10 Optimized Sustainable Eco-production Paradigms in Drylands

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Drylands in China can be divided into five natural or semi-natural regions based on physical and socioeconomic features, e.g., the mountain-basin system in arid desert regions, the Loess Plateau region, the Inner Mongolia Steppe region, the Inner Mongolia agropastoral transitional region and the Ordos Plateau region (Fig. 10.1). The first three regions are biogeological regions that are relatively independent. The Ordos Plateau region is a special biogeological region that is separate from the Loess Plateau region, and the

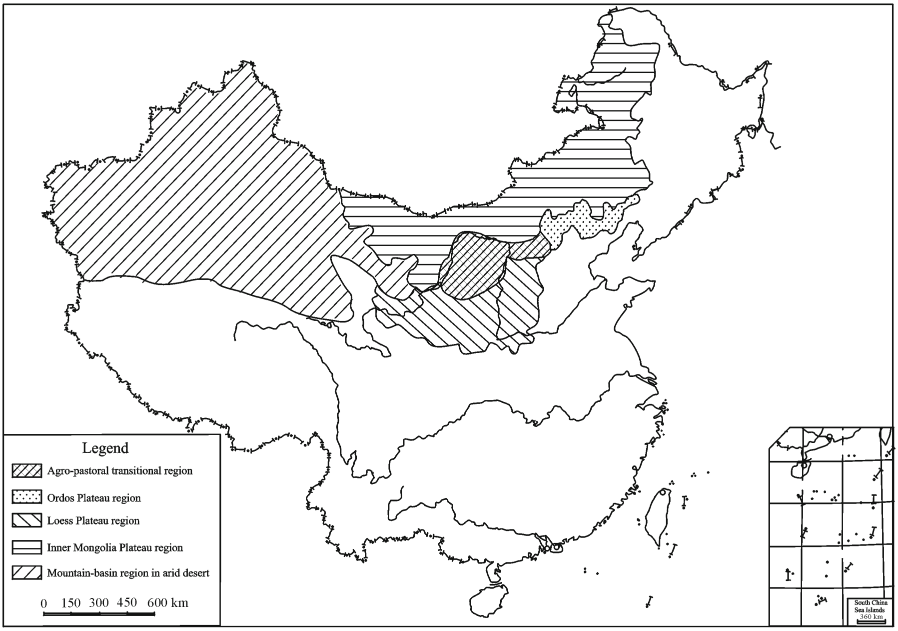

Fig. 10.1 Distribution map of five natural or semi-natural regions in the drylands of China (Yang et al., 2008, with permission from authors)

agropastoral transitional region is a land-use based, semi-natural region rather than a biogeological region.

In this chapter, four sustainable eco-production paradigms are established. The Inner Mongolia steppe and agropastoral transitional regions are combined into one pattern. Here, a sustainable eco-production paradigm refers to the integration of ecosystem management, regional landscape patterns and geologic functional belts to optimize ecological functions, production potentials and economic benefits based on the replicate complex of the regional landscape and its energy and material flows (Zhang, 2000; Zhang and Shi, 2003; Ci et al., 2007). In these paradigms, different functional belts are determined and used in consideration with regional biogeophysical processes, biogeochemical cycles and biogeosocial relations.

10.1 Three-circle eco-production paradigm in drylands

Three-circle paradigm is the first eco-production paradigm we generalized in Ordos Plateau, then the paradigm was expanded to the whole drylands at different scales, and a large area of degraded landscapes in drylands have been restored based on this paradigm. Here, we give descriptive introduction to this paradigm at regional and local scales.

10.1.1 Physical geography background for the three-circle eco-production paradigm

10.1.1.1 Geographical belt features of bioclimatic zones

Bioclimatic patterns of drylands follow patterns of geographical belts (Ci and Wu, 1997). The northwest-southeast direction in China is controlled by the Mongolian-Siberian anticyclone and has bioclimatic zones with circles or rings encompassing extremely arid, arid, semi-arid, dry sub-humid and humid climates. Bioclimatic types differ among deserts, sandlands and their peripheral regions. For example, the Taklimakan Desert and its peripheral sandland is a warm-temperate arid desert; the Gurban Tonggut Desert and its peripheral sandland is a temperate arid desert; deserts in the Qaidam Basin are cold-temperate deserts; a high-elevation cold desert is located north of Tibet; the Ordos Plateau and its sandland is a temperate sandified grassland; and the Horqin Sandland, Hulun Buir Sandland and other sandlands in eastern China are located in the temperate steppe zone.

According to the UNCCD, bioclimatic zones for desertification-prone zones include arid, semi-arid and dry sub-humid areas, other than polar and sub-polar regions, in which the ratio of annual precipitation to potential evapotranspiration falls within the range of 0.05–0.65 (Ci, 1994; INCD, 1994). Correspondingly, the bioclimatic zone of China was classified using the Thornthwaite Method with 10 years of meteorological data collected from 1914 stations (Ci and Wu, 1997; Thornthwaite and Mather, 1957; Zhang, 1989). Extremely arid zones include the Taklimakan Desert and some deserts in northwestern China. Arid areas are distributed throughout China from the Tianshan Mountains in the north, to the Pamler Plateau in the west, to Helan Mountain in the east, and to the Kunlun and Qilian Mountains in the south, as well as the northwestern part of the Qinghai-Tibetan Plateau. Semi-arid areas consist of typical steppe and desert steppe in the east and high and cold steppe and desert in the Qinghai-Tibetan Plateau. Most of northern Xinjiang is semi-arid, including desert and semi-desert. Dry sub-humid areas include the Hulun Buir Plateau in the north, the border between typical steppe and meadow steppe in the east, the north part of the Loess Plateau and north edge of the Qinghai-Tibetan Plateau and the border around the Qaidam Basin to the southwestern part of the Qinghai-Tibetan Plateau.

10.1.1.2 Concentric-circle rules in drylands

Drylands around the world are mainly distributed within the Tropic of Cancer and Tropic of Capricorn, which are controlled by the subtropical high. In China, the lifting of the Qinghai-Tibetan Plateau, resulted in drylands with complex and diverse ecological relationships and geologic boundaries.

(i) Concentric circle patterns — geological basis for constructing large, regional three-circle paradigms

The famous Russian geologist, Vladimir Obruchev, gave a classic concept of concentric aeolian deserts in China and Mongolia after his field survey in 1895. In his theory, the Mongolia-Siberian high-pressure anticyclone is the strongest and most frequent desert wind system in mid-Asia and is the driving force of the rocky Gobi Desert, desert and Loess Plateau geological patterns (Zhang, 1992). The basic processes forming these systems are as follows. ① Gravel or rocky desert (Gobi): In the center of the anticyclone area, the climate is arid and cold in winter and extremely arid in summer. Fine particles, such as sand and dust formed through weathering, are transported to other regions with strong winds, leaving behind gravel and stone. ② Deserts or sandlands: At the edge of the anticyclone area, the ground surface is covered with less xerophytes and hyper-xerophytes. Finer dust is removed by winds, and coarse particles are redistributed with blowing and accumulating processes to form deserts or sandlands. ③ Loess soil: In the periphery of the anticyclone area, dust-carrying air flow is hindered by mountains or meets humid air flow. Dust and sand precipitate and accumulate to form loess soil. The Loess Plateau is the dust precipitation belt at the periphery of arid areas.

(ii) Interfaces between mountains, basins and deserts (sandlands) — geological basis for constructing small, local three-circle paradigms

Deserts and sandlands in China are mainly located in basins surrounded by mountains or plateaus. For example, the Taklimakan Desert, which is the largest mobile desert in the Tarim Basin, the Gurban Tonggut Desert in the Junggar Basin, the Mu Us Sandland in the Ordos Plateau and the Otindag Sandland in the Inner Mongolia Plateau have similar geologic patterns.

10.1.2 Structure of the three-circle eco-production paradigm

The three-circle eco-production paradigm is an optimized ecological management and design paradigm based on the spatial pattern of arid ecosystems and landscapes and their mechanisms of energy and material flow. It is based on the Mu Us Sandland of the Ordos Plateau but follows rules of natural geographic belts with geographic cycles in drylands in general (Zhang, 2000). This kind of landscape forms heterogeneous ecosystems through redistribution of water, energy, material and salt and includes differences among ecosystem components, productivity, biogeochemical cycles, biogeophysical processes and biogeosocial relationships (human activities). It also includes relationships among ecosystems and material and energy exchange and flow at the landscape scale.

10.1.2.1 Large three-circle paradigm

The large three-circle paradigm is designed at the national scale, which is the landscape pattern for sand control, sand-dust storm alleviation and optimized eco-production models at the macroscopic scale. It consists of three components including arid desert, steppe and agropastoral transitional circles.

