7 Steppe Degradation and Rehabilitation in Northern China

Zhongling Liu and Xinshi Zhang

Steppe is the natural grassland in temperate semi-arid areas of the northern Asia, with the potential for desertification. Although the desertification of the steppe is not as strong or rapid as earthquakes and floods, it has become the most extensive and serious ecological event. The main objectives and basic measure to combat the steppe desertification is developing a high-quality and high-yielding and eco-friendly intensive modernized husbandry to gradually supersede the traditional low productivity and eco-unfriendly backward mode of husbandry production that had characterized grazing practices in natural grassland for thousands of years.

7.1 Territorial distribution of steppe and natural geographic conditions

China's steppe is a part of the temperate grassland and the eastern half of the Eurasian steppe zone. The special geographical position of China's steppe decided it's significant position in ecological function and economy-cultural impact in East Asia and Northern China, but, also gave it a strong potential and trends of desertification; China's grassland might (actually) develop varying degrees of desertification, it is also available through reasonable conservation and ecological restoration for an effective front edge and barrier for combating desertification, conservation field for biodiversity, as well as the sustainable production base of grassland agriculture.

7.1.1 Evolution and territorial location of steppe in northern China

Steppes in northern China are found in the sub-humid zone, semi-arid zone and arid zone in a temperate climate zone that stretches for thousands of kilometers from east to west. Vast steppe areas occur in the semi-arid zone of the Inner Mongolian Plateau. As the largest area of steppe, they are linked to the steppe in the Republic of Mongolia to the north; join with the Nenjiang Plain grassland in western Heilongjiang Province and Jilin Province to the east; extend east to the steppes in northern Hebei Province, northern Shanxi Province, northern Shaanxi Province, eastern Ningxia Hui Autonomous Region and eastern Gansu Province in the south; and have the Helan Mountains as their western boundary.

The steppe in temperate zone in Northern China has experienced a long geological and environmental evolution. Since the Oligocene epoch of the Tertiary period, the once vast Tetisi Sea in western China has retreated and disappeared due to the Himalayan uplift. The continental dry warm-cold climate has gradually accelerated and the forest vegetation evolved and turned into sparsely forested grassland and steppe. Various angiosperm genera displayed good adaptability and, malleability during the plant evolution and gradually became the main components of the plant communities. In particular, *Stipa* spp., which first appeared during the Oligocene epoch and dissociated and developed in the later Tertiary period, becoming the dominant species in steppe evolution until the Pliocene Epoch and eventually forming various different *Stipa* spp. which dominate the steppes.

There are a total of 970,000 km^2 of steppe in Northern China representing more than 10% of the total land area of China. The north part of the steppe zone is the grazing area of the Mongolian ethnic minority, while the eastern and southern parts of the steppe zone are transitional areas of agriculture and animal husbandry. The population is made up of multi-ethnic minorities in these transitional areas. With the East Asia monsoon climate circulation system, steppes in Northern China are situated at the frontlines of the Siberia-Mongolia cold fronts and winter winds, and these steppes become source regions for blown sand disasters and harsh climate conditions, which move southeast toward Beijing and the coastal cities of China.

Before the 1960s, steppe vegetation was well conserved, delivering a range of ecological services such as providing a natural ecological protective belt in Northern China. During the 1970s, because of the rapid growth of livestock populations, inappropriately cultivated steppes and ruthlessly exploited plant resources, steppe vegetation and soils became degraded and damaged by shifting sands, and the ecological environment deteriorated. At present, these steppes are under the threat of severe desertification and the productivity of the agriculture and animal husbandry sectors is critically limited.

7.1.2 Geological and geomorphologic conditions in steppe areas

The geological structure of the steppe areas in Northern China is controlled by the Cathaysian structural system and parallel structures. The orientation is northeast–southwest with an arc-belt shaped distribution. Geologically, the steppe zone starts from the Helan Mountains in the west, links with the Yinshan Mountains and Da Xing'anling Mountains in the east and forms the peripheral mountains at the southeast of the Inner Mongolian Plateau. It is an important natural boundary line in Northern China and affects all the natural elements, including biogeographic distribution. The massive geomorphologic patterns, like plains, mountains and plateaus, in steppe areas run east-west or northeast-southwest and are distributed in belt shapes stripes that reflect the geotectonic forms of the underlying strata.

The vast Inner Mongolian Plateau lies to the north of the Da Xing'anling Mountains, the Yinshan Mountains and the Helan Mountains, which are linked and form an uplift belt. The elevation of the plateau is 700–1,400 m and its topography is gradually inclined and declined from south to north and from west to east. Geomorphologically, it generally alternates successively from peripheral mountains to full round low and gentle hills and uplands.

The Hulun Buir Plateau in the northeastern part of the Inner Mongolian Plateau consists of piedmont hills and uplands along the western foothills of the Da Xing'anling Mountains with an elevation of 700–900 m above sea level. There are vast sediment deposits of loess materials and moraines on the piedmont hills belts and is characterized by forest grassland landscapes. In the middle of the upland, zonal grassland vegetation is widely distributed. The sediments are composed of sand layers and sand-gravel layers of different thicknesses. Sparse forests, bush communities and semi-bush vegetation are well developed on parts of the sandlands. Both Hulun Lake and Buir Lake are low lying centers in the upland and there are some salinized lowlands surrounded by various types of meadows. Along both sides of several rivers, there are some areas of wider riverbank swamps, flood-land, bush communities and meadows.

From the Hulun Buir Plateau towards the south, the Inner Mongolian Plateau stretches across the east part of Mongolia into the Xilin Gol Plateau of Inner Mongolia and with an elevation varying from 900 m to 1,300 m above sea level. In the eastern area, mountains from the southern section of the Da Xing'anling Mountains close in with an arc-shape and in the southern area, low hills rise along base of the Yinshan Mountains. Some inland rivers and depressions are distributed in this vast region and these are covered by various meadows. The eastern half of the Xilin Gol Plateau extends from the center of Ulagai River and forms the Uzhumuqin Basin, of which the central part is the Abaga lava tableland, the western part is the Erlian Basin, and the southern part is the vast Otindag Sandland.

The western neighbor of the Xilin Gol Plateau is the Ulan Chabu Plateau.

Its elevation is 1,000–1,500 m above sea level, the south area consists of vast piedmont foothills in the north of Yinshan Mountains, and the northern part of the foothills are level and consist of caved belts at 1,300 m elevation. This is a transitional belt of agriculture and animal husbandry. In the north part of this caved belt, an east–west rocky hill uplift belt, with an elevation of 1,500–1,600 m, has been severely denuded. Northward, it enters into an upland area where the landform is flat and elevation varies from 1,000 m to 1,200 m. The surface materials are mainly composed of Tertiary mudstones and sandstones, which are the natural landscape of the desert steppe. There are some areas of dried river courses and lake depressions on the upland terraces which originated from the Yinshan Mountains, and have developed into a salinized meadow habitat.

The Ordos Plateau is an ancient terrace with an elevation of 1,100–1,500 m. The bedrock is composed of loose Mesozoic sandstone which has formed various landform patterns due to the denudation and sedimentation in the Quaternary period. The middle part of the Ordos Plateau is seriously denuded and there are some denuded residual hills, gullies and lake depressions on the upland with significant carved topography. The western part of the Ordos Plateau is a piedmont alluvial plain of the Zhuozi Mountains and the eastern part is carved and broken loess hills eroded by flood waters that have exposed bedrock areas. The southern part is the Mu Us Sandland which is covered by aeolian sands from the Quaternary period and the northern part is the Qubqi Desert, which stretches from east to west. Accordingly, there is a wide distribution of psammophytes and semi-bushes which are adaptable to topsoil erosion and sedimentation on the Ordos Plateau.

The Loess Plateau area in northern Hebei, northern Shanxi, northern Shaanxi, eastern Ningxia and eastern Gansu provinces are Quaternary aeolian landform patterns and they consist of various geomorphological units of tablelands, ridge lands, terraces and mesa. Natural steppes have almost disappeared due to long term agricultural cultivation and as a consequence, serious soil erosion has occurred and this area has become an originating source of sediments to the Yellow River. At present, these regions are defined as the core region for implementing the national project of “rejecting crop farming for reforesting and revegetating degraded lands” (the Grain for Green Project). This national project will, in the context of ecological safeguards, form an integrated management area of natural and developed landscapes composed of agriculture, animal husbandry, forest plantations, plant breeding and processing industries.

7.1.3 Climate conditions of the steppe areas

Steppes in Northern China are situated inland or adjacent to inland regions at medium latitudes, and are characterized by a temperate continental climate. The climate on all steppes is controlled by the Mongolian high pressure air currents in the winter season as cold fronts from the continental center frequently move to the coastal areas. The influence of the southeast ocean monsoon becomes gradually weaker from the southeast to northwest and the monsoon is unable to influence climate in steppe areas. This is because of the encirclement by the Changbai, Yanshan, Taihang and Luliang Mountains, and inside the steppe areas, and because of the impediments formed by the Da Xing'anling and Yinshan Mountain ranges. The climate in the vast areas in the western part of the Helan Mountains is under the control of the continental air mass. Under the effects of ocean and continental distributions and topographic structure, the climate elements in the steppe areas in the arc-shaped belt that runs from northeast-southwest are determined by characteristics of atmospheric circulation.

The temperature in the steppe areas reduces gradually from northeast to southwest and both the southern periphery and the western region of the steppe have an annual accumulated temperature of greater than 3,200−3,300 °C. The zonal difference in temperature affects significantly the botanical composition of plant communities.

Long sunshine hours are also an important feature of the climate in steppe areas. The annual accumulated sunshine hours are 2,500–3,400 hours in various regions and the sunshine percentage is around 55–78%. The steppe area is one of the regions with the richest sunshine hours in China. This is particularly important in the areas with low temperature and a short frost-free period in Northern China. High levels of sunshine are a favorable condition for plant growth and agricultural production.

The geographic distribution of precipitation is determined by the effect of the southeast air currents. Due to the blocking effect of the high mountains, precipitation in the eastern part of the Da Xing'anling Mountains, and in the southern part of the Yinshan Mountains is higher than that of the Inner Mongolian Plateau. Precipitation declines gradually moving further inland. In the northern area and along the eastern foothills of the Da Xing'anling Mountains, the annual precipitation is 400–450 mm; along the Xiliao River valley, in the piedmont plain areas and hilly areas of the southern foothills of the Yinshan Mountains and in the east part of the Ordos Plateau, annual precipitation is as high as 350 mm. However, on the Hulun Buir and Xilin Gol Plateaus in the western part of the Da Xing'anling Mountains and the central part of the Ordos Plateau, the annual precipitation is about 300 mm. Annual precipitation declines in a westerly direction and varies from 200 mm to 250 mm. In the eastern Alxa Plateau in far west Inner Mongolia, the annual precipitation is less than 200 mm. Atmospheric precipitation, in this vast region, is the fundamental water source for plant growth and biological existence and almost all water supplies originate from atmospheric precipitation. The amount of precipitation is the important driver in this vast region.

The seasonal distribution of precipitation is also an important ecological element. The precipitation in the steppe areas is mostly distributed in the summer and autumn seasons, namely July, August and September and the precipitation during these seasons accounts 80–90% of the total annual precipitation. The daily mean temperature during the period with a daily maximum more than 10 °C is around 20 °C. This temperature is favorable for the growth of plants. However, in the spring season, frequent droughts are unfavorable for the re-greening of steppe.

The annual evaporation rate in steppe areas is typically three to five times the annual precipitation rate, but can be eightfold in some areas and in even as high as fifteen to twenty times in desert regions. The annual evaporation in different regions increases from the east to the west along with a decline in humidity, reduction in cloud cover and increase in sunshine. Beside the Da Xing'anling Mountains, the average evaporation varies from 1,200 to 3,000 mm while in some western regions, it can be as high as 4,600 $\mathrm{mm \cdot a^{-1}}$.

Frequent wind is another important feature of the steppe climate. Under the control of the Mongolian high pressure systems in the winter and spring seasons, strong winds blow frequently in steppe areas. The prevailing wind in the winter season is from the north-west and the most frequent winds in the summer season are from south and southeast. In most regions, the mean annual wind speed is 3–4 $\mathrm{m \cdot s^{-1}}$. In arid and semi-arid regions, wind force is always an important driving force in the creation of the natural landscape. The occurrence of deserts, sandlands and loess landforms are all closely related to the effects of the wind. The geomorphological structure in various deserts in the steppe regions is consistent with the dominant wind direction. Loess hills are often subject to long periods of wind denudation and accumulation, and the ground surface is unstable. Consequently, there is some redistribution of plant communities on sandland and eroded lands in steppe areas. Strong windstorms are one of serious natural disasters destroying the steppe landscape, threatening agriculture and animal husbandry production and worsening the habitats in the affected regions. In recent years, due to steppe degradation, sand encroachment and acceleration of land surface erosion, sand-dust storm weather often occurs in the steppe areas and also affects Beijing and adjacent regions and other districts in north China.

