CHINESE GEOGRAPHICAL SCIENCE
Volume 11, Number 2, pp. 104 - 114, 2001
Science Press, Beijing, China

LANDSCAPE ECOLOGICAL CONSTRUCTION IN RURAL CHINA: THEORY AND APPLICATION

XIAO Du-ning

(Cold and Arid Regions Environmental and Engineering Research Institute, the Chinese Academy of Sciences, Lanzhou 730000, P. R. China; Institute of Applied Ecology, the Chinese Academy of Sciences, Shenyang 110015, P. R. China)

ABSTRACT: In landscape with overpopulation, intensive management for economic production, and where even small natural-vegetation patches are scarce, ecological conservation generally must be developed in the course of economic development. Thus "*landscape ecological construction*" has evolved in China. This approach adds spatial elements and alters landscape pattern to strengthen inter-ecosystem linkages, improve functioning of damaged ecosystems, and increase productivity and stability of the whole landscape. Five examples of managed landscapes in China are presented: dike-pond systems in a river delta; multi-pond system in a rice paddy landscape; field-grass-wood grid system on unstable sand dunes; shelterbelt network in a crop field area; and field-grass-wood mosaic system on highly erodible hilly farmland. These indicate that ecological conditions can be improved along with increased economic production. Altering landscape structure and ecological flows by introducing small landscape elements in distinct spatial patterns is considered a key to the results. This reshaping of the land has focused on changing patch size, regularity of arrangement, biological and hydrological corridors, and networks, the matrix and grain size. It suggests that such changes can increase negative feedbacks and increase stability. Finally, planning and design principles are pinpointed for the landscape ecological construction process.

KEYWORDS: landscape planning; ecological construction; rural China

CLC number: P901 Document code: A Article ID: 1002-0063(2001)02-0104-11

1 THE STRATEGY OF ECOLOGICAL CONSTRUCTION

1.1 Active Ecological Balance

The guidelines of current ecology are changing from balance, stability, homogeneity and small scale into imbalance, instability, heterogeneity, multi-scale, and hierarchy characteristics. The so-called ecological balance means that in the relatively stable status of an ecosystem in a specific time period, material and energy input equals to their output. Also by self-adjusting, the ecosystem can rehabilitate to its original stable status. Ecological balance includes two aspects, one is the ability of resisting disturbance, and the other is the ability of rehabilitating to its original stable status. According to the viewpoints of cybernetics, convolution theory, and dissipation theory, this balance is a kind of stability and order that differs from the balance status between ecological thresholds. The ecological balance human need is a kind of active ecological balance which can improve, adjust and gradually increase the amount and process of ecological order, rather than simply rehabilitating and reconstructing the balance of the origi-

Received date: 2000-09-28
Foundation item: Under the auspices of the main projects of the National Natural Science Foundation of China(No. 49631040 and 49731030).
Biography: Xiao Du-ning(1938 -), male, a native of Changsha City, professor. His research insterest includes landscape ecology.

nal ecosystem.

Ecological construction (MA *et al.*, 1984) proposed by Chinese ecologists, means adjusting the relationship between human beings and nature, organizing the production of renewable natural resources and managed ecosystems, putting the active ecological balance into practice and constructing new environments suitable to the life of human beings. From this point of view, a branch of applied ecology, which provides theoretical guidelines for the practice of ecological construction, is called construction ecology, including the preliminary study of ecological security theory, the mechanism of ecological processes and roles which regulate human beings, and applied disciplines like ecological planning, projects and ecological management. With the development of human society from industrial to information era, human beings deconstructed the natural environment first, then acclimated to it, and finally must construct a new environment according to symbiosis theory of man and biosphere. The proposed ecological construction strategy exactly meets the demands of current era and is especially suitable to the Chinese situation today.

1.2 The Ecological Roles of Human Beings

The research field of traditional ecology has been greatly extended by studies on the ecological roles of human beings. Landscape ecology, which studies the spatial changes of landscape structure and the relationship between landscape pattern and ecological processes at different scales, mainly focuses on the influence of human activities on landscape pattern, ecological processes and their changes. Hence, it is an interdisciplinary theory between natural science and humanities. The formation of existing landscape on the earth is more or less related to human activities. According to the impact extent of human activities on the shaping of landscapes, landscapes can be classified into three types: natural, managed and artificial. Their weighting index of energy density is *X*, *3X* and 10*X* respectively, according to ODUM H T (1990). In natural landscapes, the impact of human activities is generally very small or even can be ignored, compared to natural disturbances/stresses, such as flood, fire, wind, plant diseases and insect pests, etc. However, it is quite different in a managed landscape where the impacts of human activities are represented as following: First, vegetation, the unstable element in landscapes, was reshaped; second, local species were harvested or managed, or in addition, soil, the more stable element in landscapes, was remolded. The most typical landscapes of the third category, artificial landscapes, agricultural and suburban landscapes have the following characteristics (XIAO *et al.*, 1998):

(1) The productivity of renewable natural resources.