(i) Arid-desert circle

The outer circle is the arid desert belt, which includes the Gobi Desert along the national boundary with Mongolia in Xinjiang, the Hexi Corridor of Gansu, western Inner Mongolia, Junggar Desert, Badain Jaran Desert, Tengger Desert and Qubqi Desert. Loose sand cover in these areas provides rich source materials for large sand-dust storms. Likewise, sandlands formed because of vegetation destruction between deserts and oases and farmland along desert edges. Denuded oases during winter and spring also provide sand materials for large sand-dust storms. Hence, emphases in desertification control and sustainable development should be placed on natural vegetation protection, sound land-use management, setup of vegetation shelterbelts along rivers, roads and irrigated channels, and windbreaks and sand control vegetation belts near deserts.

(ii) Steppe circle

The transitional circle is located at the temperate steppe belt in northern China, which includes five of six grassland provinces in China undergoing conversion to sandlands. Grasslands in Inner Mongolia, Xinjiang, Qinghai and Gansu account for 94% of grasslands in drylands, in which 70–80% of the area is degraded. Conversion of grassland to sandland is a major type of grassland degradation, which provides dust material for large sand-dust storms. Therefore, pen-raised livestock and artificial grassland development will be helpful in restoring natural grasslands and reducing expansion of deserts.

(iii) Agropastoral transitional circle

The inner circle is the agropastoral transitional area, or forest-steppe transitional belt. The modern agropastoral transitional area is located at both sides of the northeast-southwest diagonal in China. Annual precipitation is about 400–450 mm. Ecosystems here are unstable due to their transitional features. In addition, they are under dual pressure from natural forces and human activities. Ecosystem processes are dominated by positive feedback mechanisms involved in desertification. Hence, ecosystem instability and fragility are increasing, and conversion to sandland is becoming serious. For instance, in the hilly mountains of Duolun and Zhangbei counties, Hebei Province, continuous drought, over-reclamation, overgrazing and excessive fuelwood collection result in deteriorating environmental conditions. Large, black sand-dust storms are formed as thick, black, wind-blown soil is loosened by over-cultivation and overgrazing of the meadow steppe in the Hulun Buir Steppe. Hence, raising pen-fed livestock with artificial grassland should be advocated, and transforming farmland into forest and grassland (Grain for Green) should be implemented to increase surface cover to combat desertification and improve the quality of people's lives.

10.1.2.2 Small three-circle paradigm

The small three-circle paradigm is a local eco-production paradigm to combat desertification and enhance agricultural development. It is also a basic element of the large three-circle paradigm. Ecological restoration and combating desertification within one geographical unit, one small watershed or one oasis can be accomplished with the small three-circle paradigm. The following are two examples of small three-circle paradigm in Beijing and the Ordos Plateau.

(i) Small three-circle paradigm in Beijing

The Beijing region is a forest-steppe bioclimatic zone with an annual average precipitation of about 500–600 mm. Due to drought and extensive human activities, conversion of soil to sand is a serious problem. In spring, a large amount of sand-dust is transported to Beijing from northwestern China and Mongolia with the Mongolian-Siberia anticyclone. Muddy rains or sand-dust storms are formed in Beijing, which negatively influence Beijing's environment. Hence, sand control projects in and around Beijing have been initiated, and a small three-circle paradigm was accordingly submitted to assist in this project.

The sand control system in Beijing consists of three ecological circles. The first circle for water conservation and soil erosion control covers the hilly and mountainous areas of Yanshan Mountain. The second circle for windbreaks and stabilizing sand covers the piedmont fluvial plain. The third circle for urban greening covers transition areas between suburbs and downtown Beijing.

Outer circle: water conservation and soil erosion control

The Yanshan Mountain in north Beijing and Taihang Mountain in west Beijing are important regions for water conservation. Water in the branches of the upper reaches of the Haihe River and Guanting and Miyun Reservoirs originates from these mountainous regions. Vegetation in these mountainous regions formerly consisted of coniferous forests, such as *Picea koraiensis* and *Larix gmelinii* in higher mountainous zones (>800 m a.s.l), and deciduous-broadleaf forests, such as pine-oak mixed stand or *Quercus liaotungensis* in lower mountainous zones. These stands have been replaced by secondary shrubs or bushes dominated by *Ziziphus acidojujuba*, *Lespedeza bicolor* or *Vitex negundo*. Biodiversity has declined, and soil erosion is severe. Therefore, the following measures should be taken. ① Regenerate highly-efficient water conservation forests by enclosing vegetation and revegetating with coniferous trees, oak-dominated broadleaf-deciduous forest or coniferous-oak mixed forest in the middle mountains. ② Convert cultivated land into forest or grasslands in lower mountains. Fruit tree belts including *Diospyros kaki*, *Ziziphus jujuba*, *Castanea mollissiwa* (chestnuts), *Pyrus* spp. (pears) and *Prunus* spp. (apricots) are planted on gentle-sloping terraces. Landscape or timber forests consisting of *Ginkgo biloba*, *Acer* spp., *Fraxinus velutina*, *Magnolia denudata*, *Quercus liaotungensis*, *Quercus dentata*, *Gleditsia sinensis*, *Koelreuteria paniculata*,*Pistacia chinensis*, *Pinus bungeana*, *Pinus armandi*, *Platycladus orientalis* and *Sabina chinensis* can sometimes be planted. Shrub belts of *Caragana* spp. can be planted on south slopes for soil and water conservation, and shade-tolerant leguminous grasses can be intercropped with fruit trees for soil and water conservation and to increase soil fertility.

Transitional circle: windbreaks and sand stabilization

This transitional circle lies in the suburban counties of Beijing and is the alluvial plain of the Haihe River and its tributaries and the main agricultural cultivation area in Beijing. Due to long-term agricultural cultivation, natural vegetation has almost complete disappeared. The soil surface is bare in winter and spring. Strong airflow in early spring results in severe wind erosion. This is especially true along dry river courses and alluvial plains. Conversion to sandland is serious, and areas with low productivity are becoming the main source of locally blown sand in Beijing.

This region is managed to control wind erosion. Windbreaks and a combination of trees, shrubs and grasses should be setup to form an artificial savanna-like landscape. Following the implementation of the project to transform farmland into forestland or grassland, this circle will be planted with forests (protection, timber and landscape forests), gardens (orchards, vineyards, seedling nurseries and flower gardens), grasslands (artificial or natural) and farmlands (cropland, melon field, herb nursery and forage land). The ratio of these four land-use types is about 3:3:2:2. Grasslands consist of two categories. Artificial grasslands include legumes and graminoids, which can be used as a base for pen-raised animal husbandry (cow, beef cattle and goat farms) in suburbs combined with artificial forage lands. Natural green grasslands function to beautify the landscape.

The aforementioned ratio of land uses is based mainly on local annual precipitation. In temperate climates, forest zones occur where annual precipitation is no less than 800 mm. Areas where annual precipitation is less than 800 mm cannot be covered entirely by forests without supplemental water. A forest coefficient of 0.33 is the area coefficient assigned to forests from an economic viewpoint. In Beijing, annual precipitation is about 500 mm. The maximum forest cover rate (*MFC*, without irrigation or other supplementary water sources) is: $MFC=500/800=0.625$, which is multiplied by the forest area coefficient. The planned forest cover is: $PFC=0.625\times0.33=0.21$, or 21%.

Due to the large area of this circle in Beijing (about 60% of the total land area), this temperate savanna-like landscape pattern will be the dominant landscape in the paradigm.

Inner circle: urban greening

The inner circle is downtown Beijing. The greening circle consists of trees, grasses, water bodies and canals and also a core circle for city greening, beautification and purification. The scientific design in this circle is the prudent arrangement of buildings, roads and highways, squares, community gardens, parks, sidewalk trees, lawns, flower gardens, roof gardens, climbing plant covered walls and water bodies (channels, canals and lakes). An urban landscape system integrating protection, greening and aesthetics will be formed.

(ii) Small three-circle paradigm in the Ordos Plateau

i) Geomorphological features in the Ordos Plateau

The Ordos Plateau, located at 37°38′–40°52′ N and 106°27′–111°28′ E, is surrounded by the Yellow River on the north, west and east and abuts the Loess Plateau on the south (Shi, 1991). It has an elevation of 1,100–1,500 m above sea level, and the climate is arid and semi-arid, temperate and continental. Three terrains on the Ordos Plateau are distinguished as follows (Fig. 10.2).

Hard ridge: Purple, horizontal Cretaceous sandstone and grey-green Jurassic sandstone several thousand meters thick form the base and backbone of the Plateau. Called a hard ridge locally, the rock is usually covered by sandy gravel loam of different depths or a rock mass with a thin soil layer. The relative height of the ridge is generally 30–50 m. The northwestern part of the Plateau is 1,500–1,600 m in elevation, which gradually descends to 1,300 m in the southeast.

Soft ridge : In the lower part of the plateau, a gentle-inclined terrace is formed by the thick Quaternary and Tertiary fluvial or alluvial deposit layer and is usually deeply eroded and cut by surface runoff. It is called the soft ridge locally and forms the second terrace of the area.

Quaternary fluvial and lacustrine deposit plain: The plain is the alluvium of the interior drainage, which interchanges with the ridge. The alluvium in the plain consists of fine sand, silt and bog deposits. The plain is flat and broad but is usually characterized by poor drainage capacity and various degrees of salinity.