Climate elements cause variations in steppe types, steppe landscape structure and the material and energy conditions of steppe productivity. The temporal and spatial differences of temperature and humidity create different combinations of water and heat which are the leading factors affecting various biogeographic features of steppe. The differentiation of steppe landscape belts coincides with the distributions of climate belts. Table 7.1 shows climate elements in different districts of steppes in Northern China.

Table 7.1 Climate elements values in different districts of steppes in Northern China

Steppes	Temperature (°C)				Precipitation (mm)			H	GP(day)
	MAT	AT	HMMT	CMMT	MAP	MAM	MIM		
I	2.5–4.4	2,150–2,665	20.5–23.2	–17.2– –19.8	417–458	141–152	0.6–1.7	0.53–0.70	172–188
II	–2.8– –3.4	1,622–1,886	17.5–19.6	–27.8– –29.5	356–425	118–130	2.0–3.8	0.61–0.74	150–164
III	5.8–6.4	2,844–3,108	23.7–24.8	–13.8– –15.4	448–514	147–168	0.4–1.4	0.60–0.78	185–205
IV	–2.2–4.7	1,888–2,485	17.8–21.3	–17.8– –27.7	258–406	66–114	0.8–3.1	0.28–0.54	160–175
V	0.6–3.8	1,894–2,320	18.2–24.0	–13.9– –19.3	378–411	109–149	0.6–2.1	0.30–0.82	166–180
VI	5.2–6.0	2,665–3,022	19.8–24.8	–12.7– –16.1	352–424	98–137	0.7–1.7	0.34–0.49	188–210
VII	2.8–5.1	2,086–2,590	19.2–22.7	–15.4– –18.6	148–262	41–77	0.2–1.1	0.12–0.26	180–205
VIII	6.5–7.6	3,046–3,312	22.4–25.5	–10.6– –13.2	418–528	132–164	0.8–2.8	0.48–0.56	195–220
IX	4.8–7.5	2,658–3,266	21.2–23.8	–11.3– –15.1	344–446	90–145	0.5–2.5	0.31–0.47	205–228
X	6.6–7.9	2,653–3,257	22.2–24.5	–10.2– –13.6	246–315	68–102	0.3–1.2	0.19–0.25	205–232

I: Meadow grassland in the Nenjiang River valley; II: Meadow grassland in the west Xing'anling Mountains; III: Meadow grassland on the Liaohe River Plain; IV: Typical steppe on the Inner Mongolian Plateau; V: Typical steppe in the south Xing'anling Mountains; VI: Steppe of Horqin Sandland; VII: Sunite Desert steppe; VIII: Forest grassland on the Loess Plateau; IX: Typical steppe on the Loess Plateau; X: Desert steppe on the Loess Plateau; MAT: Mean annual temperature; AT: Accumulated temperature ≥ 10 °C; HMMT: Hottest month mean temperature; CMMT: Coldest month mean temperature; MAP: Mean annual precipitation; MAM: Maximum month; MIM: Minimum month; H: Humidity; GP: Growth period

7.1.4 Hydrological conditions of the steppe areas

The distribution of surface water systems is determined by geomorphological structure and atmospheric precipitation. Inside the steppe areas in Northern China, the mid-eastern part of the Hulun Buir Plateau, the eastern side of the Da Xing'anling Mountains and the southern part of the Yinshan Mountains are the outflow water systems, including the Ergun, Nenjiang, Xiliao and Yellow Rivers. The headwaters are sufficient and the river networks are densely developed. Along the banks of these rivers, wide river beaches or alluvial plains were formed and these are adaptable to the growth of meadows, swamp plants, riparian woodlands and other riverbank plant communities and halophytic vegetation. Most parts of the Inner Mongolian Plateau have inland rivers with few streams and rivers and low water discharge. The few permanent rivers are the Kelulun, Ulagai and Xilin rivers. The bends of these rivers are well developed and river beaches and riverbeds are colonized by meadows, salinized meadows and halophilous vegetation.

There are vast numbers of different sized lakes on the Inner Mongolian Plateau. However, because of arid climate and strong evaporation, most of the lakes are highly mineralized saline lakes. Fresh water lakes with low mineralization are mostly located in the eastern and middle parts of the Inner Mongolian Plateau, and include the Hulun Lake, Buir Lake, Dali Nur and Uliangsu Nor, which have large areas of water. Low wetlands and salinized lowlands are distributed around these lakes and nors and are dominated by intra-zonal vegetation types.

The distribution of groundwater varies significantly in response to the variation of stratum and regional climate. The regions with sufficient groundwater are mostly located in semi-closed basins, such as the Tumote Plain, the Xiliao River plain, the Uzhumuqin Basin, the Mu Us Sandland, the Otindag Sandland, the Horqin Sandland, and the Wuerson Lowland in the Hulun Buir Plateau. These regions are rich in shallow aquifers with low mineralization and have a large distribution of intra-zonal vegetation. In upland areas, due to the complex geological structure, aquifers are unstable and there is substantial regional variation in groundwater in terms of distribution, quality and accessibility. In general, these regions are short of groundwater. Other than lake basins and areas adjacent to river courses, the groundwater table is normally less than 30–50 m and there is a wide distribution of zonal plants which are indirectly impacted by groundwater, especially riverine forests like *Populus euphratica*.

7.1.5 Soil conditions of the steppe areas

The zonal soils formed under the bioclimatic conditions in steppe areas are complex types, mainly composed of black soil, black calcium soil, chestnut soil, brown calcium soil, gray-brown desert soil, drab soil, black loam soil, and grey calcium soil. In addition, under special conditions which exist in some regions, such as low wetlands with a high groundwater table, and some sandlands and gravel slopes, there are some areas of meadow soil, swamp soil, saline soil and low-fertility sandy loam and gravels. The soil belt, which typically coincides with the bioclimatic belt of steppe described above, mainly comprises a zonal soil type with some non-zonal soil types.

Black soil is mainly located on the piedmont plain areas on the eastern foothills of the northern Da Xing'anling Mountains and is combined with other types of soils to form the black soil belt. By analyzing the differences in black soil profiles, it can be classified into three sub-types as deep-thick black soil, normal black soil and meadow black soil.

Black calcium soil is largely distributed along both sides of the foothills of the Da Xing'anling Mountains in the form of a continuous but narrow belt of black calcium soil mainly found in the forest-grassland. The development of black calcium soil is closely related to meadow grassland vegetation under sub-humid climate conditions. *Stipa baicalensis* steppe, *Leymus chinensis* steppe and *Filifolium sibiricum* steppe are all commonly found on black calcium soil. Black calcium soil can be classified into sub-types of dark black calcium soil, normal black calcium soil, light black calcium soil, and meadow black calcium soil.

Chestnut soil is a typical steppe soil originated under semi-arid climate conditions, which coincides with the typical steppe belt to form a chestnut soil belt. This chestnut soil belt is widely distributed from the Hulun Buir Plateau and the Xiliao River valley in the east to the northern foothills of the Daqing Mountains and the Ordos Plateau in the west. As the climate aridization accelerated and the xerophilization of steppe vegetation increased, the chestnut soil formed different sub-types, including dark chestnut soil, normal chestnut soil and light chestnut soil. The depth, thickness, quantity and patterns of alluvial sediment layers vary depending on regional water and thermal conditions and soil parent materials. For instance, chestnut soils in the southeast foothills of the Da Xing'anling Mountains and the Ordos Plateau contain the highest calcium carbonate content and the thickest calcium sediment especially in topsoil layers. Different types of chestnut soil are all related to the steppe community.

Brown calcium soil is formed under the hottest and most arid steppe climate and is mainly found on the Inner Mongolian Plateau and the western part of the Ordos Plateau, which coincides with desert steppe to form the brown calcium soil belt. This belt is dominated by brown calcium soil with patchy saline desert soil, salinized meadow soil, salt soil, sandy soil and alpine chestnut soil. The bioclimatic conditions forming brown calcium soil are characterized by transitional features of steppe and desert and are the result of soil forming factors from both steppe and desert. These processes include humus accumulation and calcium carbonate sedimentation balanced by occurrences of rough gravel, sand shifting and crust formation. The sub-types of the brown calcium soil are dark brown calcium soil, light brown calcium soil and meadow brown calcium soil. Vegetation in this brown calcium soil belt is mainly composed of a *Stipa* spp. dominant desert steppe community and *Caragana tibetica* and *Reaumuria soongarica* dominant steppe desert community. *Stipa tianschanica* var. *klemenzii* steppe covers the majority of the area. In addition, the *Stipa breviflora* community can be found on dark brown calcium soil, the *Stipa glareosa* community on sandy brown soil, and *Caragana tibetica* and *Reaumuria soongorica* communities on sandy gravel brown calcium soil are also found on the brown calcium soil.

The black loam soil is found in the southern regions in the warm-temperate steppe area and is normally developed on loess parent material. The Loess Plateau is the original source of the black loam soil. Due to special structural features of loess soil, it is highly erodible and as a result, a limited amount of black loam soil has been preserved following long term erosion after the destruction of surface vegetation. The natural vegetation growing on residual black loam soil is dominated by *Stipa bungeana*.

The grey calcium soil is distributed from the southwestern part of the Ordos Plateau to the loess hills of Ningxia and Gansu in the southern and western areas of the steppe. This soil type is formed in warm-temperate desert steppe of the Loess Plateau and its parent material is mainly loess. The grey calcium soil has sub-types of light grey calcium soil and meadow grey calcium soil. The vegetation that is adapted to the grey calcium soil is a desert steppe community dominated by *Stipa breviflora*.

The soils described above are zonal soils distributed on steppe belts and are characterized by pedogenic features of steppe soils, which play an important role in the provision of ecological services by the various steppes.

Meadow soil, swamp soil, saline soil and aeolian soil are all azonal soils from different parts of the steppe areas and they interact significantly with eco-geographic nature of the intra-zonal plants.

7.2 Steppe types, landscape ecological structure, and its regional characteristics

The typical plant community of steppe vegetation type or biome is dominated by the xeric grasses and mixed with a few xeric forbs. Steppe is in the position of the Earth's ecological zones between the mesic forest and super-xeric desert. Because of this, differentiation of steppe types and species composition structure is happening. There were very close relationship between the types and species composition of steppe with desertification.

7.2.1 Botanical composition of steppe and the differentiation of steppe types

The steppe is an ecosystem pattern (biome) that evolved and formed under the various climate conditions found in arid, semi-arid and sub-humid zones in the temperate climate regions of the inland. The plant community of the steppe is a primary producer in the steppe ecosystem. Therefore, the differences of steppe type are principally manifested in the nature of the steppe plant communities they support. All steppe plant communities are composed of low-temperature tolerant and drought tolerant perennial species. Since the Oligocene epoch of the Tertiary period, various plant species have been differentiated and these plants are mainly drought-resistant and adaptable to extremely arid and cold climates and different soil conditions. Many are xerophytes including bunch grass, chamaephytes including rhizome grasses and axial root grasses, and geophytes. There are also some chamaephytic dwarf semi-bushes and semi-bushes.

According to the living form of the main steppe plants, the steppes can be classified into patterns of herbosa associated steppe, rhizoma herbosa steppe, axial root herbosa steppe and dwarf semi-bush steppe . Based on the ecogeographic environment of the steppe, it can be classified into three types, i.e., meadow steppe developed in the sub-humid zone, typical steppe in the semi-arid zone, and desert steppe in the arid zone.

The following sections briefly describe the features of the main representative plant communities (formations) of the various types of steppes.

7.2.2 Main types of steppes

7.2.2.1 *Stipa baicalensis* steppe, one of the main types of temperate meadow steppe

Stipa baicalensis steppe is a peculiar aboriginal type in the eastern part of the Asian steppe. Its distribution is centered on the Songhuajiang-Liaohe River Plain in northeast China, in the eastern part of the Inner Mongolian Plateau, in the northeastern part of the Mongolian Steppe and the Baikal Steppe in eastern Siberia of Russia. This type of steppe is widely distributed along the foothills of the two sides of the Da Xing'anling Mountains. It is a herbosa community steppe type of meadow steppe.

Stipa baicalensis steppe is located in low temperature regions of the semi-arid and sub-humid zones where the annual precipitation is 350–450 mm and the rainfall in July is generally over 100 mm. Annually, there is a 1–2 month semi-dry period and there is no absolutely dry period. There are about 70 (maximum 140) snowy days per year. Annual mean temperature is –2.3 °C to 5 °C and the accumulated temperature $\geqslant 10$ °C varies from 1,500 to

2,700 °C. The growth period is 180–210 days and humidity is 0.4–0.7. The elevation is 700–1,700 m.

Stipa baicalensis formation can be classified into six association groups and eleven associations (Table 7.2).

