecological symbiosis

Man can control man-environment system through symbiosis and cooperate with nature. One of the most important tasks of ecological planning is to analyze the cause-result and feedback relations develop towards stable direction. Excessive and illogical exploitation of the water and land resources in the arid regions generally result in land desertification. One major measure to mitigate desertification is to introduce drought-tolerant and sand-fixing plant patches or to establish canal green corridors, triggering the neg-

ative feedbacks of land degradation.

2.3.2 *Ecological integration of society-economy-nature complex system*

On landscape and regional scale, three systems of different properties, nature, economy and society often integrate into a crisscross and interacted complex ecosystem. Multipurpose and multiattributive analyses for the policy-making should be conducted in view of spatial arrangement of the structure-function relation and dynamic trends of the three subsystem components, in accordance with the rationality of natural system, profitability of economic system and efficiency of the social system, in order to optimize the design of landuse patterns and resources production ways, and make out satisfactory, optimum landuse landscape.

2.3.3 *Protecting and increasing landscape diversity and heterogeneity*

Landscape diversity refers to the structural and functional diversities of landscape elements. It can reflect the landscape complexity and has significant influences on mass transfer, energy exchange, productivity level, species distribution, seed spreading and food searching, contribute to a better protection of biodiversity, natural landscape elements and cultural values. One of the important design principles in this respect is to increase the spatial heterogeneity on landscape scale through engineering or biological measures, improve restoration ability and stability of an ecosystem.

2.3.4 *Local control and overall adjustments*

Landscape ecosystem is a multiple, hierarchic organization associated with organic mass and energy, low level local disturbance may affect the entire system, while the entirety can be adjusted by controlling the locality. Although man can not control the nature in a large scope yet, local control has proved to be effective. Successful landscape planning lies in finding out the key localities or strategical components which can control the ecological flows in the landscape. Then, the health and safety of the landscape ecological processes can be maintained via introducing or altering the landscape patches at these key localities and

using minimum land and optimal pattern.

3 PROSPECTS OF THE LANDSCAPE ECOLOGY IN ARID REGIONS

Landscape ecology has a broad application in the study of the eco-environmental problems in arid regions. It has displayed a strong power to solve problems in dry land eco-environment characteristics, ecological processes and landscape ecological theories have good consistency, although the landscape ecology is still in the fledgling stage. However, it requires to enrich its theoretical systems through the studies of typical problems in arid regions. Over a long period of time, there has been a sharp contradiction between socio-economic development and eco-environment protection. Scientists involved in the study of sustainable development and local people are also pestered by this dilemma, and extensive land desertification has been imposing a direct threat on the human communities in arid regions. It is recognized that landscape ecological methods aided by the modern techniques, such as remote sensing, geographic information systems and global positioning systems, can provide quick and effective solutions to these problems such as landscape change or land mosaic type changes. In the future, with the continuous development of the eco-environment researches in arid regions and cross-penetration of multiple disciplines, the application of landscape ecological theories and methods has a very important significance and the hot-spot problems in the ecological and landscape ecological studies in the arid regions. The important breakthroughs will probably occur in: 1) landscape heterogeneity analysis and ecological spatial mosaic stability; 2) spatial pattern of the oasis landscape and ecological processes; 3) corridor connectivity and its ecological effects; 4) ecological thresholds of the desertification and regional ecological risk assessment; 5) landscape evolution and ecological monitoring; 6) landscape ecological prewarning and ecological safety pattern; 7) model design and optimal assemblage of landscape ecological construction; and 8) environment value assessment

and calculation of regional ecosystem. These objects include some eco-environment problems facing the dry lands today and needed to be solved urgently, also deal with the theoretical frontier of the landscape ecology and some new problems in ecology. With the continuous development of society and economy in the arid regions, manifold challenges in the eco-environment respect and different regions may have different crucial problems. The problems, with increasing degree of the water and land exploitation, even more urgent and serious eco-environmental issues and construction problems may arise.

4 CONCLUSIONS

Landscape is an open large scale system and contains middle scope, different-size spatial sequence. The foothold of the landscape ecological study is the human scale landscape, accordingly in which the influence of human activities on the landscape patterns and processes inevitably lies in the central position. As for the eco-environment issues caused by human activities and socioeconomic development patterns, with artificial oases as its cores, landscape ecology has a vital significance to the ecological management and regional sustainable development. The characteristics of arid landscape ecology, structure, functions and ecological processes are radically different from those in other regions. The purposes of this branch of ecology is to understand the ecological spatial characteristics and evolution processes of the arid regions in the views of landscape.

The central problem in the regional sustainable development is to establish a concordant coexistence between human communities and natural environment.

Its main content is to set up an active ecological balance, which coincides with the ultimate goal of the ecological construction. The proposed three major contents on the principles and measures are unquestionably of update concerns in the landscape ecological construction and sustainable development in the arid regions.

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