The largest surface characteristics on the Plateau, occupying three-fourths of the total area, are sand dunes and sand flats that widely cover the various ridges, flats and even fluvial terraces. The sand originates from local fluvial and lacustrine deposits, weathering products of sandstone and the sand interlayer in loess deposits. The main geomorphological types of sand are moving sand dunes, semi-fixed sand dunes, fixed sand dunes and undulating sand flats. Large moving crescent dunes can be up to 10–30 m high. Semi-fixed and fixed sand dunes, which are usually lower than 10 m, are covered by sagebrush (*Artemisia ordosica*) and are referred to as "Bala" locally. Owing to long-term overgrazing, cutting and cultivation, the historic vegetation on the sand dunes is almost extinct. Fig. 10.2 gives a detailed illustration of a vegetation transect and its associated topography, parent rocks, materials and typical soils on the Ordos Plateau.

ii) Ecological principles for paradigm establishment and revegetation

According to research results and requirements for local economic development, the following ecological principles should be matched or considered during paradigm establishment and revegetation (Zhang, 1994).

First, water and bioclimatic conditions are key

Water is the major limiting factor for plant growth in arid and semi-arid areas. Moisture and heat conditions vary greatly among different bioclimatic zones. The three-circle, eco-production paradigm should be designed for each bioclimatic zone. First, the region is classified into site types. Second, each type is designed following the criteria of the three-circle, eco-production paradigm. Third, suitable, high-quality plant species are selected. Fourth, soil for afforestation or grass-sowing is prepared.

Second, selection of shrubs as dominant species to enrich local biodiversity

Selection of suitable, high-quality plant species is necessary for successful ecological functioning. Dominant plant life in arid and semi-arid areas consists of sand- and drought-tolerant shrubs due to diverse geomorphological conditions, high sand content and low soil moisture. Shrubs are characterized by multi-branching, lignified stems and small, dense crowns, which are adapted to strong, blown sand areas and easily form sparse green spots on the surface of barren sandland. The root system of shrubs is more horizontally or vertically distributed and the ratio of roots to stems is higher than those of trees. Hence, shrubs are better able to stabilize the sand layer and take up more water than trees in rocky habitat. In addition, the root system of shrubs can grow into rock cracks to reach deeper soil water and form a dense shrub community. Some shrub species are also good for forage. Leguminous shrubs are especially good because they have symbiotic rhizobium, which allow them to grow well in poor soil and increase soil fertility. Therefore, shrub species play a significant role in regulating environmental factors and soil moisture,

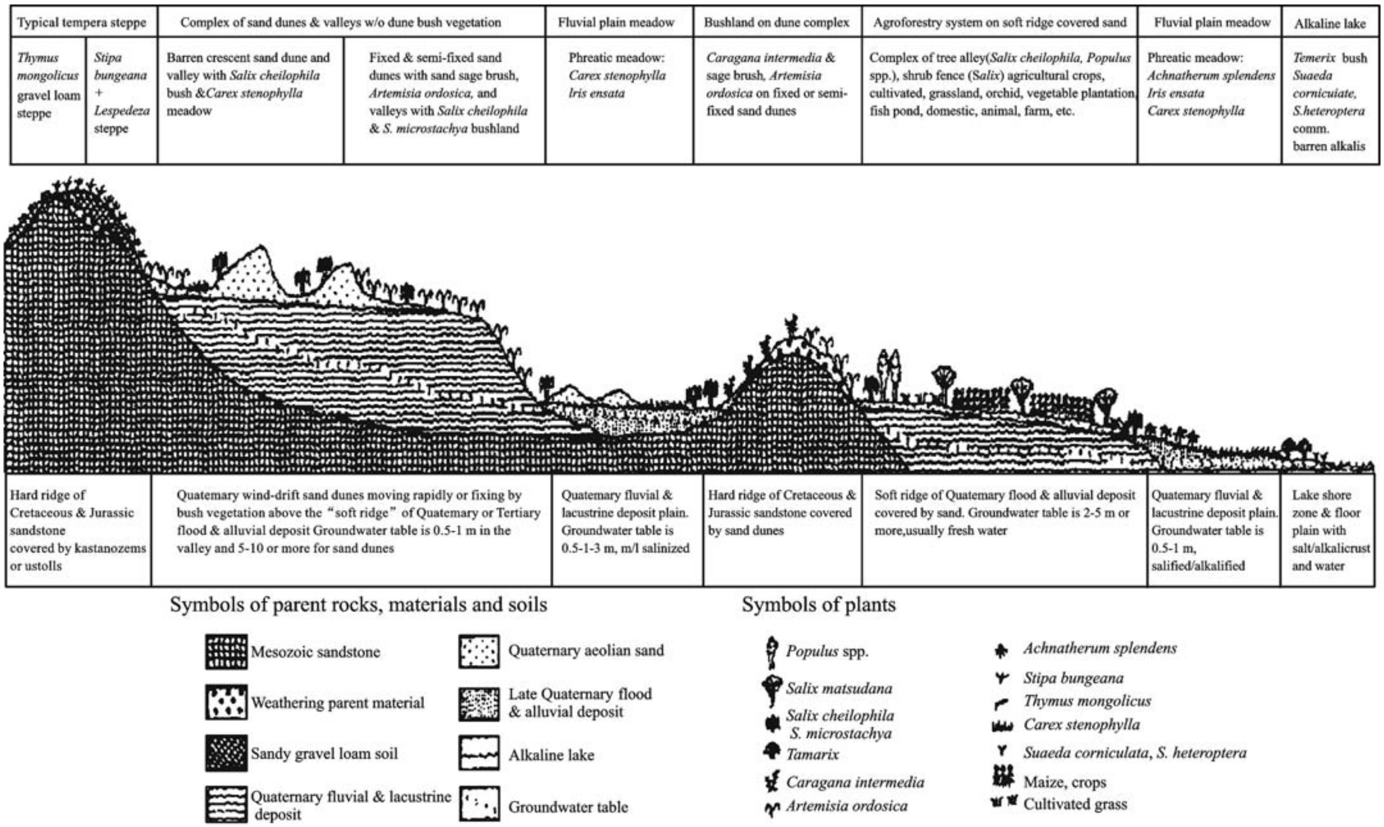

Fig. 10.2 Schematic transect of vegetation and associated topography, parent rocks, materials and typical soils on Ordos Plateau (Ci, 1997, with permission from author)

interactions among wind, water and sand materials, relative equilibrium of plant communities and balances between livestock and forage.

The role of shrubs in three-circle paradigm establishment should be better understood. In addition, Poplar species planted in northern China should be carefully selected.

Third, scientific arrangement of various protection forest systems

A protection forest system is an important component of the three-circle paradigm. Research shows that protection of forested systems in arid and semi-arid areas must have the following features: ① a comprehensive and integrated system; ② a narrow shelterbelt and small network size is the main component of a protection forest system; ③ the shelterbelt has good spatial structure with a combination of trees, shrubs and grasses to better utilize light and water; ④ multiple species should be mixed to prevent disease and pest damage; and ⑤ a protection forest system should be matched to roads, rivers, irrigated systems, etc (Ci, 1980).

Fourth, semi-fixation principle for sandland management

Vegetation cover is low in sandy areas limited by water. When revegetating these regions without irrigation, the supply of groundwater and lateral runoff must be considered in advance. Therefore, to keep the water balance in the sand, vegetation cover in sandy areas should be no more than 25%, less than 30% and less than 40% in western, central and southeastern areas of the temperate steppe zone of China, respectively. In highly mobile sandy areas, non-biological measures should be used to enhance successful revegetation. Non-biological materials should be non-pollutant, non-toxic and have no harmful effects on the environment.

(iii) Structure of the small three-circle paradigm in the Ordos Plateau

The following optimized, eco-production paradigm framework, referred to as three-circles, was constructed based on the particular geomorphological features of the Ordos Plateau (Fig. 10.3).