Table 7.2 Classification of *Stipa baicalensis* association formation

Association classes	Association groups	Associations
Stipa baicalensis herbosa community	*Stipa baicalensis – Stipa grandis*	*Stipa baicalensis + Stipa grandis*
	Stipa baicalensis – Cleistogenes polyphylla	*Stipa baicalensis + Cleistogenes polyphylla + Lespedeza davurica + Artemisia gmelinii*
Stipa baicalensis – rhizoma herbosa	*Stipa baicalensis – Leymus chinensis*	*Stipa baicalensis + Leymus chinensis + Filifolium sibiricum* *Stipa baicalensis + Leymus chinensis + Stipa* spp. *Stipa baicalensis + Leymus chinensis* *Stipa baicalensis + Leymus chinensis +* weeds *Stipa baicalensis+Leymus chinensis+Cleistogenes squarrosa+Lespedeza davurica*
Stipa baicalensis – forbs	*Stipa baicalensis –* mesophilous weeds	*Stipa baicalensis + Melissitus ruthenica + Dyxtropis coerulea*
	Stipa baicalensis – Filifolium sibiricum	*Stipa baicalensis + Filifolium sibiricum +Stipa* spp. *Stipa baicalensis + Filifolium sibiricum +Melissitus ruthenica*
Stipa baicalensis – bush	*Prunus sibirica – Stipa baicalensis*	*Prunus sibirica – Stipa baicalensis +Cleistogenes polyphylla + Filifolium sibiricum*

7.2.2.2 *Stipa grandis* steppe, one of the main types of mesothermal typical steppe

Stipa grandis steppe is centrally distributed in steppe belt of the Mongolian Plateau and it is the primary steppe type within the typical steppe. It extends into southern part of Central Siberia, to the central part of the Songhuajiang-Nenjiang Plain and to the Loess Plateau of China. In Northern China, this type of steppe is also continuously distributed on the Xilin Gol Plateau (1,100–1,200 m above sea level) and to the Hulun Buir Plateau (700–1,200 m above sea level). The soil is a thick layer of typical loam and sandy loam chestnut soil and dark chestnut soil. Much of it has eroded in the last few decades.

Stipa grandis steppe is distributed in the semi-arid climate zone in the temperate zone. In this zone, the greatest temperature and rainfall are occured in the summer season, which provides the fundamental conditions for the formation of the *Stipa grandis* zonal steppe. When the habitat condition becomes drier, the *Stipa grandis* steppe will be replaced by xeromorphic *Stipa krylovii* steppe. Therefore, *Stipa grandis* steppe can be regarded as the typical representative steppe of mesothermal steppes of China. According to the classification of natural zones, *Stipa grandis* steppe is an important indicator for classification of the mesothermal forest-grassland sub-belt, typical steppe sub-belt and desert steppe sub-belt. As an original community group, *Stipa grandis* steppe forms an association with various herbosa.

Other plant species of *Stipa grandis* steppe are from Compositae, Gramineae, Leguminosae, Liliaceae, Rosaceae, Labiatae, Chenpodiaceae, and Ranunculaceae families. There are at least five species in each family. The main genus from Gramineae family include *Stipa* spp., *Cleistogenes* spp., *Leymus* spp., *Agropyron* spp; genus from Compositae family is *Artemisia* spp.; from the Leguminosae family is *Astragalus* spp., from the Rosaceae family is *Potentilla* spp. and from the Liliaceae family is *Allium* spp. These plants are indicative of typical steppe in the semi-arid zone.

Stipa grandis steppe is classified into five association classes, eight association groups and seventeen associations (Table 7.3).

Table 7.3 Classification of *Stipa grandis* association formation

Association class	Association groups	Associations
Stipa grandis – herbosa community	*Stipa grandis* – *Stipa baicalensis*	*Stipa grandis* + *Stipa baicalensis*
	Stipa grandis – *Cleistogenes squarrosa*	*Stipa grandis* + *Cleistogenes squarrosa* + *Agropyron cristatum*
		Stipa grandis + *Cleistogenes squarrosa* + *Lespedeza davurica*
		Stipa grandis + *Cleistogenes squarrosa*+ *Artemisia frigida*
	Stipa grandis – *Stipa krylovii*	*Stipa grandis* + *Stipa krylovii*
	Stipa grandis – *Achnatherum sibiricum*	*Stipa grandis* + *Achnatherum sibiricum* + *Leymus chinensis*
	Stipa grandis – *Stipa* spp.	*Stipa grandis* + *Stipa* spp. + *Leymus chinensis*
Stipa grandis – rhizoma herbosa	*Stipa grandis* – *Leymus chinensis*	*Stipa grandis* + *Leymus chinensis* +*Filifolium sibiricum*
		Stipa grandis + *Leymus chinensis* + *Achnatherum sibiricum*
		Stipa grandis + *Leymus chinensis* + *Stipa baicalensis*
		Stipa grandis + *Leymus chinensis* + *Cleistogenes squarrosa* + *Agropyron cristatum*
		Stipa grandis + *Leymus chinensis* + *Cleistogenes squarrosa*

Continued

Association class	Association groups	Associations
Stipa grandis – rhizoma herbosa	*Stipa grandis – Leymus chinensis*	*Stipa grandis* + *Leymus chinensis* + *Artemisia frigida*
Stipa grandis – weeds	*Stipa grandis – Filifolium sibiricum*	*Stipa grandis* + *Filifolium sibiricum* +*Leymus chinensis* + *Bupleurum scorzonerifolium*
Stipa grandis – semi-bush	*Stipa grandis – Artemisia frigida*	*Stipa grandis* + *Artemisia frigida*
Stipa grandis – bush	*Caragana microphylla – Stipa grandis*	*Caragana microphylla – Stipa grandis* + *Cleistogenes squarrosa* + *Agropyron cristatum* *Caragana microphylla – Stipa grandis* + *Leymus chinensis* + *Agropyron cristatum*+ *Serratula centauroides*

7.2.2.3 *Stipa krylovii* steppe, one of the main types of mesothermal typical steppe

The *Stipa krylovii* steppe is associated with herbosa steppe similar to the *Stipa grandis* steppe, and both are common steppe associations in Asian steppes. *Stipa krylovii* steppe is mainly distributed in typical steppe areas of the Mongolian Plateau, stretching northward and eastward to the boundary of the forest-grassland belts. In the south it is located in the semi-arid zone of the Loess Plateau in China, and to the west it is distributed in mountain areas in the arid zone, such as the Yinshan, Helan, Qilian and Tianshan Mountains.

In the Inner Mongolian Plateau areas, a large area of this type of steppe is distributed in a typical steppe belt alternating with *Stipa grandis* steppe. This alternating steppe belt is mainly distributed in the central and western parts of the Hulun Buir Plateau and the Xilin Gol Plateau. The climate is a mesothermic semi-arid climate and the topography is open with flat uplands and hilly slopes. The soils are mainly comprised of loamy soil, sandy loam or sandy chestnut soil.

Stipa krylovii is a xerophyte in the typical steppe and its associations are similar to those of *Stipa grandis* but the community is more restricted. However, in the western part of the typical steppe belt (adjacent to areas of desert steppe), the quantity and function of *Stipa krylovii* exceeds that of *Stipa grandis* and it becomes the dominant plant association. There are typically 15–20 species in one square meter of *Stipa krylovii* association.

Stipa krylovii steppe can be classified into ten association groups and eleven associations (Table 7.4).

Table 7.4 Classification of *Stipa krylovii* association

Association classes	Association groups	Associations
Stipa krylovii – Association of herbosa	*Stipa krylovii* + *Cleistogenes squarrosa*	*Stipa krylovii* + *Cleistogenes squarrosa* *Stipa krylovii* + *Cleistogenes squarrosa* + *Artemisia frigida*
	Stipa krylovii + *Stipa grandis*	*Stipa krylovii* +*Stipa grandis* + *Cleistogenes squarrosa* + *Artemisia frigida*
	Stipa krylovii + *Stipa tianschanica* var. *klemenzii*	*Stipa krylovii* +*Stipa tianschanica* var. *klemenzii* + *Cleistogenes squarrosa* + *Artemisia frigida*
	Stipa krylovii + *Stipa gobica*	*Stipa krylovii* + *Stipa gobica* +*Cleistogenes squarrosa* + *Artemisia frigida*
	Stipa krylovii + *Stipa breviflora*	*Stipa krylovii* + *Stipa breviflora* +*Cleistogenes squarrosa* + *Artemisia frigida*
	Stipa krylovii + *Stipa* spp.	*Stipa krylovii* + *Stipa* spp. +*Thymus vulgaris*
	Stipa krylovii + *Agropyron cristatum*	*Stipa krylovii* +*Agropyron cristatum* + *Artemisia frigida*
Stipa krylovii – rhizoma herbosa	*Stipa krylovii* + *Leymus chinensis*	*Stipa krylovii* + *Leymus chinensis* + *Cleistogenes squarrosa* + *Artemisia frigida*
Stipa krylovii – semi-bush	*Stipa krylovii* + *Artemisia frigida*	*Stipa krylovii* + *Artemisia frigida* + *Potentilla acaulis*
Stipa krylovii – bush	*Caragana* spp. – *Stipa krylovii*	*Caragana microphylla* – *Stipa krylovii* + *Cleistogenes squarrosa*

7.2.2.4 *Stipa tianschanica* var. *klemenzii* steppe, one of the main types of mesothermal desert steppe

Stipa tianschanica var. *klemenzii* steppe is one of the small types of herbosa associated steppe in the desert steppe zone and it is mainly distributed in the Ulan Qab Plateau at the northern and southern foothills of the Yinshan Mountains and the central-western parts of the Ordos Plateau. *Stipa tianschanica* var. k*lemenzii* is the dominant plant species in desert steppe in the Dorno Gobi Province of Mongolia and it is widely distributed in the Altai Mountains in Xinjiang.

Stipa tianschanica var. *klemenzii* steppe is the most drought-tolerant of the *Stipa* spp. steppes and its distribution is closely related to the location of the continental arid climate in the temperate zone. In spring and autumn seasons (particularly in spring), drought will occur for 4 to 6 months and seriously affects the stability of steppe productivity. *Stipa tianschanica* var. *klemenzii* is a typical component of the desert plant community in the Gobi-Mongolia area in Central Asia.

There are few species present in *Stipa tianschanica* var. *klemenzii* steppe and the dominant ones are: *Stipa tianschanica* var. *klemenzii*, *Cleistogenes soongorica*, *Allium polyrrhizum*, *Allium mongolicum*, *Lagochilus ilicifolius*, *Scorzonera divaricata*, *Gypsophila desertorum*, *Iris bungei*, *Hippolytia trifida*, *Ajania achilloidea* and *Caragana stenophylla.* These species are the most stable plants in *Stipa tianschanica* var. *klemenzii* steppe.

Based on differences in plant association groups and their habitats, eleven associations have been determined (Table 7.5).

Table 7.5 Classification of association of *Stipa tianschanica* var. *klemenzii*

Association classes	Associations	Ecological succession trend
Stipa tianschanica var. *klemenzii* – community herbosa	*Stipa tianschanica* var. *klemenzii* + *Cleistogenes squarrosa* + *Artemisia frigida*	Typical *Stipa tianschanica* var. *klemenzii* steppe community
	Stipa tianschanica var. *klemenzii*+ *Cleistogenes songorica*	Evolution to aridization
	Stipa tianschanica var. *klemenzii*+ *Stipa breviflora* + *Cleistogenes squarrosa*	Transition to warm desert steppe
	Stipa tianschanica var. *klemenzii*+ *Stipa krylovii* + *Cleistogenes squarrosa*	Transition to typical steppe
Stipa tianschanica var. *klemenzii* + *Allium* spp.	*Stipa tianschanica* var. *klemenzii*+ *Allium polyrrhizum*	Evolution to soil salinization
	Stipa tianschanica var. *klemenzii*+ *Allium mongolicum*	
Stipa tianschanica var. *klemenzii* + dwarf semi-bush	*Stipa tianschanica* var. *klemenzii*+ *Artemisia frigida*	Evolution to soil erosion and gravel surface
	Stipa tianschanica var. *klemenzii*+ *Hippolytia trifida*	
	Stipa tianschanica var. *klemenzii*+ *Ajania achilloidea*	
Stipa tianschanica var. *klemenzii* + bush	*Caragana intermedia* + *Stipa tianschanica* var. *klemenzii*	Evolution to sandy soil
	Caragana stenophylla + *Stipa tianschanica* var. *klemenzii*	

7.2.2.5 *Stipa bungeana* steppe, one of the main types of warm-temperate typical steppe

Stipa bungeana steppe is widely distributed in warm-temperate belts of the Asian Continent. It is mainly distributed in the Yellow River valley, and extends eastward to the North China Plain. The northern boundary of this type of steppe is the loess hills in the south part of the Xiliao River and in the south of the watersheds of the Yinshan Mountains. To the west, in Qinghai Province, it is distributed in the Qilian and Tianshan Mountains, and even into western Sichuan Province and the Tibet Autonomous Region. South, it is distributed along the Funiu Mountains in Henan Province. *Stipa bungeana* is widely distributed in the Loess Plateau areas of the warm-temperate zones of China including the provinces (or Autonomous Regions) of Shanxi, Shaanxi, Gansu, Ningxia and Inner Mongolia around the middle reaches of the Yellow River.