Research has been focused on designing landscape structure, which can develop the maximum functions of the landscape, to obtain higher bio-productivity than natural systems.

(2) The controllability of landscape change.

It is about the directional evolution of landscapes under human activities to achieve sustainable development of the landscapes by adjusting the in changing direction and its rate.

(3) The stability of the living environment for humans.

This is focused on the symbolism between bio-systems and human-systems.

Generally, the impacts of human activities on managed landscapes might be called more precisely "reforming" or "rearrangements". Artificial landscapes that are called human civilized landscapes do not exist naturally in the world. They are completely constructed by human beings, such as urban landscape, engineering landscape, etc. In this kind of landscape, human systems become the main landscape elements (i. e. matrix). In this case, the impacts of human activities on the landscape should be called "buildings" or "building systems" (XIAO *et al.*, 1997).

1.3 Ecological Construction at the Landscape Scale

The word, ecological construction, has been widely used in China. Its implications are ambiguous and its spatial extent ranges widely from the ecological design and management of a family yard (local scale) to that of ecological village, ecological town, ecological county and ecological city (landscape and regional scale). The former (on local scale) was characterized by the application of specific ecological technology, such as the widely adopted vegetable cultivation in plastic canopy-greenhouse hogpen-methane pools in northern rural areas of China. The latter was characterized by ecological and economical planning and management in a specific administrative area to improve regional environment. Hence, it is necessary to give ecological construction at the landscape and regional scale a name — landscape ecological construction. This key process strengthens inter-system ecological coordination and efficiency in a specific region by adjusting landscape pattern and by constructing landscape elements to improve the functions of stressed or damaged ecosystems, which greatly increases the total productivity and stability of inter-ecosystems in a landscape, thus to lead the impacts of human activities on landscape evolution to positive loop.

2 THE PLANNING THRORY OF LANDSCAPE ECOLOGICAL CONSTRUCTION

2. 1 Objectives

(1) Guarantee ecological security, minimize ecological risk, maintain the health and integrity of ecosystems, control the development of ecotones and increase the stability of ecosystems.

(2) Increase the total productivity of ecosystems in the landscape, such as the potential productivity of land or water body, and increase the efficiency of the cycling of energy and materials.

(3) Conserve landscape diversity, and the multiple values (economical, ecological aesthetical) of landscapes.

(4) Construct sustainable landscapes suitable for human living.

2. 2 Contents

(1) Modify the spatial pattern of landscapes. New landscape pattern can be created by introducing new elements or reshaping original elements to increase landscape heterogeneity and stability, and to construct managed landscape which are superior to their original state in combining ecological and economic benefits.

(2) Control the intensity and ways of human activities to compensate and rehabilitate the ecological functions of landscape. Factors, such as changing land use, adjusting to forest cutting, and altering grazing intensity, will all affect the rehabilitation or status of the functions of ecosystems.

(3) Exploit renewable natural resources using ecological principles. Agricultural cultivation is one of the most typical means of extensive use of renewable natural resources (light, water, heat, soil and organisms). The development of agricultural landscape construction can be categorized in two steps. The first is the change from simply increasing the quantity of agricultural products to strengthening the quality of the products (green food). The second is the change from unlimited use of fertilizer, pesticide and agricultural mechanics to the extensive use of the technology of ecological agriculture.

(4) According to the principle of imitating nature, construct new artificial landscapes, which harmonize with natural ecosystems, such as the construction of tourism scenic sites.

2. 3 Design Principles

(1) Reciprocal interactions or feedbacks between landscape structures and their functions

The ecological flows in landscapes are mainly affected by landscape structure or pattern. The interactions and feedbacks between landscape structure and its functions, or, between landscape pattern and ecological processes is the core of landscape ecology. Therefore they are also the foundations of landscape planning and landscape design.