Inner circle: Irrigated oases on plain deposits

The first circle is the efficient and integrated productive farming circle on floodlands characterized by thin sand cover (<30–40 cm) and medium depth to a water table (about 50 cm). This circle accounts for 10% of the total area. This is intensive, cost-effective farming with a high investment and includes: ① oasis agriculture, planted with maize, millet and sunflower; ② artificial forage plantation and natural grassland improvement, seeded with highly-palatable forage such as Sudan grass, smooth brome, triticale, *Leymus* spp., alfalfa, sweet sorghum, fodder maize and sugar beet. For small, degraded grass floodplains, seasonal or rotation grazing is applied for female or young livestock, and livestock can be excluded from heavily-salinizing *Achnatherum splendens* floodplains or heavily-alkalinizing *Iris pallasii* var. *chinensis* floodplains; ③ orchards, apples, grapes, almond trees and cherries are planted; ④ shelterbelts, a broad and highly-protective tree-shrub-grass belt is planted to protect the oasis. Small network shrub belts are planted around or within

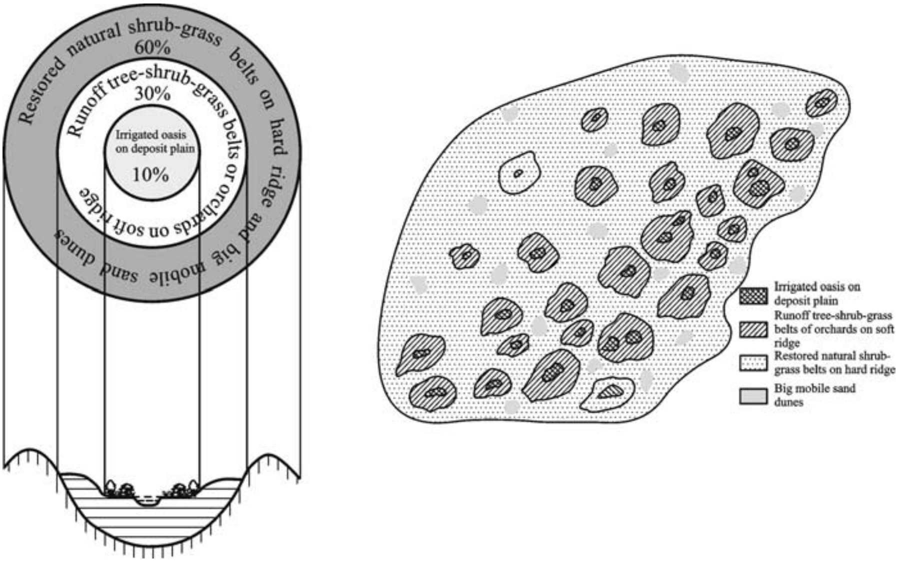

Fig. 10.3 The 3 circle eco-productive paradigm on Ordos Plateau (Zhang, 2000; Ci et al., 2007, with permission from authors)

cultivated land, rangeland and orchards; ⑤ emphasis on pen-raised livestock, fodder ensilage and animal processing is expanded; and ⑥ fishery and poultry farms are properly developed.

Transitional circle: Runoff tree-shrub-grass belts or orchards on soft ridges

The second circle is the runoff-harvesting, tree-shrub-grass circle on soft ridges, which accounts for 30% of the total area. Without irrigation, extensive agricultural development is impossible, but integrated protection and moderating exploitation are alternatives. In soft ridges and terraces with an even landform and deep soils, semi-artificial, rain-fed grassland is established by planting two to three rows of *Caragana intermedia* or *Salix psammophila* shrub belts and inter-rows of *Melilotus suaveolens*, *Medicago sativa*, and *Astragalus adsurgens* leguminous forbs. Banded shrub belts are planted in uneven or sloping positions. In some sloping ridges with good runoff-harvesting condition, small orchards or cash trees can be planted using run-on water. A degraded *Artemisia ordosica* community can be seasonally grazed with some ancillary improvement. Briefly, in this circle, the community or landscape vegetation cover should be determined in accordance with the water supply capacity.

Outer circle: Restored natural shrub-grass belts on hard ridges and large mobile sand dunes

The third circle, which accounts for 60% of the total area, is the shrub-grass shelter circle on hard ridges and moving sand dunes. It mainly serves as a windbreak and for stabilizing sand, for soil and water conservation, and as a water source for the other circles. In this circle, the *Stipa* spp. steppe, a main vegetation type on hard ridges, is degraded due to overgrazing. Hence, artificial shelterbelts can be established with shrubs such as *Caragana intermedia* and *Hippophae rhamnoides* in the relatively dry west and *Pinus sylvestris* var. *mongolica* in the humid east. Light rotation grazing can be implemented after restoration of the grass layer. On large, mobile sand dunes, some pioneer species, such as *Artemisia ordosica* and *Artemisia sphaerocephala*, are seeded to gradually stabilize the dunes. On sand dunes with high soil moisture, grasses and small shrubs can be planted on the lower part of the dunes' windward side. This will gradually level the dune and enhance conditions for either re-colonization by other species or active planting.

10.2 Mountain-basin paradigm in arid deserts

Mountain-basin systems are the most typical landscape in arid deserts of China. Here, we introduce a generalized mountain-basin paradigm in arid deserts and give an example named "Green Bridge System" from the north foot of Tianshan Mountain, Xinjiang.

10.2.1 Mountain-basin paradigm in arid deserts

In arid deserts of China, mountain-basin systems are formed from a series of geo-physiologically concentric circles, typically including a mountainous region, piedmont-tilted plain and basin region (Fig. 10.4).

Mountainous region: In the outer circle, the tectonically uplifted mountainous region consists of an alpine belt, forest/grassland belt and desert belt. The majority of the mountains greater than 3,000–4,000 m in altitude include glaciers and snow and ice covered mountain tops. More precipitation occurs in mountainous areas, which provides rich surface and ground water to the basin region. Alpine or subalpine forest is characterized by rich biodiversity, high stand productivity and strong water conservation. Alpine or subalpine meadow, mid-mountainous grassland and fewer steppe deserts have relatively high herbaceous cover.

Piedmont-tilted plain (alluvial fan): Piedmont-tilted alluvial fans are linked together in a skirt-like manner and constitute the transitional circle, the upper part of which is mostly Gobi or gravely desert characterized by a thin soil layer and deep water table that is difficult to utilize. The middle part is characterized by a thick soil layer and shallow water table, which can be used for irrigation. Some natural forests occur such as *Ulmus pumila* or *Populus euphratica*. The lower part is the fan edge belt, which has a very shallow water table (0.5–1.5 m) and heavy soil salinization. The area is covered with

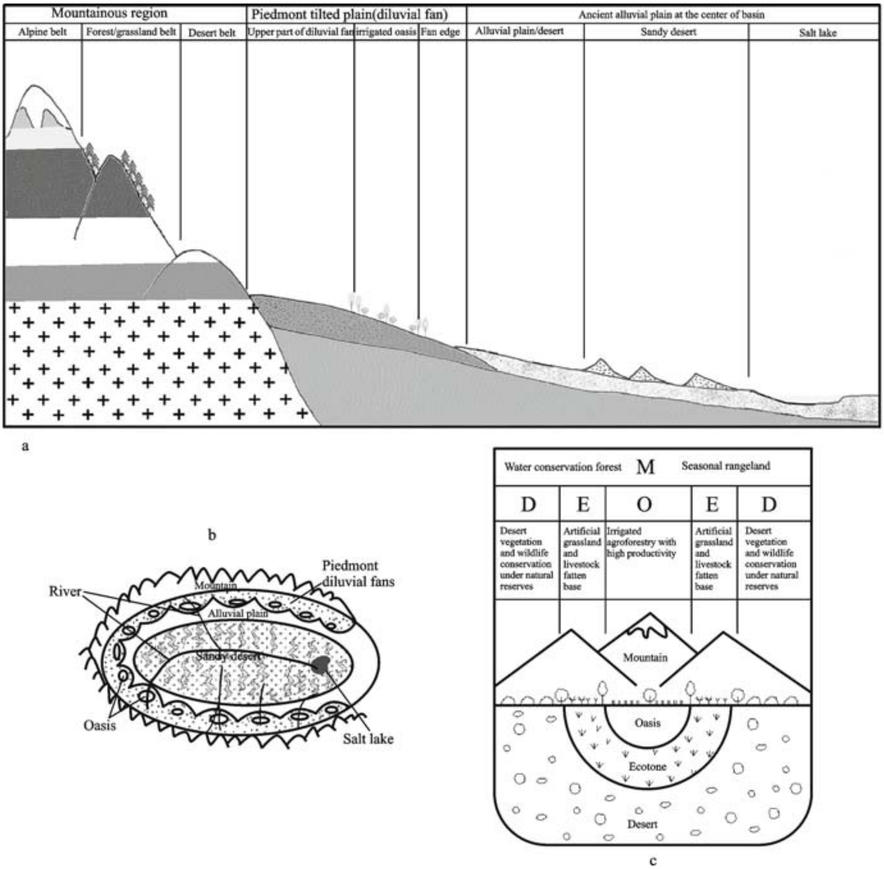

Fig. 10.4 Sketch map of geo-physiological features and mountain-basin paradigm in arid desert (Zhang, 2000; Zhang, 2001, with permission from authors)

salt-tolerant plants such as *Tamarix* spp., *Populus euphratica*, *Halimodendron halodendron*, *Achnatherum splendens*, *Karelinia caspica*, *Alhagi sparsifolia* and *Phragmites communis* or halophytes including *Halostachys caspica*, *Halocnemum strobilaceum*, *Kalidium foliatum* and *Suaeda physophora*.

Basin region: The majority of the basin is ancient alluvial-lacustrine plain with a large proportion of sandy-loamy desert covered with *Reaumuria soongarica* and *Calligonum mongolicum*. Sandy desert with sand dunes or sand dune chains is located at the center of the basin, and salt lakes, playas or salty deserts are scattered at lower elevations.