During a long history of crop farming, land was extensively cultivated and soil erosion has occurred frequently and consequently, very limited areas natural steppe were preserved. Based on research in residual natural vegetation and existing plants, analysis of spore and pollen and surveys of soil and climate conditions, the Loess Plateau has be classified as a sub-humid forest-grassland in its eastern area; a semi-arid steppe in its center; and a desert steppe zone in its western area. It is not easy to find a large piece of continuous original *Stipa bungeana* steppe. Some small pieces of secondary *Stipa bungeana* steppe can be found on abandoned cropland and grazing slopes.

Stipa bungeana is one of the thermophilic xerophytes and is distributed in dense communities to form herbosa community steppes. *Stipa bungeana* is adapted to the environment. Soils are composed of black loam soils with some carbonate brown soils and loess parent materials. There is also some growth of *Stipa bungeana* in mountain areas with thin soil layers.

The original community type of *Stipa bungeana* steppe was monomorphic and its main communities include *Stipa bungeana* + *Cleistogenes squarrosa* association groups, *Stipa bungeana* + *Stipa breviflora* association groups, *Stipa bungeana* + *Agropyron cristatum* association groups, *Stipa bungeana* + *Leymus chinensis* association groups, *Stipa bungeana* + *Lespedeza davurica* association groups, *Stipa bungeana* + *Thymus vulgaris* association groups, and *Stipa bungeana* + *Artemisia gmelinii* association groups (Table 7.6).

Table 7.6 Classification of associations of *Stipa bungeana* steppe

Association classes	Association groups	Associations
Stipa bungeana – herbosa association	*Stipa bungeana* + *Cleistogenes squarrosa*	*Stipa bungeana* + *Cleistogenes squarrosa* + *Artemisia frigida*
	Stipa bungeana + *Stipa breviflora*	*Stipa bungeana* + *Stipa breviflora* + *Cleistogenes squarrosa* + *Artemisia frigida*
	Stipa bungeana + *Agropyron cristatum*	*Stipa bungeana* + *Agropyron cristatum* + *Cleistogenes squarrosa* + *Lespedeza davurica*
	Stipa bungeana + *Leymus chinensis*	*Stipa bungeana* + *Leymus chinensis*+ *Lespedeza davurica*

Continued

Association classes	Association groups	Associations
	Stipa bungeana + *Lespedeza davurica*	*Stipa bungeana* + *Lespedeza davurica*
Stipa bungeana + dwarf semi-bush	*Stipa bungeana* + *Thymus vulgaris*	*Stipa bungeana* + *Thymus vulgaris* + *Cleistogenes squarrosa*
	Stipa bungeana + *Artemisia gmelinii*	*Stipa bungeana* + *Artemisia gmelinii* + *Cleistogenes squarrosa*

7.2.2.6 *Stipa breviflora* steppe, one of the main types of warm-temperate desert steppe

Stipa breviflora is widely distributed in warmer regions of desert steppe in the Asian steppes and it is also distributed in some mountain areas of desert regions. *Stipa breviflora* steppe is mainly located in the northwest part of the Loess Plateau, the northern part of the Yinshan Mountains and the southern part of the Inner Mongolian Plateau. This type of steppe stretches south to Lanzhou, Huining and Huanxian in Gansu Province, to Guyuan in the Ningxia Hui Autonomous Region, to Jingbian, Yulin and Suide in Shaanxi Province, and to Hequ and Pianguan in Shanxi Province. This type of steppe can be found in the east to the loess hills of Chifeng in the Inner Mongolia Autonomous Region, and to the north it is directly linked with the steppe area in the southern part of Mongolia (at 45° N latitude). To the west, it extends from Alxa in Inner Mongolia to the mountain areas in the deserts of the southern Xinjiang Uygur Autonomous Region. This species expands even into Kazakhstan. This species also can be found in loess hills in the southwest part of the Qinghai-Tibetan Plateau and in Cuomei and Longzi districts in southern parts of the Yarlung Zangbo River.

Stipa breviflora forms a permanent dense herbosa community belonging to the desert steppe classification. The associations of *Stipa breviflora* include few tall plants. The herbosa species are the most significant associated species including *Stipa* spp. and *Cleistogenes* spp., followed by legume species (predominantly *Caragana* spp.), *Ajania* species and herbaceous species including *Artemisia* spp.

Due to the wide geographic distribution, *Stipa breviflora* steppe has been divided into different community patterns which are manifested according to their individual eco-geographic features (Table 7.7).

Table 7.7 Classification of association of *Stipa breviflora* steppe

Association classes	Association groups	Associations
Stipa breviflora + herbosa community	*Stipa breviflora* + *Stipa bungeana*	*Stipa breviflora*+ *Stipa bungeana*+ *Cleistogenes squarrosa* + *Lespedeza davurica*

Continued

Association classes	Association groups	Associations
Stipa breviflora + herbosa community	*Stipa breviflora* + *Stipa krylovii*	*Stipa breviflora* + *Stipa krylovii* + *Cleistogenes squarrosa*
	Stipa breviflora + *Stipa tianschanica* var. *klemenzii*	*Stipa breviflora* + *Stipa tianschanica* var. *klemenzii* + *Cleistogenes songorica* + *Ajania achilloidea*
	Stipa breviflora + *Cleistogenes squarrosa*	*Stipa breviflora* + *Cleistogenes squarrosa* + *Artemisia frigida*
Stipa breviflora + dwarf semi-bush	*Stipa breviflora* + *Artemisia frigida*	*Stipa breviflora* + *Artemisia frigida* + *Cleistogenes squarrosa*
		Stipa breviflora + *Artemisia frigida* + *Cleistogenes squarrosa*
Stipa breviflora + dwarf bush	*Caragana intermedia* – *Stipa breviflora*	*Caragana intermedia* – *Stipa breviflora* + *Cleistogenes squarrosa*
	Caragana stenophylla – *Stipa breviflora*	*Caragana stenophylla* – *Stipa breviflora* + *Cleistogenes squarrosa* + *Ajania achilloidea*

7.2.2.7 *Leymus chinensis* steppe, one of the mesothermal rhizome herbosa steppe types

Leymus chinensis steppe is a special type of steppe found in the eastern part of the Euro-Asia continental steppe zone and it is distributed in the Baikal Steppe belt of Russia, in the Mongolian steppe belt, in the steppe belts on the Northeast China Plain, on the Inner Mongolian Plateau and the Loess Plateau of China. The *Leymus chinensis* steppe is distributed in sub-humid and semi-arid zones in the temperate zone of the middle and the eastern parts of Asia. This kind of steppe extends in the north to 62° N latitude and south to 36° N latitude and 92°–132° E longitude. Based on small to medium vegetation maps, it is roughly estimated that the total area of *Leymus chinensis* steppe in the middle and eastern parts of Asia is 420,000 km^2, of which, 220,000 km^2 are found inside China. These are the steppe types with the highest economic value for grazing purposes.

The natural distribution belt of *Leymus chinensis* steppe is wide and it is the largest steppe type in size in the forest-steppe belt. Among the typical steppes, the area of *Leymus chinensis* steppe is a little smaller than *Stipa* spp. steppe, but it still contains various steppe types.

The differences in moisture conditions and the soil salt regime are the important ecological elements differentiating the types of *Leymus chinensis* steppe communities. *Leymus chinensis* steppe is well developed in the zonal habitat and is the most developed steppe community in this habitat. In this ecological area, *Leymus chinensis* steppe often alternates with *Stipa* spp. steppe or *Filifolium sibiricum* + forbs steppe, *Leymus chinensis* + *Bromus* *inermis* steppe, *Leymus chinensis* + mesophilous weeds steppe and herbosa meadow.

Leymus chinensis steppe communities can be differentiated according to eco-geographic areas and botanical composition and can be divided into four sub-associations: (i) Typical steppe type of *Leymus chinensis* steppe; (ii) Mesophilous *Leymus chinensis* steppe; (iii) salinized wet *Leymus chinensis* steppe; and (iv) sandy and gravel *Leymus chinensis* steppe. These sub-associations are based on different plant associations.

7.2.2.8 *Filifolium sibiricum* steppe, one of the cold alpine axial root herbosa steppe types

Filifolium sibiricum steppe is a specific axial root herbosa steppe association found in mountain areas in the middle of Asia, where axial root herbosa is the dominant plant community. The geographic range of *Filifolium sibiricum* steppe formation is at 100°–132° E longitude and at 37°–54° N latitude and it is continuously distributed in the Hang'ai, Kente and Da Xing'anling mountains, the northern part of the Yanshan Mountains, the eastern part of the Yinshan Mountains and the low hills and uplands beyond these mountains.

In China, *Filifolium sibiricum* steppe is mainly distributed in the low hill districts along the eastern and western foothills of the Da Xing'anling Mountains, in the eastern periphery of the Hulun Buir-Xilin Gol Plateau and on the low mountain slopes of the Songhuajiang-Nenjiang River Plain in Northeast China, and it occupies the central part of the steppe area.

Due to the relatively low evaporation rate, the soil moisture conditions during the growth season are high and this provides good growing conditions for meso-xerophilous, xero-mesophilous and mesophilous forbs. Therefore, the *Filifolium sibiricum* steppe community is composed of a rich variety of plant species, with colorful shapes and forms in the community and is highly productive.

Filifolium sibiricum is classified as a cold-tolerant meso-xerophilous axial root herbosa. The *Filifolium sibiricum* steppe community is also characterized by a series of features that are similar to alpine steppe.

Due to the variations in eco-geographic conditions, *Filifolium sibiricum* steppe is differentiated into six association classes and twenty-one associations (Table 7.8).

Table 7.8 Classification systems of *Filifolium sibiricum* steppe associations

Association classes	Association groups	Associations
Filifolium sibiricum – mesothermal herbosa	*Filifolium sibiricum*–*Stipa baicalensis*	*Filifolium sibiricum* + *Stipa baicalensis*+ *Carex pediformis* + *Prunus sibirica* + *Hemerocallis citrina*
		Filifolium sibiricum + *Stipa baicalensis* + *Potentilla betonicaefolia*
		Filifolium sibiricum + *Stipa baicalensis* + *Galium verum*

Continued

Association classes	Association groups	Associations
Filifolium sibiricum – mesothermal herbosa	*Filifolium sibiricum–Stipa grandis*	*Filifolium sibiricum* + *Stipa grandis* + *Hedysarum gmelinii*
		Filifolium sibiricum + *Stipa grandis* + *Stipa davurica*
		Filifolium sibiricum + *Stipa grandis* + *Leymus chinensis*
		Filifolium sibiricum + *Stipa grandis* + *Artemisia frigida*
	Filifolium sibiricum–Stipa krylovii	*Filifolium sibiricum* + *Stipa krylovii* + *Chamaerhodos trifida*
Filifolium sibiricum – frigid-warm herbosa	*Filifolium sibiricum–Stipa* spp.	*Filifolium sibiricum* + *Stipa* spp. + *Aster alpinus*
	Filifolium sibiricum–Leucopoa albida	*Filifolium sibiricum* + *Leucopoa albida* + *Oxytropis filiformis*
Filifolium sibiricum – warm herbosa	*Filifolium sibiricum–Spodiopogon sibiricus*	*Filifolium sibiricum* + *Spodiopogon sibiricus* + *Atractylodes chinensis*
	Filifolium sibiricum–Cleistogenes polyphylla	*Filifolium sibiricum* + *Cleistogenes polyphylla* + *Lespedeza hedysaroides*
Filifolium sibiricum – *Carex* spp.	*Filifolium sibiricum–Carex pediformis*	*Filifolium sibiricum* + *Carex pediformis*+ *Sanguisorba officinalis*
Filifolium sibiricum – bushes	*Prunus sibirica* – *Filifolium sibiricum*	*Prunus sibirica* – *Filifolium sibiricum* + *Stipa* spp.+ *Potentilla betonicaefolia*
		Prunus sibirica – *Filifolium sibiricum*+ *Cleistogenes polyphylla* + *Lespedeza davurica*
	Caragana microphylla – *Filifolium sibiricum*	*Caragana microphylla* – *Filifolium sibiricum* +*Stipa baicalensis* + *Carex pediformis*
		Caragana microphylla – *Filifolium sibiricum*+ *Stipa grandis* + *Leymus chinensis*
		Caragana microphylla – *Filifolium sibiricum* + *Agropyron cristatum* + *Koeleria cristata*
Filifolium sibiricum – dwarf semi-bush	*Filifolium sibiricum–Thymus vulgaris*	*Filifolium sibiricum* + *Thymus vulgaris* + *Artemisia gmelinii*
		Filifolium sibiricum + *Thymus vulgaris* + *Lespedeza bicolor*
	Filifolium sibiricum–Artemisia gmelinii	*Filifolium sibiricum* + *Artemisia gmelinii*

7.2.2.9 *Artemisia frigida* steppe, one of main degraded steppe types

Artemisia frigida steppe is mainly vegetated by the dwarf-bush *Artemisia frigida* and its succession pattern has changed under the impacts of overgrazing and strong wind erosion in steppe areas.