(2) Harmonize human control with biocybernetic symbiosis

Human environment systems could be controlled according to the biocybernetic symbiosis theory to effectively link man and nature. The core of the theory is the coupling of the negative feedback loops which counteract deviation and the positive ones which en hance the deviation, by which the self-stability and self-organization of ecosystems could be fulfilled. In ecological design and planing, the most important task is to analyze the feedback interactions of ecosystems, and introduce new feedback loops into the systems so that the systems gradually become more stable. This is illustrated by desertification caused by overgrazing and reclamation in a semi-humid temperate region. Landscape construction in this area reduces cultivated land and plants Astragalus manneensis, a plant belonging to the Leguminosae, to change the cause-effect feedback loops of the system into negative feedback loops.

(3) The ecological unification of the social-economic-nature complexity

At landscape and regional scale, the natural system, economic system and social system are interleaved together to form a complex ecosystem characterized by ecological complexity. On the basis of multiple-objective analysis, the relationship between structure and function of these three systems and their dynamic trends can be made clear. Then, rational land use patterns and resource utilization methods may be determined.

(4) Conserve and increase landscape diversity and spatial heterogeneity

Landscape diversity means the diversity in structure and functions of landscape elements, reflecting the degree of complexity of landscapes. It has significant effects on material flow, energy exchange, species dispersal, foraging, etc. Conservation of landscape diversity is an extension of the conservation of bio-diversity by including two aspects. The first is the conservation of natural elements in landscapes, and the other is the conservation of the cultural value of landscapes. By landscape designing, natural landscapes are reshaped and cultural landscapes are constructed. One important design principle is to increase spatial heterogeneity on the landscape scale. This is done by incorporating engineering or biotic measures to improve the counter-disturbance and rehabilitating ability, and to increase the stability of systems.

(5) Local control, modification of the wholes and adjusting measures to local conditions

Landscape systems have a hierarchical organization associated with material and energy. Disturbance on lower levels would affect the upper ones. Therefore, control of the local will modify the whole. At present, it is impossible for humans to control nature over a large extent for a long time. However, control of the local area may be effective. In successful landscape planning, the key sites or strategic points, which have significant roles in ecological flows in landscapes, should be emphasized. By introducing new elements that reshape the existing roles on these sites, the security and health of landscape ecological processes could be maintained by the minimum land use and best spatial pattern, which was called ecological security pattern by YU Kong-jian (1996).

Because of the diversity and complexity of landscapes, measures taken in ecological projects should be adjusted to local conditions.

3 THE PRACTICE OF LANDSCAPE ECOLOGICAL CONSTRUCTION IN CHINA

China is an ancient country. Many successful models of landscape ecological construction have been created by Chinese people in the long history. Five examples highlight a variety of key approaches and solutions: 1) the dike-pond systems in a river delta; 2) the multi-pond system in a rice paddy landscape; 3) the grid model of crop-grass-forest systems in sandy lands; 4) the shelter belt network in Northern plain areas; 5) the mosaic model of crop-grass-forest in the Loess Plateau. Each will be explained in details.

3. 1 The Dike-Pond Systems in a River Delta

The dike-pond system in the Zhujiang(Pearl) River delta, which has plenty of rainfall, a low elevation and frequent flooding, is a special land use form created by local people according to the natural conditions. It is one of the typical types of agricultural landscape. Located at the core of Zhujiang River delta, the dike-pond area is 1120 square kilometers, accounting for 10% of the total delta (Fig. 1) (ZHONG *et al.*, 1987).

The dike-pond landscape, "the dike-water land" called by local people, consists of dikes and ponds.

"Dike" is where crops can grow, and also serves as the nutrient pool for the mulberry tree, silkworm and fish. "Water" is the key component of the land use mode. Dikes can be classified as mulberry dike, sugarcane dike, orchard dike and flower dike according to the different crops planted. It is usually 8 – 12 meters in width, and 0.5 – 2 meters in height. Ponds are usually rectangles with area of 0.14 – 0.40ha and filled with water from 1.7 to 3.0 meters in depth. The ratio of pond length to width is typically 6:4 (MADS, 1996).