This mountain-basin system is driven by water. Water melting from glaciers or falling in the form of precipitation flows down into the basin as surface runoff and subsurface water flow. Surface runoff converges into rivers and is used for oasis irrigation. The subsurface water flow infiltrates deep into the soil in the upper part of the piedmont-tilted plain and then is close to or emerges above the ground surface at the fan edge, resulting in soil salinization and saturated conditions. Subsurface water also infiltrates deep into the soil layer in the alluvial plain and converges into low-elevation salt lakes. This sustainable mountain-oasis-ecotone-desert system (MOED) consists of four basic utilization belts based on water movement as follows (Zhang, 2001).

Mountain belt: An alpine sub-belt covered with ice or snow serves as the main source of water from precipitation and melting ice. The alpine-subalpine forest belt consists mainly of sparse forests, young forests and clear-cut forests resulting in deforestation. The ability of the alpine-subalpine forest belt to conserve water should be restored with long-term exclosure, while timber harvesting should be transferred to the basin. The mountain meadow (grassland) sub-belt can be grazed in summer and autumn, and the desert sub-belt can be grazed in winter and spring. However, most rangelands in these two sub-belts have become degraded from severe overgrazing. Sustainable livestock numbers and sensible rangeland management should be implemented, and animal husbandry should be transferred from the mountain to the basin. In addition, beautiful scenery in the arid mountain belt provides the opportunity to develop eco-tourism (Li and Han, 2001).

Oasis belts: The oasis has abundant solar and heat energy during the growing season. Hence, this belt has high productivity, and irrigated agro-forestry consists mainly of food crops, cash crops, forage crops, cash trees and fast-growing and high-production forests. These areas also serve as sites for breeding and reproduction industries and settlements and are the center of economic, cultural and communication development (Shen et al., 2001).

Oasis-desert ecotone belt: The diluvial fan edge belt where groundwater is close to or emerging above the soil surface is called an oasis-desert ecotone belt. It is not suitable for agricultural development because of severe soil salinization. This belt can be exploited as artificial grassland that can be up to 30 times more productive than natural grassland and can support 15 sheep units/ha. To support forage production from neighboring oases, it can be developed as a livestock fattening base that receives young livestock from mountain regions. The ecotone belt also protects the oasis from wind-blown sand and moderates the local climate (Xu, 1995; Zhang, 2001).

Desert belt: The desert belt should not be cultivated unless there are guaranteed water sources for irrigation, as well as a high-quality irrigation-drainage system. Grazing activities are also unsuitable in the desert belt. Here, grazing animals should be excluded to restore and conserve natural desert vegetation. Some wild desert ungulates, such as *Gazella subgutturosa*, *Saiga tatarica mongolica*, *Equus hemionus* var. *mongolica*, *Equus przewalskii* and *Camelus bactrianus*, and other wildlife, such as *Canis lupus*, can be reintroduced, and sound wildlife breeding and hunting practices can be developed (Zhang, 2001).

The four above-mentioned belts constitute an eco-economic chain of sustainable desert-oasis development, which guarantees a sound pattern of agricultural development. Sustainable development forms optimum transformation and flow of energy and material, prevents and reverses land degradation processes and will be a sustainable desert eco-production paradigm for a long time to come.

10.2.2 Green Bridge System — an example from the north foot of Tianshan Mountain, Xinjiang

The north foot of Tianshan Mountain is a key section of the new Asia-Europe land bridge. It is a political and cultural center as well as a developing economic center. The Xinjiang economic belt on the north foot of Tianshan Mountain has been listed as a priority development area. Ecological and environmental improvements as well as the sustainable social and economic development of this region have a direct bearing on Xinjiang's economic development and the smooth implementation of China's Great West Development Strategy.

The mountain and basin areas of the north foot of Tianshan Mountain are linked together by energy flow as well as exchanges of materials, values and cultures. This area has become the support system for the region's ecology and society, and it contains the most precious natural resources in the surrounding arid area. However, following a series of human disturbances such as drastic population increase, a poor agriculture and animal husbandry structure, poor land management, a degraded environment, water shortages, pesticide pollution, etc., the ecological status of the mountain-basin system has become fragile and degraded. Industry and agriculture production, and thus people's lives and means of subsistence, have been negatively impacted. Sustainable ecological, economic and social development has been seriously impeded. The former development method of simple oasis enlargement can only continue to destroy environmental conditions.

To counter these effects, a new system called the Green Bridge System was implemented in the northern part of Tianshan Mountains. This system is a new, optimized eco-production paradigm based on field studies and a series of seminars. Green Bridge refers to the new industry belt established on the fan edge belt and oases that serves as an artificial forage and timber forest base that builds an eco-economic bridge between mountainous regions and deserts. On one side of this bridge, 60% of the animal husbandry and 100% of the timber forests were transplanted from the mountainous region to the new industry belt. This was done to rehabilitate the mountainous forests and grasslands for water conservation and soil erosion control. In the Junggar Desert, located on the other side of this bridge, grazing activities and farming cultivation were prohibited, thus establishing a nature reserve to preserve the wildlife gene-base and encourage wild ungulate breeding(Fig. 10.5). Implementation of the Green Bridge System will play an important role in the ecological security of this mountain-basin system. It will also aid the economic belt development on the northern slope of Tianshan Mountain. The sustainable social, economic and environmental development of Xinjiang will help stabilize national border areas.

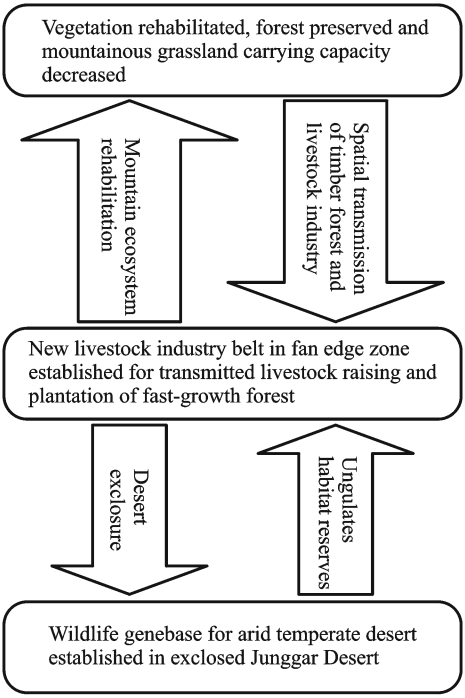

Fig. 10.5 Sketch map for Green Bridge System in Xinjiang

10.2.2.1 Modification of the oasis industry structure on the north foot of Tianshan Mountains

(i) Main existing problems

The north slope of Tianshan Mountains is characterized by large changes in altitude, complex landform, variable climate, multiple ecosystems, rich biodiversity and productive farming and animal husbandry. In the past, unsound agricultural policies and population pressures allowed large areas of grassland to be exploited for farmland. Plantation output value accounted for more than 75% of the total output value. Animal husbandry still follows the traditional nomadic grazing system. Seventy percent of livestock is grazed in the mountainous areas, and the rest are loosely grazed in the farmlands and desert. Forests in the plains were created to protect farmlands and played an auxiliary role in agriculture production. Special forest areas (fruit trees) and forage crops make up 16% and 4%, respectively, of the total land area. Cotton crops, the economic pillar industry in this region, cover large farming areas and have been seeded continuously for more than 8–10 years. This kind of simple planting structure results in a reduction in biodiversity, rampant disease and pests, weak resistance to market fluctuations and an unstable oasis ecosystem. These factors seriously cumber sustainable ecological, economic and social equilibrium and development in this region.

(ii) Thoughts and measures for modification

i) To establish multiple and complex planting structures in the oasis

Forage and forest (fruit tree) areas should be enlarged. The proportion of crops, forests (fruit trees) and grasslands in the oasis on the northern foot of Tianshan Mountains should be modified from 8:1.6:0.4 to 5:2:3. The total production output value of animal husbandry should occupy more than 60% of the total agricultural production output value.

ii) To construct forage bases in farming areas

Forage production is the material basis for modern animal husbandry and guarantees the transformation from a traditional grazing system to modern, industrial animal husbandry. Top-quality grasses and livestock corn feed should be planted in large farming areas. Simultaneously, cotton-grass rotation or an intercropping system should be implemented. Leguminous forbs, such as *Medicago sativa*, should be selected. These forbs will help control disease and pests, restore soil fertility, reduce the amount of pesticides and fertilizers needed and will also provide forage for livestock. Using forbs in combination with reusing crop straw, will basically meet livestock forage needs. Manure from livestock is returned to the farmland. This non-polluting treatment is an optimized production chain that enhances good farming practices.

iii) To develop unique fruits and cash crops

This area, characterized by rich sunshine and high variability between day and nighttime temperatures, has high plant photosynthesis and sugar accumulation and is famous for its melons and fruits. At present, the red industry, consisting of tomatoes, safflowers, wolfberries and carrots, forms the industrial base and is the predominant resource and production base for the region's famous and high-quality products, such as seed melons, grapes, watermelons, muskmelons, licorice and hops. This industry should be developed to capture a greater market share. Cotton agriculture, as the pillar industry in this region, should be modified to plant species that are in demand internationally and domestically. They should also develop specialty and top-quality cottons.