Artemisia frigida steppe is distributed to the east in steppe districts along the Xiliao River valley in northeast China and to the west in the central and eastern parts of the Mongolian Plateau, the typical steppe of the Ordos Plateau and the desert steppe belt, and it extends into the territories of Mongolia and Kazakhstan.

Artemisia frigida steppe, which is distributed in the central and the eastern parts of the Mongolian Plateau, is classified as a semi-arid typical steppe, and its typical zonal plants are *Stipa grandis* steppe and *Stipa krylovii* steppe (Table 7.9). Due to long-term overgrazing and trampling, the herbosa growth was limited and the drought-tolerant *Artemisia frigida* replaced the original dominant plants and developed the steppe into an *Artemisia frigida* steppe.

Artemisia frigida steppe in the central and west parts of the Ordos sandy-gravel upland is classified as desert steppe when the climate is drier and annual precipitation is 150–250 mm and vegetation is composed of *Stipa breviflora* and *Stipa glareosa* steppe (Table 7.9). The growth of *Artemisia frigida* steppe is closely related to long-term wind erosion and sub-stratum conditions.

Table 7.9 Classification systems of *Artemisia frigida* steppe associations

Association classes	Association groups	Associations
Artemisia frigida typical steppe	*Artemisia frigida* – herbosa	*Artemisia frigida* + *Stipa krylovii* + *Cleistogenes squarrosa*
		Artemisia frigida + *Leymus chinensis*
		Artemisia frigida + *Stipa bungeana*
	Artemisia frigida – dwarf semi-bush	*Artemisia frigida* + *Thymus vulgaris*
	Artemisia frigida – shrubby	*Caragana microphylla* – *Artemisia frigida* + *Stipa krylovii* + *Cleistogenes squarrosa*
		Caragana microphylla – *Artemisia frigida* + *Leymus chinensis*
Artemisia frigida desert steppe	*Artemisia frigida* – *Stipa tianschanica* var. *klemenzii*	*Artemisia frigida* + *Stipa tianschanica* var. *klemenzii*
		Artemisia frigida + *Stipa glareosa*
	Artemisia frigida – dwarf semi-bush	*Artemisia frigida* + *Ajania achilloidea*
	Artemisia frigida – shrubby	*Caragana stenophylla* – *Artemisia frigida* + *Oxytropis aciphylla*

Artemisia frigida is a dwarf semi-bush and it is characterized by its extensive root system, high sprouting and root growth potential, tolerance to trampling and adaptability to soil erosion.

Artemisia frigida is a xerophyte that is distributed in areas from the sub-humid zone to the arid desert steppe and it is either the dominant plant, or in different steppe community, is co-dominant. *Artemisia frigida* steppe usually has rich species diversity.

Artemisia frigida steppe is normally distributed in temperate zone steppes and forms six association groups and ten associations.

7.2.3 Ecological structure and regional differentiation of steppe landscape

During the evolution of geological environment, climate gradients between regions were formed and as a result, different steppe types and regional differentiation have occurred. A complicated series was formed from sub-humid and semi-arid zones to the arid zone in the temperate steppe zone of Northern China based on the gradient of the humidity coefficient. According to the features of landscape structure and ecological services, the zones can be divided into several different regions, and the environment and resources status of each are briefly discussed in following paragraphs.

(i) The Nenjiang-Liaohe River Valley and the piedmont plains at the eastern foothills of the Da Xing'anling Mountains, include Qiqihaer and Daqing cities in Heilongjiang Province, Baicheng and Songyuan cities in Jilin Province, Xing'an Prefecture, the northern part of Tongliao and Chifeng City in Inner Mongolia. This is a region with rich biodiversity. Due to repeated cultivation and grazing, the existing steppe vegetation has been almost totally degraded and the sandy steppe has been desertified. In some low-lying areas with poor drainage systems, the steppe was alkalized.

(ii) The Horqin Sandland along the Xiliao River valley, includes Tongyu in Jilin Province, Zhanggutai in Liaoning Province, Xing'an Prefecture, the southern part of Tongliao, and the central part of Chifeng City in Inner Mongolia. This sandland is an aeolian landform developed on the alluvial plain of the Xiliao River during the Quaternary Period. However, due to population growth in past centuries, steppe and arable land have over-used with high carrying capacities and consequently, forest and grass vegetation has been destroyed, desertified lands have been rapidly spreading over the last three decades and new sand-dust storm sources are expanding.

(iii) The piedmont plain in the western foothills of the Da Xing'anling Mountains forms the forest-grassland belt of Inner Mongolia Plateau, and includes Eerguna City, Yakeshi City, Chenbaerhu banner, Ewenke banner, Ulagai Prefecture and Xiwuzhumuqin banner in Inner Mongolia. Since the 1970s, the steppe and grassland have been inappropriately cultivated resulting in a loss of land productivity as the soil has been turned into sand or covered by shifting sand.

(iv) The Hulun Buir Basin, the western part of the Wuzhumuqin Basin, and the typical steppe belts downstream of the Xilin River, including Chenbaerhu Banner, the western part of Ewenke Banner, Xinbaerhu Zuo Banner, Xinchenbaerhu Zuo Banner, Xinchenbaerhu You Banner, Dongwuzhumuqin Banner, Xiwuzhumuqin Banner and Abaga Banner and Xilinhot City in Inner Mongolia, form another important area where typical steppe is interspersed with hills and upland. The humidity index is 0.35–0.50 and due to over-loading and overgrazing, the steppe is generally degraded at present.

(v) Otindag Sandland, including Keshiketeng, Xiwuzhumuqin, Abaga, Sunite Zuo, Sunite You, Zhenglan, Zhengxiang Bai, Xianghuang and Duolun banners or counties and Xilinhot City in Inner Mongolia, is an aeolian sandland formed during the Tertiary Period on the synclinal structure base stratum at the north foothills of the Yinshan Mountains. The sandland has a total area of 40,000 km^2 and is characterized by alternating sand ridges, longitudinal dunes and inter-dune depressions and a mosaic of small lakes. At present, the vegetation in the west part of the Otindag Sandland is seriously degraded with mobile sand. It is now one of the main sand-dust storm source areas in Northern China.

(vi) The Saihan Tala Upland, Erlianhot Basin and Ulanqab Plateau, including Sunite Zuo banner, Sunite You banner, the northern part of Siziwang banner, Daerhan Maoming'an banner and Ulatezhongqi banner in Inner Mongolia, are vast desert steppes. The climate humidity index is 0.13–0.25 and it forms a transitional zone on the edge of the inland arid zone. The structure of the ecosystem is monotonous with a low level of biodiversity, and steppe productivity is less than 40% of typical steppe productivity. This region is completely affected by desertified land and is one of the main source areas for sand-dust storms. Counter measures must be taken to control the further degradation of this area caused by immigration of people and livestock. The steppe area must be entirely fenced and maintained to restore the steppe ecology.

(vii) The eastern part of the Ordos Plateau, northern Shanxi Province and the loess hills of northern Shaanxi Province, including Hohhot City and Ordos City in Inner Mongolia, Datong, Shuozhou and Xinzhou cities in Shanxi Province, and Fugun, Shenmu, Hengshan, Jingbian and Dingbian counties and Yulin City of Shaanxi Province, is in the warm-temperate zone. The climate humidity index in this region is 0.30–0.48. Due to severe soil erosion and steep cuts in the landform, the steppe has been denuded and cut into small pieces, and plant communities, residual woodlands and arable lands have been severely degraded as seen in large expanses of destroyed landscapes. This region is a large-scale coal mining base and improvement of the ecological environment is a burning issue at the moment.

(viii) The Mu Us Sandland includes Ordos City in Inner Mongolia and Yulin City in Shaanxi Province. This region is a warm-temperate type steppe sandland. The landscape includes sand-gravel hard ridges, sandy soft ridges and coastal landscapes. A high level of biodiversity forms an abundant resource combination, and the climate humidity index is 0.30–0.45. With the development of animal husbandry and rapid increase in livestock population, desertification occurred and currently, combating desertification is a priority task of the region.

(ix) The western parts of the Loess Plateau in Ningxia and Gansu are in the warm-temperate type desert steppe belt, and include Ordos City in Inner Mongolia, the entire Ningxia Hui Autonomous Region, and Baiyin City and Lanzhou City in Gansu Province. The climate humidity index is 0.20–0.30 and the landscape is mostly loess tablelands and loess hills with sparse desert steppe vegetation. Land productivity is low and wind and water erosion is severe. The measures and policies to restore the natural steppe vegetation by retiring cropland on slopes, revegetating degraded lands by growing grass and reforesting unproductive hilly areas should be encouraged.

7.3 Steppe degradation mechanisms

Reasons and mechanisms of steppe desertification are complex, and each other involved. The reasons for this are climate, geology, hydrology, biology, human, social, and so on. The mechanism are physical, chemical, economic (market), systems, chaos, customs, culture, and so on. It can be said, that the desertification is a non-conforming and inharmonious immingling of humanities and natural forces, which produces a deleterious effect on humanities and natural forces each other and resulted in a tragedy for both.

7.3.1 Causes of steppe degradation

Steppe degradation refers to the process of decline in steppe productivity and environment quality caused by inappropriate management and over-use of steppe under the effects of climate change. Steppe degradation is complicated by interactions of many different elements. Steppe degradation is seen in the degradation of the biological composition and vegetation of the steppe, soil deterioration, degradation of the hydrological circulation system and the worsening of the climatic environment. Overgrazing pressure and over-loading of the steppe have destroyed its regenerative ability and the community composition of the steppe vegetation resulting in a decline in steppe vegetation biomass and a change in the plant community to sparse and dwarf plantings. Some grasses with high value are reduced and poor quality grass species have increased. Along with vegetation degradation, some animal species (such as rodents, insects and earthworms) have disappeared. In general, steppe degradation is one of important effects of desertification which has led to the deterioration of the ecological health of the steppe ecosystem.

The causes of steppe degradation are summarized below and each should be further analyzed.

- Climate variation, drought and frequent winds
- Growth in both human and livestock populations
- Over-loading and inappropriate use of the steppe
- Rodent and insect disasters on the steppe
- Insufficient investment in steppe infrastructure, particularly the construction of water conservation projects

By analyzing the degradation process on the steppe in the Xilin Gol Prefecture, it can be seen that by the end of 1980s, the area of degraded typical steppe in the prefecture was 35% and there were a total of nine million head of livestock in the prefecture. By the 1990s, the total livestock population had increased to over 15 million head and the total area of degraded steppe had also increased to over 60%. The growth in livestock population coincided with the accelerated degradation of the steppe.

Steppe degradation is closely related to insufficient investment in steppe infrastructure, particularly for water conservation projects in steppe areas. Through detailed analysis of the relationship between steppe degradation and insufficient investment, it can be seen that there are two main aims behind the implementation of water conservation projects in steppe areas. The first aim is to meet the needs of human and livestock drinking water. Second, projects are aimed at increasing forage/fodder by developing fodder farms and artificial grassland by pumping water from river and digging wells in depressions. There has been too little effort and investment in increasing fodder/forage production even though the livestock population has increased rapidly and consequently, steppe degradation has accelerated. The increase in livestock population and the over-use of the steppe are the leading causes of steppe degradation. The low level of awareness and lack of attention to the ecological and environmental services of steppe are the underlying causes of steppe degradation.

The immediate concern of farmers involved in animal husbandry is to increase income by raising livestock population, and there are less concerned with maintaining the ecological environment of steppe. Consequently, the limited steppe or grassland areas were inappropriately used and mismanaged on a large scale. Outcomes of this unsustainable use of the steppe lead to a breakdown of steppe ecosystems because the pressure exceeds the capacity for regeneration. Steppe degradation is a continuing and worsening process. The condition of the steppe can be improved only by combining scientific analysis, sound planning and optimum design to determine a viable steppe management system and make the use of the steppe resource sustainable.

7.3.2 Imbalance in material and energy flows in the steppe ecosystem

Steppe vegetation is a fixed source of energy in the steppe system. Soil is the nutrient bank for material circulation. When the steppe ecosystem is in its original state, the unit material energy storage inside the ecosystem is assumed to be a constant, so that the instantaneous change value for each unit is:

$$dv/dt = dl/dt = dm/dt = ds/dt = 0 \tag{7.1}$$

Where v is the vegetation in the steppe; (represented by plant biomass); l is the amount of livestock; m is the microbial community; s is the soil nutrition bank; and t is time.