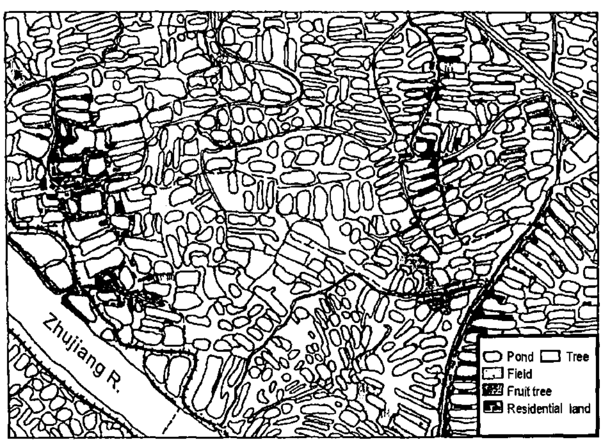

Fig. 1 Dike-pond landscape pattern of Zhujiang River delta, Guangdong Province in southern China
The map shows 1120 square kilometers core area of the delta

The most distinguishing characteristic of this kind of wetland landscape is that it has two kinds of matrix. The ratio of dike to pond area is about 1:1, ranging from 6:4 to 4:6 (Table 1).

According to the investigation in Shunde County, the constitution of patch size of ponds is as follws (Table 2).

According to analysis using aerial photographs, there are 110 000 ponds in 100 square kilometers of core area of the Zhujiang River delta. Their total area is 23 330ha, with average pond area of 0.2ha. River corridors are well developed here. The river density is 0.29 km/ha, and the surface area of rivers is 12.7% of whole land cover in Zhujiang River delta.

Based on statistics for the 21 divisions belonging to the above 5 counties, there are 11 with dike area greater than that of ponds, 2 equal to ponds and 8 less than ponds. The dike-pond system has been constructed for more than 400 years. Its total productivity is about 20 – 40t/ha. The annual productivity of ponds is 7 – 10t/ha and that of dikes is 10 – 80t/ha, with average of 37t/ha for the whole landscape.

3.2 The Multi-Pond System in a Rice Paddy Landscape

Here pits and ponds are distributed extensively in an agricultural landscape with a matrix of paddy fields. Pits and ponds vary in size from 10^3 to 10^5 square meters. The smaller ones are called pits, and the bigger ones are ponds, located at the foot of mountains, in fields and by villages. These multi-pond systems were constructed by local peasants thousands of years ago in order to acclimate to local sub-tropical conditions where rainfall is unevenly distributed. Now they have become a precious agricultural culture heritage. The scattered pits and ponds have important ecological roles in inter-

Table 1 The percentage of matrix in dike-pond areas (%)

	Shunde	Nanhai	Zhongshan	Xinhui	Heshan
Percentage of dike	51	55	50	51	57
Percentage of pond	49	45	50	49	43

Table 2 Patch size of ponds in Shunde County

Patch area (ha)	< 0.14	0.14 – 0.33	0.33 – 0.66	> 0.66	Sum
Patch number	27223	35554	11000	2231	76000
Percentage	35.8	46.8	14.5	2.9	100

:pting run off and sediments, plus filtering nutrients, ıch as nitrogen and phosphorus. As a case study, the ucha River watershed, located in Anhui Province, as used to demonstrate the structure and functions of e multi-pond systems (Fig. 2) (YIN, 1993). The ea of the watershed is 7.32km^2 with 150 water ›nds in it (Table 3). The total area of the ponds is 5ha, accounting for 4.9% of the total watershed. The ean area of the ponds is 2400m^2. Water depth in these ›nds is normally 1.5m. The ponds, with volume of 10 800m^3, can store 97mm precipitation of the entire atershed. There are 284ha of paddy fields in the watershed, which require 568 560m^3 of water to irrigate, :counting for 80% of the total water stored in these ›nds. There are 16 villages and 3000 people in the atershed. The average number of ponds is 9.4 per llage (Table 3).