10.2.2.2 Rehabilitation of mountainous vegetation on the north slope of Tianshan Mountains

The mountains north of the Tianshan Mountains provide a source of water for the whole mountain-basin system. Melting water from alpine glaciers and accumulated snow and rainfall supply Xinjiang rivers and groundwater. The volume of water from annual mean precipitation for the region is 2.43×10^{11} m^3, of which 84% occurs in mountainous areas. The mountainous forest-grassland belt, located at the lower part of the large precipitation zone, plays a significant role in water conservation, hydrological regulation and soil erosion control. This belt also has rich biodiversity and high productivity and can be used for biological resource conservation and civilization.

(i) Ecological status of the mountain vegetation

In last 60 years, about 40×10^6 m^3 of timber have been harvested from the mountainous region, occupying one-fourth of the total forest volume in Xinjiang. This mountainous ecosystem has been seriously degraded. According to incomplete statistics, existing stands are mostly sparse, clear-cut or young forests because of high-intensity harvesting. The decrease of forest area has resulted in weather extremes, severe soil erosion, low water conservation and a high frequency of natural disasters. At present, the runoff ratio of the flooding period to low runoff is increasing. Some small rivers dry up in the low runoff period, sediment in the river increases, and correspondingly, erosion also increases. As one of the main mountainous forest areas in the region, the Tianshan Mountains face the same problems. Results of a remote sensing investigation in 2000 show that the grassland area in Xinjiang of about 4.8×10^5 km^2, is decreasing by 1.38×10^5 $ha\cdot a^{-1}$. Over 70% of the livestock products come from the natural grassland. Grasslands on the north slope of the Tianshan Mountains, which represent the largest mountainous grasslands in the region, have been degraded because of summer and autumn overgrazing in the recent decades. The area and productivity of winter and spring grasslands are very low and degraded. This obvious disequilibrium between summer and autumn grassland and winter and spring grassland leads to a loss of ecological function.

(ii) Measures of ecological conservation

The mountainous forest-grasslands and desert in the northern part of the Tianshan Mountains have been nomadic rangeland for several thousand years. These lands have been severely degraded, and existing livestock numbers exceed the land's carrying capacity. In the mountainous forest-grassland belt, if existing artificial young forest is well managed and protected, at the end of this century, near-mature forest (120–150 years) will be restored to its water conservation and soil erosion control capacity. A basic, slightly-selective cutting regime for enhancement of reforestation and stand health can be applied. Livestock numbers should be reduced and a sound grazing system implemented in mountain grassland and low-mountain desert areas. With 10–20 years of rehabilitation, grassland productivity, soil nutrients and soil and water conservation are expected to be gradually restored.

Hence, mountainous timber forest and grassland animal husbandry should be evenly distributed to rehabilitate overused mountain ecosystems and to restore ecological functions of the mountain and its water supply. The main function of the mountain in the future is oriented toward water conservation and summer and autumn rangeland with a reasonable amount of livestock.

To maintain the ecological services, the majority (60–70%) of animal husbandry in mountainous forest, meadow grassland and desert should be transferred to the oasis and fan edge belt. This will establish a new ecological industry belt for timber forestry and artificial grasslands and will also form an intensive ecological industry chain that will rehabilitate mountain and desert vegetation, solve the problems of timber and grassland shortage and improve the regional environment.

10.2.2.3 Establishment of a new industry belt on the oasis and fan edge belt of the northern slope of the Tianshan Mountains

(i) Existing problems

The majority of natural or artificial oases on the northern slope of the Tianshan Mountains, especially those used for traditional agriculture, are surrounded by deserts. The oasis agricultural system is characterized by a simple and unstable structure, single crop agriculture and low productivity with unwise irrigation and land reclamation. Large land areas with secondary soil salinization are formed on the oasis edge, which results in a salty desert. The fan edge belt lies on the lower edge of the diluvial fan. Because of clayey soil and groundwater near or above the ground surface, primary salinization is widespread. Natural vegetation is salinized meadow, shrubbery and halophytes in the salty desert and boggy herbaceous plants around spring outflow sites. The fan edge belt is normally unsuitable for cultivation due to soil salinization. Though millions of hectares of land have been reclaimed as farmland in recent decades, the majority of these lands have been abandoned because of secondary soil salinization. The primary and secondary soil salinization areas on the northern slope of the Tianshan Mountains account for approximately 16% of the entire region.

(ii) Establishment of pen-raised animal husbandry and related industry development

Xinjiang is one of the main animal husbandry areas in China. At present, animal husbandry in northern Xinjiang includes grazing in natural grassland and raising livestock in agricultural areas. Management rests on the primary stage, and an optimum industry chain has not yet been formed. Currently, livestock numbers are around 50 million. Production types and management ideas must be completely transformed from the traditional and extensive seasonal nomadic mode to intensive, cost-effect, pen-raised animal husbandry. A national livestock production base should be established based on artificial grassland. The animal husbandry industry should be developed as a key supporting industry for the economic development of northern Xinjiang (Fig. 10.6).

Development of the forage industry guarantees the strategic transfer of animal husbandry in mountainous areas and desert. Crop rotation and intercropping between cotton and leguminous plants, such as *Medicago sativa*, should be extended into the oasis to enhance herbivore animal husbandry. The fan edge belt is unsuitable for agriculture and forestry, but some salt-tolerant plants or halophytes such as *Populus euphratica*, *Alhagi pseudalhagi*,

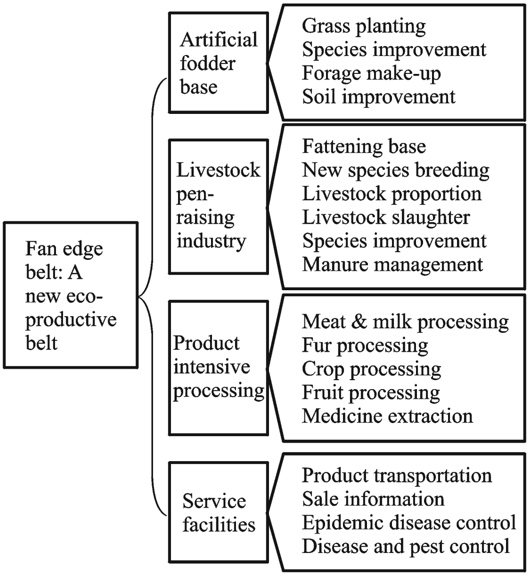

Fig. 10.6 Sketch map of industry belt on oasis and fan edge belt

Halocnemum strobilaceum, *Halostachys caspica*, *Achnatherum splendens* and *Melilotus suaveolens* can grow well. These plants can be planted as an artificial forage base and ecological barrier for oasis development.

It has been estimated that the area of fan edge belt on the northern slope of the Tianshan Mountains was about 1.08×10^6 ha, and the arable land area with channel water projects or water-saving irrigation projects was about 4.86×10^5 ha. At present, there are 1.14×10^6 ha of farmland from Urumqi to Jinghe on the northern foot of the Tianshan Mountains. Based on population analysis and the land resource carrying capacity, a single agricultural structure can be modified, i.e., 4.57×10^5 ha can be used for a grass-sowing base. It was estimated that $1–1.5 \times 10^6$ ha of artificial grassland can be established in the oases and fan edge belts of the northern slope of the Tianshan Mountains. It has also been measured that the yield of *Achnatherum splendens* planted in the abandoned land of the fan edge belt is up to $15–18 \times 10^3$ kg·ha^{-1} and that the yield of maize silage sown in an oasis is up to $12–15 \times 10^4$ kg·ha^{-1}. In addition to supplements from the agriculture ecosystem, it has been calculated that $0.6–0.7 \times 10^3$ kg fodder is needed for each sheep. Artificial grassland in a fan edge belt can support 22.5–27 sheep·ha^{-1}, and artificial grassland and fodder land in an oasis can support 45–180 sheep·ha^{-1}. Hence, the new ecological industry belt on the northern slope of the Tianshan Mountains can carry about 30 million sheep, or approximately 60% of the total livestock of Xinjiang or about 100% that of northern Xinjiang. The ratio of livestock between mountainous areas and deserts can be modified from 7:3 to 3:7. A highly productive, good-quality and cost-effective animal husbandry base can be established. Pen-raised and fattened animal husbandry, supported by an artificial grassland and fodder base, will become the supporting industry in this region.

(iii) Development of modern, pen-raised animal husbandry and integration of regional agriculture and animal husbandry

In mountainous areas, productivity for traditional nomadic animal husbandry is very low. The herder's lifestyle is difficult to change, and increasingly, overgrazing results in grassland degradation, especially in winter and spring grazing in low mountain areas. Hence, the only way to change local animal husbandry is with a strategic transfer from grazing in natural grassland to pen-raised livestock in an agricultural area. In other words, traditional nomadic animal husbandry in mountainous areas is transferred to modern, pen-raised animal husbandry in artificial grassland and fodder base oases. In the future, oasis agriculture should emphasize forage production and pen-raised animal husbandry, and grassland should be managed using agricultural methods. Forage production in agricultural land is advantageous not only to stabilize animal husbandry but to increase the overall health of the agricultural ecosystem.