When the element of economic income is incorporated into a steppe ecosystem and the livestock population increases incrementally, $dl/dt > 0$, vegetation will also be changed and the velocity of energy flow will be increased, in other words $dv/dt < 0$, namely, plant biomass will be decreased. As the plant biomass is reduced, so is the photosynthesis area which reduces the energy flow from solar energy into the vegetation. Due to the increase in dwarf plants and the alterations to the dominant plant community, the energy flow is not able to support the increase of dl/dt, in other words, livestock are hungry. Under these circumstances without disturbance of the soil bank, the degraded steppe vegetation has a certain recovery potential (CR). When $dv/dt = dl/dt$, i.e., when livestock intake is equal to the regrowth of steppe vegetation, a new balanced relationship between forage and livestock is established. When this occurs, v in the system becomes v', l becomes l', and m and s are respectively become m' and s'. In other words, a new, balanced system, which is different to the original system, is established.

$$dv'/dt = dl'/dt = dm'/dt = ds'/dt = 0 \tag{7.2}$$

This kind of system occurs in degraded steppe ecosystems. When the steppe becomes degraded, and the new system is established, the materials and energy storage of the various biological units within the ecosystem are less than those of the original system and the flow rates of energy, water and nutrients have decreased. Therefore, the energy level of the ecosystem for self-maintenance and self-control will be reduced. It is therefore clear that differences in use patterns (such as harvesting of forage and grazing of steppe) determine the feedback regulation effect and this will result in different changes to steppe vegetation. The final regime of the ecosystem varies depending on the use patterns and there are also different degradation patterns. With similar land use models, the change dl/dt of domestic animal units is different, so the feedback flow intensity, dl/dt, is different and the energy level, when the system is in a stable state, will also be different. These balanced regimes at different energy levels are seen with different degradation intensities.

It can be concluded from the analysis above that the imbalance in the steppe ecosystem caused by over-use is a leading cause of steppe degradation. Under low energy conditions, the realization of balance in the ecosystem is limited by the conditions of utilization intensity and restoration capacity underpinned by well preserved soil. However, this new relative balance can also be broken.

The structure, texture and nutrient contents of soil resources can be seen as either the nutrient source for the supply of moisture and nutrients, or the environmental elements of a steppe ecosystem. For instance, when the saline and alkali ion storage is high and the groundwater depth is shallow, steppe ecosystems with a potential salinization risk will be frequently become salinized due to the reduction of vegetative coverage. Soil salinization increases unfavorable ecological elements and reduces the absorptivity of mineral nutrients by plants. On a sandy steppe, for example, any reduction of vegetative coverage will make the land surface more susceptible to wind erosion, which can damage soil structure, and result in the development of shifting sands and/or mobile dunes. In a worst case scenario, the steppe may become a lifeless physical system, as the ecosystem completely collapses.

7.3.3 Deterioration of primary productivity in degraded steppes

In normal years, the existing above ground biomass of undegraded typical steppe in Inner Mongolia can be as high as 300 $g \cdot m^{-2}$ while in poor years with harsh conditions, the biomass can be as low as 200 $g \cdot m^{-2}$. The average yield of typical steppe biomass is 250 $g \cdot m^{-2}$. After 8–10 years of restoration of degraded steppe communities, the productivity approaches 30% of the non-degraded community productivity.

Plants of poor palatability and low preference cover a large percentage of the degraded steppe community. In the summer season, the existing plants, which livestock dislike browsing on, such as *Artemisia frigida* and *Artemisia pubescens*, comprise 38% of the existing community. *Cleistogenes squarrosa*, which has a low forage value covers 12%, *Caragana microphylla* covers 4%, while *Leymus chinensis*, *Stipa grandis* and *Agropyron cristatum* which have good palatability cover only 15%. Among the dominant plant associations, at least 50% of the above ground biomass is composed of low palatability plants mainly *Artemisia frigida*. However, these same plant species cover only 4% of the area in non-degraded steppe communities. When the steppe is degraded and covered mainly by *Artemisia frigida*, the productive potential is approximately 16.7% of the non-degraded community. With continuous grazing of the degraded steppe, a relative stable degraded community can be maintained provided the land use intensity remains constant. Of course, a reduction of grazing or steppe utilization intensity can lead to the restoration of the plant community. Animals grazed at low stocking rates on degraded steppe can keep the intake and restoration processes in a dynamic balance so that the community can be maintained in a relatively stable state.

The decline in primary productivity is a basic feature of steppe degradation, and it is also a regulating mechanism to readjust the over-use of the steppe ecosystem through a feedback pattern. The decrease in productivity refers to both the decline in plant biomass and a worsening of plant forage quality. These two factors interact, and a lower availability of poor quality forage provides poor animal nutrition.

The original cause of decline in primary productivity is over-use but more particularly, the impact of selective grazing on the higher value plants. At present, the utilization pattern of steppe resources leads to the almost continuous harvest of high quality plants. During earlier times, the processes of synergistic evolution between steppe and livestock meant that there were sufficient forage sources with good palatability for livestock. However, overgrazing led to a decline of tall herbosa that were the main contributors to primary productivity of steppe communities. In non-degraded steppe communities, the above-ground utilization rate per unit area of tall herbosa plants is high and below ground, the resources of deeper soil layers will be exploited by tall herbosa plants with their extensive root systems. For instance, in the non-degraded communities of *Leymus chinensis* and *Stipa grandis*, the biomass of *Leymus chinensis*, *Stipa grandis* and *Achnatherum sibiricum* account for 75% of the biomass of community. Therefore, the decline of tall herbosa plants causes a significant change to the available resources of the community. The tall herbosa species are replaced by low plants which mainly consume water and nutrient resources from shallow soil layers and are unable to explore the deeper soil layers. This is one of the mechanisms leading to decline in primary productivity of steppe.

The changes to the micro-environment and soil regime that have occurred along with the degradation of the steppe are also relevant controlling factors for the decline in primary productivity. These changes are particularly obvious on the sandy steppe and salinized steppe. Changes to the micro-environment and soil regime threaten the disappearance of some species and cause a decline in overall productivity.

7.3.4 Rehabilitation of degraded steppe

The process of restoration and transformation of degraded steppe begins with a reduction in grazing pressure. Over-utilization must be eliminated if degraded steppe is to be restored. However, some restoration processes require a long time. For instance, the stabilization of shifting sandlands and the desalinization and de-alkalization of salinized steppe are slow interactive processes between biology and the environment. Furthermore, during the restoration process, fluctuations in various elements lead to changes to the restoration process and an uneven rate of progress. The primary condition to restore the degraded steppe is to remove pressure of over-loading or overgrazing of steppe to reach the threshold that leads to restoration of steppe. Once grazing pressure is relieved, the factors that will favor restoration of the degraded steppe are: (i) the fact that on a local scale the temperature, sunshine and atmosphere precipitation do not alter significantly; and (ii) where soil retains its basic structure, there is still a resource in the soil bank of the ecosystem. The soil bank contains seeds and other disseminules, nutrients and water as well as soil biota and micro flora. Even where the soil structure has been partially destroyed, biological processes will allow for the soil structure to be rebuilt over time.

7.4 Successional pattern and diagnosis of steppe degradation

There are different types of steppe vegetation and steppe ecosystems, due to different characteristics in the eco-environment, and the utilization and management patterns and utilization intensity are different. Therefore, the successional patterns, botanical composition and degradation intensities are also quite different. The types of degraded steppe and the degradation series can be differentiated based on eco-environment and land use patterns.

7.4.1 Series and types of meadow steppe degradation

The main community types of meadow steppe are *Stipa baicalensis* steppe and *Leymus chinensis* steppe + forbs steppe. The steppe degradation sequences include:

Stipa baicalensis → *Stipa baicalensis* + *Stipa krylovii* +*Artemisia frigida* → *Artemisia frigida* + *Cleistogenes squarrosa*,

Stipa baicalensis → *Stipa baicalensis* + *Carex duriuscula* → *Carex duriuscula*,

Leymus chinensis + forbs → *Leymus chinensis* + *Carex duriuscula* → *Carex duriuscula*.

The above three degradation sequences indicate different degradation processes but a tendency towards similarity in the degradation results. All processes occur due to overgrazing and over-use, although different steppe types have been manifested. *Artemisia frigida* is a chamaephyta, which is well adapted to steppe, highly tolerant to grazing, and is often a winner in the process of steppe degradation succession (Liu et al., 2002).

7.4.2 Series and types of typical steppe degradation

Typical steppes include *Stipa grandis* steppe, *Stipa krylovii* steppe, and *Leymus chinensis* steppe. With intensive grazing and utilization, different degradation successional sequences have appeared which are similar to the steppe types dominated by *Artemisia frigida*. They can be briefly described as follows:

Stipa grandis → *Stipa grandis* + *Stipa krylovii* + *Artemisia frigida* → *Artemisia frigida* + *Cleistogenes squarrosa*,

Stipa krylovii → *Stipa krylovii* +*Artemisia frigida* → *Artemisia frigida* + *Cleistogenes squarrosa*,

Leymus chinensis → *Leymus chinensis* + *Stipa krylovii* + *Artemisia frigida* → *Artemisia frigida* + *Cleistogenes squarrosa*.

Under long-term intensive grazing and over-use of steppe, the *Artemisia frigida* community is eventually succeeded by *Potentilla acaulis* or *Steellera chamaejasme* which are the dominant species in totally degraded steppe — a steppe type that is completely degraded and useless.

7.4.3 Series and types of desert steppe degradation

The main types of desert steppe include *Stipa tianschanica* var. *klemenzii* steppe and *Stipa breviflora* steppe. Under impacts of continuous intensive grazing, *Ajania achilloidea* and *Artemisia frigida* species groups are increased. The degradation successional orders are:

Stipa tianschanica var. *klemenzii* → *Stipa tianschanica* var. *klemenzii* + *Ajania achilloidea* → *Ajania achilloidea* + *Cleistogenes songorica*,

Stipa tianschanica var. *klemenzii* → *Stipa tianschanica* var. *klemenzii* + *Artemisia frigida* → *Artemisia frigida* + *Cleistogenes songorica*,

Stipa breviflora → *Stipa breviflora* + *Artemisia frigida* → *Artemisia frigida* + *Cleistogenes songorica*.

Under intensive grazing, the *Ajania achilloidea* and *Artemisia frigida* communities are eventually succeeded by *Convolvulus ammanni* communities.

7.4.4 Distribution of degraded steppe

The area occupied by degraded desert steppe (located in the western part of the Xilin Gol Prefecture, the northern part of the Wulanqab Prefecture, the northern part of the Bayan Nor Prefecture and the central part of Ordos City) is the highest percentage of degraded land. The typical steppe belt provides the second highest percentage of degraded area, and the forest-grassland belt has the least degraded land. This indicates that the harsh natural conditions in the desert steppe make this more vulnerable to degradation. The Table 7.10 shows the areas and distribution of steppe degradation between the three different degradation grades. The area of degraded desert steppe is more than 82% of the total area of desert steppe.

According to satellite images, remote sensing survey results and ground survey data of steppe and grassland resources conducted during 1994–1996, steppe degradation is widespread in all steppe regions of Northern China. Table 7.11 shows the areas of steppe degradation in the provinces, prefectures and cities of Northern China calculated based on the administrative divisions present in 1995.

It can be seen from Table 7.11 that the area of steppe degradation covers more than 50% of the total steppe area. The area of degraded steppe in Hohhot City, Baotou City, and Chifeng City, where crop farming is well developed, and in Ordos City, where natural erosion (soil and water losses and wind erosion and sand encroachment) is worst, is more than 50%. In Xilin Gol Prefecture, where animal husbandry and steppe management are well developed, the area of steppe degradation covers 32.85% of the total steppe area.

7.4.5 Diagnosis of steppe degradation

With appropriate grazing, the plant compositions of the various steppes remain stable but the annual biomass is highly variable due to variations in annual precipitation and the seasonal distribution of precipitation. The process of steppe degradation caused by overgrazing results in an obvious decline of total forage biomass, but also changes of the plant community structure and botanical composition. Some plant species disappear and other plant species gradually increase. According to the changes in quantity and type of plant species, the degradation processes on the steppe can be diagnosed.

7.4.5.1 Classification of steppe degradation intensity grade

Monitoring of steppe degradation was conducted continuously from 1983 in the middle reaches of the Xilin River in the central part of the typical steppe of Inner Mongolia. Based on the survey and the determination of steppe degradation in the northern China, the grading criteria of steppe degradation intensity were outlined as shown in Table 7.12.