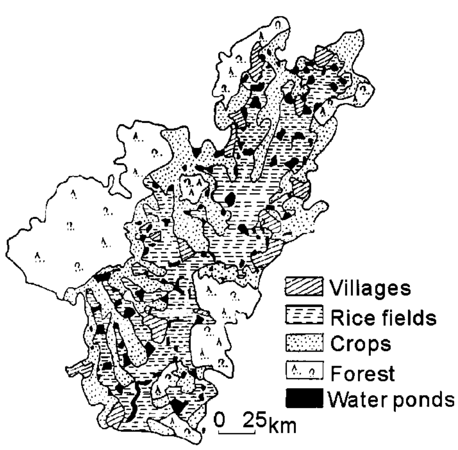

Fig. 2 Land use of the Liucha River sub-watershed

The paddy field in the southern hilly area is one high productivity agricultural regions in China. The ınual average productivity of rice is 12.6t/ha for rice ıd 2.25t/ha for rapeseed in rice-rapeseed rotational elds. In order to maintain the high productivity, fertilizers were used at 2.1t/ha. The large amounts of fertilizer, together with dung of people, livestock and poultry run into the water body as main pollution sources to the agricultural landscapes, and often cause eutrophication in lakes. For example, Nest Lake is the most seriously eutrophicated lake in Anhui Province. According to the study by YIN Cheng-qing (1993), there are a number of pollution sources per unit area because of the heterogeneity of the landscape (Table 4). Surface source pollution is always accompanied by run off after a thunderstorm, which often occurs abruptly. From Table 4, we can see that about 440 kg/ha phosphorus was lost due to run off, accounting for 98% of the total. About 2200kg/ha of nitrogen was lost due to the same reason, accounting for 80% of the total. However, more than 95% of the lost nitrogen and phosphorus was accumulated in the pits and ponds. Therefore, pits, ponds and ditches as critical landscape patches and corridors can store water that has a significant role in sustainable agriculture development, as well as water quality conservation. This landscape ecological structure is especially appropriate for the rainy areas in the sub-tropical and tropical zone.

3.3 The Grid Model of Crop-Grass-Forest Systems in Sandy Lands

There are large areas of stable sandy land in the western part of Northeast China Plain, which belongs to the semi-humid region of the temperate zone, with annual precipitation of 400 – 500mm. The majority of the sandy land is sandy flat land with good soil and water conditions. The natural vegetation is a *Ulmus maciocarpa* community and a *Armeniaca sibilica* community, while prairie grows on the flat land forming the forest-steppe landscape in this area. Because of the excessive forest removal and irrational land use, the conflicts between agriculture and forestry, and the in-

Table 3 The landscape composition of the Liucha River watershed

ndscape element	Paddy field	Unirrigated land	Forest land	Village	Pond	Total
rea(ha)	284	229	131	52	36	732
ːrcentage	38.8	31.3	17.9	7.1	4.9	100

Table 4 The load capacity of run off in the Liucha river watershed (kg/ha)

Pollutant	Village	Unirrigated land	Paddy field	Forest land	Average	Total
Nitrogen	15.92	2.49	1.96	1.12	3.01	2200
Phosphorus	5.43	0.26	0.14	0.21	0.59	440

creased predominance of agriculture and pasture, serious desertification occurred. For example, there are over 1 000 000ha of sandy land, and this grows at the rate of 0.72% per year. The productivity of crops planted on the sandy land is very low, with total productivity of 1.5 – 3t/ha (JING, 1991a).

In order to reconstruct the degraded ecosystems, the key approach is to change landscape pattern by constructing forest belts and forest networks to control the growth of sand dunes, and at the same time, planting *Astragalus manneensis*, a plant species belonging to Leguminosae, to form a negative feedback loop. The landscape planning based on this kind of crop-grass-forest system includes the following forms.

(1) Construct a complex ecosystem in the shape of a grid on sand dunes with flat tops. The distance between main forest belts is 200 meters, and 300 meters between by-forest belts. *Astragalus manneensis* was planted along the forest belts in bands of 50 meters wide. The inner part of the grids have become arable land. The appropriate ratio of forest to grass to crop area is 2:1:5 (JING, 1991b).

(2) Construct forest-grass-crop system in the shape of a ring in areas which are enclosed by sandy land in the outer rim, the inner parts of which are shaped as plates.

(3) Construct a mosaic system composed of forest network and grassland patches on sandy land that has multiple sand dunes. In order to stabilize the sand, the suitable forest grid should be 200 meters long and 100 meters wide (Fig. 3).

At present, the dry biomass of poplar trees planted on sand dunes is 8 – 12t/ha, and 10t/ha for *Astragalus manneensis* which is relatively good forage for livestock. So this complex system provides benefits to both agriculture and livestock. As for the long low-lying land, hydrological and biological measures should be taken to intercept run off in summer. A sand dam at 2000 meters long and 2 – 3 meters high can store (50 – 100) $\times 10^4 m^3$ of water. The homogeneous character of the long low land was changed by constructing dams with interval of 5 – 6 meters. Landscape heterogeneity was increased as a result, and different crops could be planted according to the local conditions.