Due to the shortage of winter and spring grazing land in pasture areas, a great deal of commercial livestock can be transferred to agricultural areas from pasture areas before winter and then sold after 3–4 months of fattening. This will alleviate grazing pressure on mountainous areas and deserts and will also restore grassland productivity and ecological functions. In addition, organic manure is provided for agricultural production the following spring. Establishing a new industry belt can replace ineffective, destructive grazing activities with artificial grassland that has higher ground cover and better ability to stabilize sand, control soil salinization and protect oases.

(iv) Prolonging the ecological industry chain and establishing a corresponding service system

During an increase of animal husbandry production, out-of-region sales for livestock products such as skin, feather, meat and milk, is an important production chain with many economic benefits. However, thorough processing of primary livestock should be developed locally to realize local profits. The animal husbandry production process has various products that can be produced locally, such as skin, feather, meat and milk. Viscera and blood can also used for biochemical products and medicinal materials. Local production will significantly increase animal husbandry profits by multiples of tens or hundreds. In addition, local institutions, such as good species breeding bases, livestock fattening bases, veterinarian stations, epidemic prevention stations, mechanical cultivation stations, disease and pest control and related service systems, should be further strengthened. Transportation, food processing, finance, information and consultation services should also be expanded.

10.2.2.4 Resource care for biodiversity in the Junggar Desert

(i) Ecological status

The desert in the Junggar Basin covers an area of 4.55×10^4 km^2. Because of unwise human activity and modern agricultural development, biological processes of the desert ecosystem in the Junggar Basin have been degraded. Effects include biodiversity loss, shrinking metapopulations, simplified food chains and trophic levels and fragile and unstable ecosystems. Habitat destruction has resulted in endangerment and extinction of many wild animal species.

(ii) Implications for biodiversity conservation

The Junggar Desert consists of a number ecosystems including typical natural and artificial desert vegetation, salt-desert vegetation, desert wetland (e.g., Manas Lake) and desert fresh and salt-water lakes (e.g., Ulungur Lake and Ebinur Lake). These ecosystems are the ecological barriers for oases and desert steppes in the northern part of the Tianshan Mountains. They are also the biological resource base for sustainable ecological and economic development in northern Xinjiang.

The Junggar Desert has the richest plant species resources of any temperate desert in the world. It is located at the joint and transitional belt between the Central Asian Desert Irano-Turanian flora and the North Asian Mongolian Gobi flora and also includes Tethyatc xerophytic flora. The desert vegetation includes the typical desert plant community and typical salt desert community, as well as abundant ephemeral plants. The Junggar Desert is also the distribution zone of precious medicinal plants such as *Cistanche deserticola*, *Ephedra sinica* and *Capparis spinosa* . An abundance of lichen species in the sand dunes on the southern edge of the Junggar Desert forms a 1–3 cm thick biotic crust that stabilizes mobile sand dunes.

The Junggar Desert is a natural rangeland for wild ungulates. Many large, wild, herbivorous ungulates, such as *Gazella subgutturosa*, *Saiga tatarica* var.*mongolica*, *Equus hemionus* var. *mongolica*, *Ovis ammon darwini*, *Equus przewalskii* and *Camelus bactrianus*, have adapted to the harsh environmental extremes of high summer temperatures, cold winters and a shortage of water. They can effectively utilize desert plants, and their feeding habits are adapted to plants that are high in fiber and salinity.

The Junggar Desert is also a precious wildlife gene bank in the arid temperate zone. Many special plant species and genotypes have evolved during natural selection and adaptation throughout the area's long-term geologic history. These include many that are drought-tolerant, tolerant of high-temperatures, resistant to low-temperatures, tolerant of radiation or have high photosynthetic efficiency or special secondary metabolic compounds (perfume oil, alkaloid). Internationally, wild plant gene resources in drylands is listed as the first focus of international biodiversity conservation and the most important resource for agriculture, food, medicine and industrial materials in the 21st century. Hence, the rich biological resources of the Junggar Desert may help determine the region's development potential.

(iii) Urgent need for establishing biodiversity conservation

Principles of biodiversity conservation in the Junggar Desert state that extensive desert grazing at the expense of the natural environment should be forbidden by local or national policies. Petroleum extraction should avoid disturbing or destroying the desert ecosystem as much as possible, and a seedbank or gene bank of desert plants should be established.

The former Soviet Union has propagated *Saiga tatarica mongolica* successfully in the Central Asian Desert, and the U.S. has restored America's bison which had gone extinct in the fields of the Great Plains. In recent years, a few institutions in China have successfully reintroduced *Equus przewalskii* and *Saiga tatarica mongolica*, which were bred and brought from overseas. Therefore, it is suggested that the Junggar Desert nature reserve should be established with a focus on biodiversity conservation. Wild animal breeding farms should be established and systematically designed in the Junggar Desert to breed wild ungulates that will be released to reestablish wild animal populations. Afterward, moderate ecotourism and range game land can be developed. The ecological security of the Junggar Desert will not only be advantageous to the sustainable social, economic and environmental development of the northern slope of the Tianshan Mountains and the surrounding Xinjiang area, but it is also important for biological resource conservation of temperate arid zones all over the world.

10.2.2.5 Artificial fast-growing and highly-productive forests

Timber needs in Xinjiang increase from year to year because of economic development and increases in standard of living. For example, the amount of timber needed in 2001 was 35×10^4 m^3. However, timber production was reduced to 8×10^4 m^{3}in 2001 from 28.2×10^4 m^{3}in 1997 due to implementation of a national natural forest conservation project. The rest of the needed timber, 27×10^4 m^3, was imported. Hence, planting artificial fast-growing and highly-productive forests in plains will alleviate pressure on the timber supply and will help to improve the environment of the oasis edge.

Planting artificial fast-growing, highly-productive forests in plains would provide economic benefits for agriculture, forestry, animal husbandry and their related industries. At present, the proportion of agriculture, forestry and animal husbandry in oasis agriculture is about 8:1.6:0.4. The proportion of forestry is relatively low. In Xinjiang, where timber is in short supply, timber prices and their indirect costs are equal to the cost of cotton or grass needed for raising livestock. Therefore, a part of the artificial fast-growing, highly-productive forest can be planted during the period of industry structure modification and reforestation of protective forests in the oasis. In addition, the loamy desert plain boasts rich land resources and high solar radiation, which has great potential for growing this kind of forests. By introducing fast-growing and high-quality timber species with intensive management, timber can be harvested in 6–7 years with a timber volume of 180–225 $m^3 \cdot ha^{-1}$. This timber can be used to produce high or medium density boards for a good profit. Accordingly, in sites with enough regional surface water and a partial groundwater supply, water needed for forestry irrigation is 9,000 $m^3 \cdot ha^{-1}$. Through many years of planting, 16,700–20,000 ha of fast-growing, high-quality forest can be planted in the oasis, fan edge zone and loamy desert areas of the Junggar Desert. 2,000 – 2,670 $ha \cdot a^{-1}$ could then be rotationally cut, and 36–50$\times 10^4$ m^3 of timber could be provided. In addition, the Ili Valley has abundant water and soil resources. More than 133,000 ha of fast-growing, high-quality forest could be planted, which would form the largest artificial timber forest base in Xinjiang. 20,000 ha of forest per year could be cut, which would provide 360$\times 10^4$ m^3 of timber and meet the paper pulp and timber needs in Xinjiang. Therefore, timber forests can be transferred from mountainous areas to plains.

10.2.2.6 Necessary strategies for implementing the Green Bridge System

- Traditional nomadic grazing activities in mountainous area must be changed to decrease livestock in mountainous areas by 60%. Animal husbandry must be transferred from the oasis to the fan edge belt to allow mountainous grasslands to recuperate and rehabilitate.
- Cost-effective artificial forage bases must be established in oases and fan edge belts to provide feeding sites for livestock that are usually grazed in mountainous grassland in the short-term. An organic system between mountainous grasslands and feeding sites in farming areas must be formed to enhance sustainable animal husbandry on the northern foot of the Tianshan Mountains.
- During the implementation of new productive belts and ecological conservation practices, advanced technology must be applied and increasingly extended. These technologies include crossbreeding, fine livestock raising, precise processing, and environmental protection, etc.
- The ratio of farmland to grassland to forest in a newly-built oasis should be 5:4:1, and the ratio in an old oasis should be modified to 5:3:2. This will ensure oasis stability as well as sustainable social and economic development.
- The Junggar Desert, as a whole, should be established as a nature reserve for a valuable gene base of natural vegetation and as a breeding base for wild desert ungulates.
- A series of ecological compensatory policies, similar to policies for transforming cultivated land to forest, should be enacted to transform cultivated land to grassland or grazing-free grassland for revegetation. Economic compensation or other preferential treatment should be provided for local minority herders. Preferential and encouraging policies should be enacted for enterprises which invest in the forage industry, pen-raised animal husbandry, thorough processing of animal husbandry products

and other service trades.

10.3 Other eco-production paradigms

In addition to two typical paradigms introduced above, two other paradigms, i.e. integrated animal husbandry paradigm in the Inner Mongolia Steppe and agropastoral regions and small watershed based paradigm on the Loess Plateau, have been established and will be introduced as follows.