7.4.5.2 Diagnosis of decline and succession of dominant plant populations

Using *Leymus chinensis* steppe, *Stipa grandis* steppe and *Stipa tianschanica* var. *klemenzii* steppe as examples, when the steppe is subjected to overgrazing pressure, these three species and other dominant plant species will gradually decline. At the Grade I degradation intensity stage the rate of steppe degradation is less than 30%; at the Grade II stage the steppe degradation

Table 7.10 Areas of degraded steppes in three steppe belts (1996) (10^4ha)

Steppe belts	Total area of steppe	Area of degraded steppe	% of degraded steppe in total steppe areas	Grade I degradation		Grade II degradation		Grade Ⅲ degradation	
				Area	% of degraded steppe	Area	% of degraded steppe	Area	% of degraded steppe
Forest grassland	1,066.4	329.3	30.88	106.8	32.4	130.6	39.7	91.9	27.9
Typical steppe	3,228.3	1,847.3	57.22	262.5	14.2	780.0	42.2	804.8	43.6
Desert steppe	2,317.9	1,925.6	83.08	495.2	25.7	849.8	44.1	580.6	30.2
Total	6,612.6	4,102.2	62.04	864.5	21.1	1,760.4	42.9	1,477.3	36.0

Table 7.11 Areas of degraded steppe in provinces, prefectures and cities of Northern China (10^4 ha)

Provinces(Autonomous Regions)/Cities(Prefectures)	Available steppe	Total area of degraded steppe	% of available steppe	Grade I degraded steppe	% of degraded steppe	Grade II degraded steppe	% of degraded steppe	Grade III degraded steppe	% of degraded steppe
Heilongjiang	7,442,510	358,7450	48.20						
Jilin	2,837,430	1,528,225	53.86						
Hebei	1,525,200	814,440	53.40						
Shanxi	1,464,250	782,050	53.41						
Shaanxi	1,582,630	744,770	47.06						
Ningxia	1,248,500	683,255	54.73						
Gansu	2,012,480	1,016,820	50.53						
Inner Mongolia	45,632,587	22,258,764	48.37	10,046,966	47.28	8,305,404	35.32	3,906,394	17.40
Hohhot City	149,315	91,239	61.10	26,768	30.00	29,911	32.78	33,960	37.22
Baotou City	424,392	252,553	59.31	136,213	52.93	38,711	15.33	77,630	30.74
Chifeng City	4,565,010	2,885,325	63.17	964,307	33.43	1,086,607	37.65	834,410	28.92
Hulun Buir City	7,233,775	2,330,402	41.52	813,193	56.58	491,862	34.26	125,342	9.16
Xing'an Prefecture	2,612,174	968,748	34.08	305,628	40.28	194,712	25.66	258,409	34.06
Tongliao City	3,715,396	2,414,293	65.01	807,558	33.45	673,052	27.88	933,582	38.67
Xilin Gol Prefecture	17,660,962	91,882,945	32.85	3,472,446	47.66	2,994,256	41.01	819,072	11.24
Ulanqab Prefecture	5,084,420	261,775	51.43	1,515,678	57.96	625,926	23.94	473,481	18.44
Ordos City	2,175,689	1,415,106	64.35	514,937	37.26	608,069	42.45	292,100	20.29
Bayan Nir Prefecture	2,010,282	800,414	40.37	613,812	3.94	160,258	22.51	28,010	3.55

rate is less than 50%; and at the Grade III steppe degradation level the rate of steppe degradation is about 70%. Table 7.13 shows the results from survey estimations of sampling sites on different steppes.

Table 7.12 Classification of steppe degradation grade

Degradation indicators	Degradation intensity			
	I	II	III	IV
% of decrease of biomass productivity of plant community	20–35	36–60	61–90	>90
% of decline of dominant plant population	15–30	31–50	51–75	>75
% of productivity reduction of palatable grass population	30–45	46–70	71–90	>90
% of increase of productivity of unpalatable plants	10–25	26–40	41–60	>60
% of increase of plants indicative of degradation succession	10–20	21–45	46–65	>65
% of the decline in plant height (dwarf)	20–30	31–50	51–70	>70
% of the decline of vegetative coverage	20–30	31–45	46–60	>60
Degree of erosion of light texture soils	10–20	21–30	31–40	>40
% of increase in bulk density and compaction of medium and heavy texture soils	5–10	11–15	16–20	>20
Duration of reversibility and rehabilitation (year)	2–5	5–10	10–15	>15

I: Grade I degradation; II: Grade II degradation; III: Grade III degradation; IV: Grade IV degradation

Table 7.13 Decline and growth rates of dominant species during the processes of plant community degradation of different steppes

Steppe community	Dominant plants	I	II	III	IV
Leymus chinensis steppe	*Leymus chinensis*	–28.3	–48.2	–68.6	–94.5
	Stipa grandis	–32.2	–55.0	–77.6	–96.0
	Cleistogenes songorica	+ 5.5	+6.3	+1.8	+2.6
	Artemisia frigida	+21.5	+37.2	+66.4	+68.7
Stipa grandis steppe	*Stipa grandis*	–30.55	–52.6	–75.8	–95.4
	Cleistogenes songorica	+ 8.8	+10.5	+6.2	–5.4
	Artemisia frigida	+22.8	+33.3	+61.4	+67.1
Stipa tianschanica var. *klemenzii* steppe	*Stipa tianschanica* var. *klemenzii*	–31.0	–49.6	–49.6	–81.7
	Cleistogenes songorica	+10.6	+8.2	+8.2	–20.4
	Ajania pallasiana	+24.0	+41.4	+41.4	+68.2

Numbers refer to proportion of biomass loss relative to non-degraded plant community. I: Grade I degradation (population %); II: Grade II degradation (population %); III: Grade III degradation (population %); IV: Grade IV degradation (population %).

7.4.5.3 Diagnosis of the growth rate of plants indicative of degraded steppe

In the process of typical steppe degradation, *Artemisia frigida*, *Potentilla acaulis* and *Steellera chamaejasme* often increase as the steppe becomes more degraded, due to their specific adaptation of grazing-tolerance. Therefore, they are plant species that are indicative of the degradation process. In the process of desert steppe degradation, the plant species indicative of degradation include *Ajania achilloidea*, *Hippolytia trifida*, *Artemisia frigida*, *Cleistogenes soongorica*, *Allium polyrrhizum*, *Convolvulus ammanni*, and *Peganum harmala*. In the degraded plant communities of meadow steppe, *Carex duriuscula* is a very good grazing-tolerant indicator plant. The intensity of steppe degradation can be determined according to proportion of these plants. Table 7.14 shows the proportion of indicative plants at different levels of degradation series of the steppe (Wang et al., 1996a,b,c; Wang et al., 2000a,b).

7.4.5.4 Diagnosis of grazing forage composition of grass community

Livestock grazing causes variable degradation to different plant species according to the palatability and quality of steppe plants. Due to intensive and selective grazing, the ratio of good quality grasses in plant communities will gradually decrease and the ratio of poor quality grasses increases along with other non-edible and poisonous plants. Depending on the quality of forage grasses, steppe plant communities with different degradation intensities can be classified as good, fair, poor and non-edible, and this classification is an effective measure for diagnosing and assessing steppe degradation. Using *Leymus chinensis* steppe as an example of a degradation series, an assessment of plant forage edibility can be seen in Table 7.15.

7.4.6 Moisture and nutrient regime of degraded steppe

Based on dynamic monitoring of *Leymus chinensis* steppe degradation types with an *Artemisia frigida* community, the status of plant resources of degraded steppe can be defined.

The moisture regime of the steppe is reflected in the composition of plant moisture ecotypes. Normally, under relatively humid conditions, mesophilous plants form a high percentage of plant species. In drier habitats, the proportion of xerophytes is higher. The plant communities discussed in this chapter come from four moisture ecotypes, namely, xerophytes, meso-xerophytes, xero-mesophytes and mesophytes. The process of restoration succession can be measured from the proportion of plants representative of different moisture ecotypes. Xerophytic and meso-xerophytic plants are the dominant plant species in degraded steppes. Perennial mesophytes make up a low proportion of the total plant species during the process of restoring the normal succession. However, a high proportion of mesophilous annual and biennial plants is present during the initial stage of restoration but after six years, they comprise a very low proportion of the plant species. This shows that, due to the low biological productivity of degraded communities, perennial plants were unable to fully use the available water thus allowing annuals and biennials to flourish in the absence of grazing and make full use of remaining water,

Table 7.14 Survival rates of indicative plants in degradation series of steppe

Indicative plants	Typical steppe				Desert steppe				Meadow steppe			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
Artemisia frigida	+	++	+++	++	+	++	++	+	+	+	++	+
Potentilla acaulis	+	++	++	+++					+	++	+	
Cleistogenes squarrosa	+	++	++	+								
Heteropapus altaicus	+	+	+						+	+	+	
Thymus vulgaris	+	++	+++	++								
Steellera chamaejasme	+	++	++	++								
Ajania achilloidea					+	++	+++	+++				
Hippolytia trifida					+	++	+++	+++				
Cleistogenes songorica					+	++	++	+				
Allium polyrrhizum					+	++	+++	++				
Convolvulus ammanni			+	+	+	++	+++	+++				
Peganum harmala					+	+	++	+++				
Carex duriuscula									+	++	+++	++

Note: +++ for dominant species, ++ for sub-dominant species, and + for normal species; I: Grade I degradation; II: Grade II degradation; III: Grade III degradation; IV: Grade IV degradation.

Table 7.15 Diagnosis of forage plants community of degraded *Leymus chinensis* steppe (biomass unit: $g \cdot m^{-3}$)

	Grass community patterns	I		II		III		IV	
		Biomass	%	Biomass	%	Biomass	%	Biomass	%
Good quality forage plants	Rhizoma herbosa	71.2	26.6	58.8	26.1	20.2	14.2	7.6	11.5
	Tall herbosa community	55.5	20.7	45.5	20.2	21.6	15.1	8.2	12.4
	Allium spp.	14.4	5.3	7.7	3.4	3.6	2.5	1.8	2.7
	Legume plants	12.2	4.6	8.2	3.7	3.1	2.2	1.2	1.8
	Total	153.3	57.2	120.2	53.4	48.5	34.0	18.8	28.4
Medium quality forage plants	Small herbs	15.0	5.6	12.6	5.6	11.5	8.1	8.5	12.8
	Carex spp.	10.6	4.0	7.5	3.3	4.2	3.0	0.5	0.8
	Small bushes	12.5	4.8	11.5	5.0	10.8	7.6	4.1	6.2
	Total	38.1	14.4	31.6	14.1	26.5	18.0	13.1	19.9
Inferior weeds	*Artemisia* plants	30.6	11.9	34.4	15.3	32.5	22.7	28.2	42.7
	Weeds	36.5	13.6	31.4	14.0	28.5	20.0	2.2	3.3
	Non-edible plants	9.0	3.3	7.8	3.5	6.6	4.7	3.8	5.7
	Total biomass	267.5	100.0	225.4	100.0	142.6	100.0	66.1	100.0

I: Grade I degradation; II: Grade II degradation; III: Grade III degradation; IV: Grade IV degradation.

occupying survival space in the degraded community.

Measurement of soil nutrients (Table 7.16) from sampling sites on the degraded steppe (He and Kang, 1994) shows that the concentrations of soil nutrients in the degraded community are not obviously reduced. The biomass productivity of the degraded steppe community is only one third of the biomass productivity of the community after fifteen years of restoration succession, and soil nutrients in the degraded community are not fully utilized (Hao et al., 2004; Wang et al., 2008). When the steppe is degraded and covered by *Artemisia frigida* communities, the soil fertility does not decline immediately. This indicates that soil deterioration is slower than vegetation degradation and that is why there are some nutrients still remaining in the degraded steppe. Moisture, nitrogen and phosphorus are the limiting elements that control the productivity of the steppe community. The remaining nutrients and moisture provide the basis for the restoration succession of the degraded community.

Table 7.16 Concentrations of soil nutrients in degraded (*Artemisia frigida*) steppe and revegetated steppe (He and Kang, 1994)

Sampling sites	Organic matter (%)	Total Nitrogen (%)	Total Phosphorus (%)	NO_3–N (mg·100g^{-1})	NH_4^+–N (mg·100g^{-1})	Available P (mg·100g^{-1})
During restoration (1993)	1.7478	0.1491	0.1155	0.4399	0.1569	0.1863
Degraded without restoration	1.5163	0.1224	0.1076	0.4469	0.2056	0.1820
Restored after ploughing treatment	1.2604	0.1248	0.0964	0.3231	0.1135	0.1861
Site reseeding with *Leymus chinensis*	1.1406	0.1319	0.1208	0.5250	0.1297	0.1861
Restored after scarification treatment	1.8371	0.1594	0.1121	0.4018	0.2163	0.1741

7.5 Restoration and rehabilitation of degraded steppe

When the steppe degradation is too serious to self-recover with resilience, some artificial measures to assist the recovery succession must be applied. The ecological restoration of degraded steppe must follow the rules and principles of ecology and economy, so as not to create new degradation and destruction on steppe.