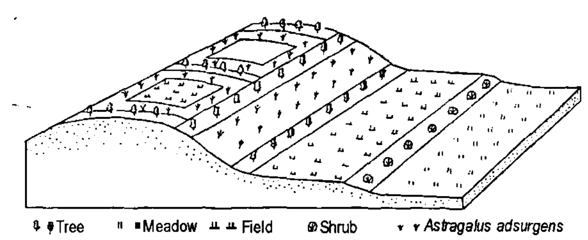

Fig. 3 The model of systematic design for forest, meadow, field on sand land

3.4 The Shelter Belt Network in Northern Plain Areas

In China, a huge shelter belt network is located in the Songnen Plain in Heilongjiang Province. The total length of forest belts is more than 200 000km, forming 150 000 forest network grid cells. More than 4 000 000ha of agricultural fields were protected. Based on typical investigations, the average production of the protected fields was increased 15%, and the area of wind erosion reduced 35 300km². Shelter belts have been constructed in more than 1100km² agricultural fields of the "three-north" regions, including the western parts of Heilongjiang and Jilin provinces, the irrigation area along the Huanghe (Yellow) River in Hui Autonomous Region of Ningxia, Hexi Corrider in Ganshu Province and the Hetan area in Uygur Autonomous Region of Xinjiang. A large amount of observation data showed that within the effective protection area of the shelter belt networks, wind speed near the surface of the earth decreased 30% – 35%, and the soil water content increased 10% – 30%. Compared with the same crop fields without shelter belts, food production increased 10% – 30% (XIAO, 1997).

With trend analysis, Nong'an County with shelter lts, and Changling County without, were compared : the changes in average wind velocity from April to :tober. The results showed that wind velocity in ›ng'an County dropped 35% from 1978 to 1987, iile in Changling County, there was no significant ange in wind speed for the same period. The effect of elter belts on temperature over the large extent was ınd for two aspects: increasing temperature in winter d decreasing temperature in summer.

The shelterbelt grids can be considered as corridor stems in agricultural landscapes. Evaluation of spatial ttern of the forest grids can be mainly characterized their number, evenness and spatial geometry. The ›st commonly used indices are ratio of the area of est grids to the area of their protected crop fields, minance, connectivity and circuity. The key problem landscape ecological construction in plain areas is to ıstruct shelter belt grids with minimum afforestation :a, while achieving maximum protection effects. The :al layout of forest grids is to have all the protected crop fields within the effective protection extent of the forest grids, while taking up the least land and minimizing overlap. The water balance is the main limiting factor which affects forest coverage in plain areas. It is appropriate for forest coverage to be 18% -24% in semi-humid steppe area, 14% -20% in the semi-arid steppe area, and 10% -16% in arid oasis. Wide belts and large grids were adopted. Thin shelter belts and small grids were also used.

As a case study, the forest grids in Qiangang Town, Nong'an County, Jinlin Province, were evaluated. The town has 11 829ha arable land in total, of which 5.87% was taken up by shelter belts with an average grid cell size of 534 by 569 meters. Landscape pattern indices are shown in Table 5 (ZHOU *et al.*, 1994).

When the actual value of the landscape pattern indices is 0.85 - 1.15 times of its corresponding theoretical value (Table 5), the forest grids could be thought as good ones. Those in Qiangang Town meet this standard. So we can say that forest grids in Qiang Town were rationally distributed in the landscape.

Table 5 Landscape pattern indices of the shelterbelt forest landscape in Qiangang Town

:ms	Area of forest girds(ha)	Number of forest belts	Number of grid/cell	Forest/field ratio by area	Dominance	Connectivity	Circuitry
tual value	694.9	757	206	0.067	40.2	0.606	0.370
sign value	617.3	1112	497	0.060	37.6	0.926	0.780

5 The Mosaic Model of Crop-Grass-Forest System in : Loess Plateau

The key problem to improve the ecological envinment of the Loess Plateau is how to control the loss soil and water, which is the most serious in the world th large extent and high intensity. Based on experices of eleven exemplary experiment areas in five ›vinces or autonomous regions, it is possible to in:ase productivity and to reduce soil and water loss of : ecosystems by changing the land use structures, by roducing new energy and technology into the sysns, and by taking small watersheds as the controlling its (LI, 1997). Great ecological and economic benefits have been achieved. In the eleven experiment areas, the spatial configuration of fields, forest and grass land has changed from 1: 1.2: 1.5 in 1986 to 1: 1.43: 1.37 in 1990. The forest coverage changed from 18% to 24% between 1986 and 1990, and to 34% in 1995. The average forest area per capita is more than 0.2ha. The amount of sediment lost was reduced 62% from 1986 to 1990, and 39% in 1995 due to the implementation of water conservation projects. The income of peasants increased 5 times.