10.3.1 Integrated animal husbandry paradigm in the Inner Mongolia Steppe and agropastoral transitional regions

The Inner Mongolia Steppe is located on a flat, undulating plateau characterized by two typical geomorphological units. The lower unit, with an elevation of 960–1,000 m, consists of first class and second class terraces and is covered with zone-typical steppe vegetation such as *Stipa grandis*, *Leymus chinensis* and forbs. The higher unit, with an elevation of 1,200–1,400 m, consists of first-class and second-class terraces and is a meadow steppe covered with *Stipa baicalensis* and xerophytic and mesic forbs. At the plateau level, incised river valleys form lower terraces, floodplains and wadis with good moisture condition, as well as a few large sand dunes or sand belts distributed on the plateau surface. The agropastoral transitional region is not a biogeological region. It is a land-use based transitional region along the eastern and southernmost edge of the Inner Mongolia Steppe and is one of the most serious desertification-affected regions due to excessive human activity. Considering the close interactive relationship between the Inner Mongolia Steppe and agropastoral transitional regions, we establish the two-in-one integrated eco-production paradigm as follows (Fig. 10.7).

In the Inner Mongolia Steppe, the basic development framework is designed as grazing rangeland, mowing grassland and artificial grassland. In the first and second terraces, enclosed rotation grazing rangeland should be established. In the third and fourth terraces, where the meadow steppe exists and grass cover is abundant, mowed natural grassland is suitable but limited by longer distances from water points. In the valley and floodplain where runoff water can be used, artificial grassland with high production capabilities can be developed. On sand dunes or sand belts, sand stabilization shelterbelt systems should be established with shrubs or trees, and some rain-fed forage plants can be planted within the shelterbelt system.

However, because of widespread rangeland degradation, small areas of artificial grassland development, high livestock numbers and frequent spring drought and winter snow disasters, an intra-regional disequilibrium has formed

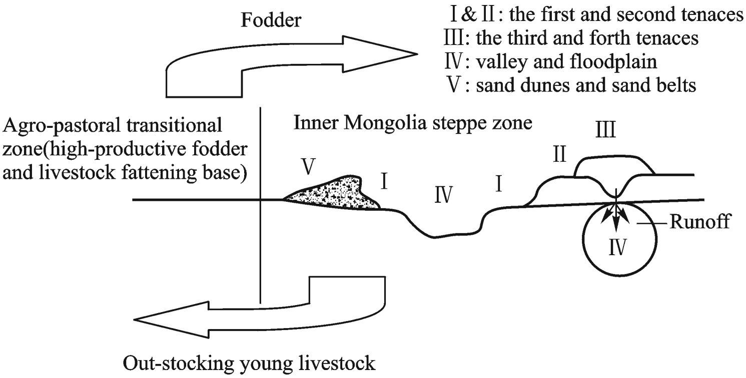

Fig. 10.7 Sketch map of Inner Mongolia Steppe and agro-pastoral transitional region (Yang et al., 2008, with permission from authors)

in the development framework, which is difficult to change. Therefore, the agropastoral transitional region is combined to form an integrated eco-production paradigm. With better physical conditions, high-producing, artificial forage bases can be established in the agropastoral transitional region. This forage can be transported to the steppe in the winter. A livestock feeding base can be established to receive young livestock from the steppes each autumn to fatten the livestock and increase profit. Only mother, newborn and breeding livestock are raised in the steppe during the winter. Thus, an integrated animal husbandry paradigm in the Inner Mongolia Steppe and agropastoral transitional region is formed as enclosed rotation grazing rangeland, mowed natural grassland, artificial grassland, high-productive forage and livestock feeding base (Fig. 10.7) (Zhang, 2000).

10.3.2 Small watershed-based paradigm on the Loess Plateau

The Loess Plateau covers 626,800 km^2, or 6.5% of the national territory, and is famous for its ancient civilization and severe soil erosion (Chen et al., 1988; Tang and Chen, 1990; Yang et al., 2005b). The climate is warm, temperate, and semi-arid with a mean annual precipitation of 350–700 mm. More than 70% of precipitation is distributed between the months of July and September. Deposited with aeolian soil from the periphery of the Gobi, deserts and other sandlands, the majority of this region is covered with deep, loose, loamy soil with relatively even soil textures that gradually become finer moving from north to south (Sun and Ding, 1998). Loess physiognomy, with an altitude of 800–1,800 m and evolving from aeolian processes in the Cenozoic and from severe water erosion associated with historical human activity, can be divided into two types. The first is the loess deposition type that primarily includes loess Yuans (a large flat surface with little or no erosion), ridges and hills characterized by ancient highlands formed from original deposit surfaces incised from gully erosion. The second is the loess erosion type that consists of various gullies. When water flows toward a gully bottom, soil erosion gradually increases. Gully erosion accounts for more than 80% of soil erosion in a watershed (Kang et al., 2003). Considering the arrangement of landscape elements, runoff and sediment redistribution, a small watershed-based paradigm is designed as follows(Fig. 10.8).

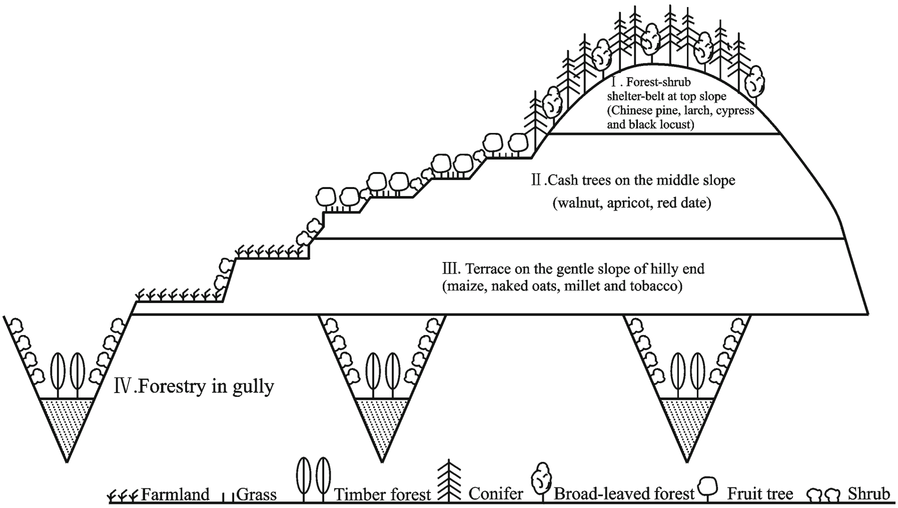

Fig. 10.8 Sketch map of small water-based paradigm on Loess Plateau (modified from Tang and Zhang, 2003, with permission from authors)

Tree-shrub-grass shelterbelt at the hilltop: This belt lies at the top and upper part of the loess ridges and hills. Combined with non-biological measures such as diversion ditches, this belt is established mainly as a soil and water conservation belt to stop headward gully erosion. Trees or shrubs should be planted with horizontal ditches, and grasses should be sown between the rows. The grasses and shrubs act together as livestock forage (Fu, 1989).

Cash tree belt with intercropped forage grass on the middle of the hill slope: Cash trees, especially dry fruit trees, can be planted at the middle of the hill slope. Tree density should be low, and water-harvesting techniques should be applied. Leguminous forbs, such as trefoil, can be sown on the micro-catchment area (Li et al., 2005; Yang et al., 2005a), and some shrub species, such as *Caragana intermedia*, can be planted at the brim of the runoff ditch.

Terraced farmland belt at the hill foot: On gentle slopes at the foot of the loess hill, terraces, which are traditionally used on the Loess Plateau (Lu and Stocking, 2000a), are built for rain-fed agriculture. Grain crops, cash crops or rotation grass-crops are planted on level or anti-slope terraces. On ridges of the terrace, one or two rows of shrubs can be planted to protect the terrace from floods or erosion from rainstorms.

Gully forestry: On gentle gully slopes, shrub belts are planted along contour lines as buffer zones and soil and water conservation zones. Silt-trapping dams are built at the bottom of the gully (Chang et al., 1996; Lu and Stocking, 2000b). Fast-growing, high-production timber, such as Poplar, is planted in sediment land formed by silt-trapping dams. Because of possible flooding, the newly-formed land is not suitable for agricultural development.

Drylands cover a large proportion of China's territory, and physical conditions in different regions are diverse and complex and are characterized by poverty and fragile physical conditions. For these reasons, economic and environmental development should be synchronously implemented. Hence, new dryland development paradigms are needed for sustainable regional development (Reynolds et al., 2007). We do not expect that the four above-mentioned eco-production paradigms include all possible types, but these paradigms cover the main biogeographical regions of China and provide theoretical frameworks and practical models for sustainable dryland development in China. These paradigms are helpful in making regional development plans and aid in government decision-making. At present, these paradigms have been applied in dryland development, which is partly or completely combined with national ecological projects. More detailed designs for specific regions based on these frameworks will be made in the future.

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