According to the study on Yangjuangou watershed in Yanan City by FU Bo-jie *et al.* (1998), the terraced field-grassland-forest land has better capacities in soil water and nutrient maintenance in the four typical land use types that have about 15 years of cultivation history on Liang (hill with a long and stable top). The landscape ecological construction mode has been accomplished in this watershed, which is characterized by constructing terraced fields on sloping land, building dams in erosion ditches, and planting trees and herbs in a mosaic pattern. The main components of this mode are as follows.

(1) Modulate the configuration of land use, reduce arable lands on steep slopes to increase grass and forest land according to land suitability. As a result, the arable land has been changed from 45% - 55% to 25% of the total, while grass and forestland to 60%.

(2) Construct horizontal terraced fields on slopes less than 25 degrees, and build dams in ditches to make new fields. In this way, 2.6 - 4ha fields can be made in $1km^2$. Irrigation system has to be set up to ensure the bumper harvest of the fields.

(3) Restore vegetation by planting grass and trees. Perennial Leguminosae herbs are planted on 20 to 25 degree slopes to support livestock. Shrubs are planted on slopes of ditches to conserve water and soil, and orchards are developed according to local conditions.

The local people describe this mode as "grass on top, forest in ditch, terraced fields on slopes and dammed fields by irrigating".

Restoration of vegetation is the core of landscape ecological construction. The interception rate of canopy to precipitation is 12.5% to 26.7%. The percolation rate of soil in 40 - 50 year poplar forest is ten times higher than that of soil in agricultural fields. The anti-erosion capacity of topsoil in forestland is 93 times higher than that of fields, and 32 times higher than that of grassland. Based on observations in Seabuck thorn forest with coverage rate of 0.85 in Lishi experiment area, run off and sediment were reduced 85.2% and 98.4%, respectively in case of rainfall at 75.3mm within 45 minutes. Observations on 12 grass species showed that run off and sediment were reduced 47.5% and 74.7%, respectively. The results in Ansai experiment area showed that soil erosion was reduced 60% to 90%. Ecological laws must be followed in the construction of forest and grassland to intercept and store precipitation.

The function of water storage could be fully developed in the thick and loose soil in the Loess Plateau by constructing terraced fields on slopes, leveling the land and increasing soil fertility. In the Lishi area, the average food production is 3.5t/ha, after changing the slopes into terraced fields where five crops were planted. That is 3.1 times the productivity in non-restored land. Water use efficiency increased 3.23 times. In those slope areas that have not been changed into terraced fields, cultivation methods that can conserve water and soil must be adopted, such as planting along contours and intercropping grass and crops. The factors that affect the productivity in the Loess Plateau areas are the shortage of nutrients and water. The former is more important than the latter. So, increasing the nutrient input is an important measure for a great increase in food productivity. Only when food can meet the demand of the local people will the deforestation and land exploitation be prevented, and the ecological environment can be changed into better conditions.

4 DISCUSSION

All the above five practical examples indicate that the landscapes managed by ecological laws can reach or even exceed the productivity of natural systems, while maintaining sustainability.

First, measures which can increase landscape heterogeneity to create new landscape patterns were adopted. These included changing the matrix of the original landscapes, constructing biological or hydrological corridors, and reshaping patches, by changing their size and mosaic arrangement to form uniform or unevenly distributed landscape patterns and fine grain or coarse grain landscapes. For example, the dike-pond system belongs to a uniformly distributed fine grain landscape, while the multi-pond system is an unevenly distributed fine grain landscape. The grids in the plain areas are thin belt coarse grain landscapes in the shape of chessboards. The osaic model of the crop-grass-forest system in sandy land is an irregular tree branch pattern, and the forest-grass system in the Loess Plateau is an irregular mosaic of wide belts and coarse grain. These landscape spatial patterns were formed by introducing new coarse grain. These landscape spatial patterns were med by introducing new human culture on the basis of : original geomorphic, climatic and biological char- ers. They were the results of humans trying to find ys to coordinate with nature and to refine a land-use del. They also represent an attempt by people to iieve sustainable development at a landscape scale.

Second, new negative feedback loops were intro- ced into the original ecosystem to increase the sta- ity of the system in all the examples above. A no-management model was changed to mul- nanagement and integrated development , by way of nbining agriculture, forestry and pasture, or com- ing agriculture, forestry and orchard, or combing a- culture and fishery. The total productivity of the e- system was greatly increased and the economic and logical profits were developed simultaneously. It is : effective way for local people in ecotones to live ter.

FORMAN (1995) put forward a landscape plan- g model and best combination of ecology and land : on the basis of the experiences of land use and e- ogical construction in North America and Western rope. Its core idea is to protect and increase the ural patches in landscapes by modifying landscape tial patterns. The field, residential and natural ches were generally aggregated, and partly scat- ed, so that landscape heterogeneity can be achieved l ecological conservation can be fulfilled. This pos- le landscape design is quite enlightening.

However, China is an ancient country with thou- ds of years of cultivation history. It is overpopulated l has a high ecological load. Natural patches in rural dscapes are seldom present because of intensive land : over a long time. The conflicts between large pop- tion and less usable land are obvious. So landscape nning and ecological construction in China cannot ape from this situation. The concept of landscape logical construction proposed in this paper is a way landscape planning adapted specifically to China. e key problem that the ecological construction should ve is how to coordinate increasing population while serving the living environment. Ecological con- ction should be carried out in the course of economic elopment, and intentionally by human activities, such as adjusting agricultural production structure, planting shelter belts, building water and soil conservation projects, and so forth.

In intensive agricultural areas, landscape planning should emphasize the following principles:

(1) Construct highly efficient managed ecosystems, implement intensified land management and protect aggregated crop patches.

(2) Rebuild natural vegetation patches, increase green corridor and scattered natural patches according to local conditions, and compensate and restore the ecological functions of landscapes.

(3) Control aimless expansion of artificial patches, use land economically for engineering and residential purposes, and reshape beautiful residential environments and comfortable landscapes in harmony with natural systems.

(4) Arrange hill, water, forest, field, and road as a whole, and create better land, manage the water, plant trees, and control pollution comprehensively.

REFERENCES

FORMAN R T T, 1995. *Land Mosaics. The Ecology of Landscape and Region*[M]. Cambridge: Cambridge University Press, 12 - 116.

FU Bo-jie *et al.*, 1998. Impacts of land use structure on soil nutrient distribution on the Loess hill region[J] . *Chinese Science Bulletin*, 43(22): 2444 - 2448. (in Chinese)

JING Gui-he, 1991a. The landscape ecological reconstruction in some degraded land in northeastern China[J]. *Acta Geographica Sinica*, 46(1): 8 - 15. (in Chinese)

JING Gui-he, 1991b. *Landscape Ecological Construction of Sand Land in the Middle-western Jilin Province*[M] . Changchun: Northeast Normal University Press. (in Chinese)

LI Yu-shan, 1997. Progress of the study on soil and water conservation in the Loess Plateau[J] . *Bulletin of National Natural Science Foundation of China*, 11(3): 190 - 194. (in Chinese)

MA Shi-jun, WANG Ru-song, 1984. Compound ecosystem of society, economic and nature[J] . *Acta Ecologica Sinica*, 4 (1): 1 - 9. (in Chinese)

MADS Korn M, 1996. The dike-pond concept: sustainable agriculture and nutrient recycling in China[J]. . *Ambio.*, 25 (1): 6 - 13.

ODUM H T, 1982. *System Ecology*[M]. New York: John Wiley.

XIAO Du-ning, 1997. Ecological environment assessment for the

"Sanbei" shelter-forest project[J] . *Science & Technology Review*, (8): 403 - 412. (in Chinese)

XIAO Du-ning , LI Xiu-zhen, 1997. Development and prospect of contemporary landscape ecology[J]. *Scientia Geographica Sinica,* 17(4): 356 - 374. (in Chinese)

XIAO Du-ning , ZHONG Lin-sheng, 1998. Ecological principles of landscape classification and assessment[J] . *Chinese Journal of Applied Ecology,* 9(2): 127 - 221 (in Chinese)

YIN Cheng-qing, 1993. A multi-pond system as a protective zone for the management of lakes in China[J]. *Hydrobiologia,* 251: 321 - 329.

YU Kong-jian 1996. Security patterns and surface model in landscape ecological planning[J] . *Landscape and Urban Planning,* 36: 1 - 17.

ZHONG Gong-pu, WANG Zeng-qi, CAI Guo-xiong, 1987. Landscape characteristics of the pond-based system in Zhujiang River delta and their exploitation[A]. In: XIAO Du-ning (ed.) . *Landscape Ecology: Theory, Method and Applications*[C]. Beijing: China Forestry Press, 215 - 219. (in Chinese)

ZHOU Xin-hua , SUN Zhong-wei, 1994. On measuring and evaluating the spatial pattern of shelter belt networks in landscape [J] . *Acta Ecologica Sinica,* 14(1): 24 - 31. (in Chinese)