7.5.1 Restoration and succession of degraded steppe

The structure and appearance of the steppe plant communities are characterized by the dominant species and the botanical composition. Therefore, an alteration to the dominant species can be a signal as to the succession stage of the community. The above ground biomass is the indicator for judging and determining the dominant species. This is because there is functional relationship between the quantitative criteria of height, density, coverage, frequency of plant community and the biomass of the plants. The change in dominant species during the restoration succession is reflected in the biomass production of each species in the plant community. By analyzing the restoration succession of a degraded community of typical steppe, different successional stages can be classified according to the changes in the dominant species (Hao et al., 1997; Liu et al., 1998).

7.5.1.1 Dominant plant is *Artemisia frigida*

The plant community on a typical degraded steppe is dominated by *Artemisia frigida*, *Artemisia pubescens*, and *Cleistogenes squarrosa*. These species are representative of the final successional pattern in degraded typical steppe and can therefore be considered as a starting point for the study restoration succession. The dominant effect of *Artemisia frigida* is significant in this type of degraded community, and during the growing season the community is grey green in color, while the *Caragana microphylla* community is a dark green color that forms a mosaic of small bush layers.

Plants in such communities are dwarf sized and when the above ground biomass production is as high as possible, the mean heights of *Artemisia frigida*, *Artemisia pubescens*, and *Cleistogenes squarrosa* are respectively 13.0 cm, 16.7 cm and 12.3 cm, and the mean height of *Caragana microphylla* is 18.5 cm. The average dried weight of each individual *Artemisia frigida* plant is 0.25 g per bush. In comparison with the height of the original grass, this plant is very small and short. Thus, the exposed surfaces (bare ground) in the degraded communities are bigger. Due to the limitation of nutrients, the generation and growth of various communities are slow and therefore their seasonal changes are non-significant. Thus, this degraded community is a community that is maintaining itself on a lower energy level.

7.5.1.2 Growth stage of *Artemisia frigida* + *Agropyron cristatum*

During the initial phase (year 1–3) of the restoration succession, *Artemisia frigida* is the dominant species but *Cleistogenes squarrosa* is replaced by *Agropyron cristatum* which gradually exceeds the coverage of *Artemisia pubescens* becoming the second dominant species. During this stage, exploitation of various residual resources enables rapid generation and above ground biomass increases quickly during the growing season. The height of plant community increases and the biomass of each individual plant also gradually increases. This means that the remaining resources are transformed into a productive of plant community. Interactions between different species also take place, with the exception of *Cleistogenes squarrosa* which, at a lower layer of the community, continues to decline. *Artemisia frigida* and *Artemisia pubescens*, due to their capture of a large share of the nutrients, become the dominant plants. At the initial stage of restoration, *Artemisia frigida*, *Artemisia pubescens* and other dominant species did not fully use the resources (moisture and nutrients) available to the plant community; therefore, pioneer annual and biennial plants with a strong regeneration potential flourished.

7.5.1.3 Dominant plant — *Agropyron cristatum*

Agropyron cristatum is further developed from the previous stage and is one of the main contributors to the biomass of the plant community. *Leymus chinensis* is slowly increasing while *Artemisia frigida* and *Artemisia pubescens* decline, and the annual and biennial weeds also increase. The succession of community species is one of gradual replacement. The replacement of dominant species shows that a redistribution of community resources has taken place and it also indicates that the restoration succession is developing processes where inter-specific competition for remaining resources is a key factor in the redistribution of resources. During the early stages, the productivity level of the community is not obviously increased and the remaining resources are inefficiently used. Because both *Agropyron cristatum* and *Artemisia frigida* are densely crowded, some plant species are overshadowed and struggle for light. The appearance of the different patches of plant populations results in an unevenness in the plant community. The dominant plants have a dull color during the growing season, but *Allium bidentatum* and other *Allium* spp. flower in July.

7.5.1.4 Dominant plant — *Leymus chinensis*

Five years after the closure of the degraded steppe, *Leymus chinensis* becomes a co-dominant plant species with *Agropyron cristatum*, while *Artemisia frigida*, *Artemisia pubescens* and *Cleistogenes squarrosa* form a low proportion of the plant community. Along with the increase in *Leymus chinensis*, the plant community productivity rises to a high level and the maximum annual biomass of individual plants are approximately 200 $g \cdot m^{-2}$. Thus, the plant community is now able to fully utilize any residual resources from the previous stages of the succession. However, the redistribution of resources is not yet complete and the patches of different populations within the community structure become more pronounced. These patches of different populations enable different species occupy their own spaces among the community, forming a confrontational or competitive situation in the interspecies relationships. Because *Leymus chinensis* occupies the dominant position in the plant community, the height and density of plants increases and the accumulation of withered and dead vegetation (plant litter) also increases.

7.5.1.5 Dominant plant — *Stipa grandis*

During the succession stage from degraded steppe to typical steppe, *Stipa grandis* slowly increases to become the dominant plant species and it competes and grows and declines with *Leymus chinensis* in a spot-like pattern. As a perennial species, the population of *Agropyron cristatum* is stabilized, and other plant species in the community are redistributed. For example, *Achnatherum sibiricum*, *Serratula centauroides*, *Adenophora* spp., *Allium* spp. and other species increase. Thus, the process forming the spatial structure of the plant community is initiated by the gradual changes in the spatial distribution of various species and the patchy occupation of sites by other species.

7.5.2 Changes in primary productivity of plant communities during restoration

By measuring the time taken to achieve maximum above ground biomass of the plant community in the growing seasons during the restoration succession we can track changes in the productivity level of the main plant species during the restoration succession.

7.5.2.1 Step changes and metastable levels of plant community productivity during the restoration succession

The maximum above ground biomass of the degraded community increases, on average, to 250 $g \cdot m^{-2}$ and during the increase there are two step changes between three levels. The initial productivity level is the biomass of the degraded community which reflects productivity level of the degraded community under grazing pressure. The first step change occurs as the biomass of the community increases from 70 $g \cdot m^{-2}$ to 160 $g \cdot m^{-2}$ and then gradually increases to the second productivity level. The recovering degraded community remains at this productivity level for several years and its biomass is about 160–170 $g \cdot m^{-2}$. After 4–5 years, the second step change occurs as the community reached the third level of productivity with a mean biomass value of 240 $g \cdot m^{-2}$ which is similar to the productivity level of an undegraded community (Ren et al., 2001; Shi et al., 2001).

Following the two step changes, the annual change in productivity of the community is relatively small. Along with the replacement of the main species during the restoration succession, a metastable community is formed at two productivity levels.

7.5.2.2 Causes of step changes in primary productivity and the appearance of metastable states during the restoration succession

Based on the analysis above, it can be seen that the increases in primary productivity of the community during the restoration succession occur in the form of alternating step changes and metastable states.

7.5.3 Relationship between primary productivity of the community and water resources during the restoration succession

Water (moisture) is a factor limiting the primary productivity of the steppe community. For the plant community of the zonal typical steppe, atmosphere precipitation is the only method for harvesting the water resource. Based on the precipitation and the maximum existing above ground biomass from May 1st through the growing season every year (Table 7.17), the following paragraphs discuss the significance of precipitation on restoration succession, metastable states and the step changes in primary productivity of the degraded community.

It is useful to study the dynamic process of restoration and succession over time. The ratio of precipitation during the growing season to the existing above ground biomass is a useful criterion for measuring the utilization efficiency of water resource of the plant community.

It can be seen from Table 7.17 that the availability of water resources in the steppe community is not a direct factor governing the change in dominant species during the restoration succession.

7.5.3.1 Analysis of dominant species of *Artemisia frigida* community at degradation stage

It can be seen from Table 7.17 that the water volume consumed for biomass production by the degraded community is 2.55 $\mathrm{mm\cdot g^{-1}}$ but this is reduced to only 1.09 $\mathrm{mm\cdot g^{-1}}$ in second year of succession. This shows that available water resources in degraded community are sufficient. If the minimum value of water volume required per unit of dried material is 1.09 $\mathrm{mm\cdot g^{-1}}$, the most effective ratio of water use in the community is as high as 1.10 $\mathrm{mm\cdot g^{-1}}$. Using this ratio, the production of 74.13 $\mathrm{g\cdot m^{-2}}$ of dried material by the degraded community requires only 81.5 mm of precipitation. Under pressure from overgrazing, plant growth and regeneration in the degraded community will be limited and even an increase in precipitation cannot significantly increase biomass production by the community. Accordingly, the productivity of the community at the degraded stage is primarily controlled by grazing pressure and it is not significantly related to precipitation.

Table 7.17 Dynamics of plant community biomass and precipitation during restoration succession

Testing date (month/day/yr)	Direct effective rainfall (mm)	Survival biomass of community ($g{\cdot}m^{-2}$)	Ratio* ($mm{\cdot}g^{-1}$)
08/03/1983	188.7	74.13	2.55
07/25/1984	175.5	161.60	1.09
08/15/1985	237.3	164.20	1.45
08/29/1986	275.0	171.92	1.60
08/30/1987	221.7	164.92	1.34
08/29/1988	247.6	166.01	1.49
08/30/1989	158.6	131.54	1.20
09/01/1990	401.2	250.90	1.60
09/01/1991	256.0	182.99	1.40
08/04/1992	303.8	246.39	1.23
08/14/1993	243.8	217.01	1.12

*Ratio = Effective precipitation/plant community biomass

7.5.3.2 Analysis of first meta-stable state

During the first meta-stable state, the maximum difference in precipitation during the growing season is 99.5 mm and the maximum difference in community biomass is 10.32 $g{\cdot}m^{-2}$. (Table 7.17). For instance, the precipitation during the growing seasons of 1988 and 1993 were almost similar, but the difference in biomass produced by the community was as high as 51 $g{\cdot}m^{-2}$. The average biomass was 166 $g{\cdot}m^{-2}$ (± 3.82) during the first meta-stable state when precipitation in the growing season was over 175 mm. When the precipitation increased, the change in the biomass of the community was remarkable.

The biomass of community at this stage of the succession is mainly determined by productive potential and resource utilization by the dominant species of community. Even when the precipitation is higher, the dominant plant species during the early stages of the succession (*Artemisia frigida*, *Agropyron cristatum* and *Artemisia pubescens*) will not be able to fully utilize the moisture. This is because these dominant plants are dwarfs with good drought-tolerance and they have a relatively low efficiency of biological accumulation and low water consumption. Therefore, the oversupply of water resources occurs during this stage and this is one of the factors leading to further succession. In general, the correlation between the biomass of community and higher precipitation at this stage in the succession is also unremarkable. The minimum water usage for the production of dry matter can be estimated at 1.10 $mm{\cdot}g^{-1}$ and thus the mean biomass of the community at 166 $g{\cdot}m^{-2}$ during this stage needs only 183 mm of precipitation. At this stage, precipitation during the growing season in most years exceeds the requirement.

7.5.3.3 Analysis of second meta-stable state

There is a significant interrelationship between the community biomass and precipitation during this stage. When there is an increase in precipitation during the growing season, the biomass of plant community will also be significantly increased. When the precipitation is very high during the growing season (if the rainfall is higher than 300 mm), the biomass of community will slowly increase. For instance, in 1989, precipitation was 158.6 mm and the water usage volume for the production of dry matter was 1.20 $\text{mm}\cdot\text{g}^{-1}$ (Table 7.17), which was a little more than the estimated 1.10 $\text{mm}\cdot\text{g}^{-1}$. In 1993, precipitation was 243.8 mm and the use efficiency of the water resource was the highest. In 1990, the precipitation during the growing season was 401.2 mm and biomass was very high at 250.9 $\text{g}\cdot\text{m}^{-2}$. If the precipitation during growing season is particularly high (more than 400 mm), the rate of increase of biomass would slow down or cease. Accordingly, the relationship between precipitation during the growing season and community biomass during this metastable state can be interpreted as a logarithmic curve with the mean precipitation at approximately 400 mm and the community biomass around 250$\text{g}\cdot\text{m}^{-2}$. After 1990, the volume of water used for the production of dry matter by the community gradually decreased and this shows that the water resource use efficiency of the community with increased each year becoming more suited to the habitat conditions of the community.

To summarize, the step change in community productivity and the occurrence of meta-stable states are part of the process of restoration succession and are not directly related to precipitation.

7.5.4 Changes in community density during restoration succession

The resource ratio hypothesis of succession emphasizes only one area occupied by mature individuals and does not take into account the spatial variations and different life stages (Tilman, 1985; 1994). The method of calculating plant individuals is different to calculating plant species (calculations should be conducted on the basis of individual plants, communities and branches of different species); therefore, community densities are not comparable during the restoration succession process. To obtain comparable data, the community densities should be standardized, by converting the existing biomass of various communities above ground into a unit of density related to a single individual plant of *Leymus chinensis*, identified as the "*Leymus chinensis* Unit". Thus, the standardized community density (SCD) is calculated by:

$$SCD = \sum_{i=1}^{n} \frac{d_1}{W_1} W_i \quad (i = 1, 2, \cdots, n) \tag{7.3}$$

Where d_1 refers to the density of *Leymus chinensis*, W_1 refers to the dried above ground biomass weight of *Leymus chinensis*, W_i refers to dried biomass weight of species i, and n refers to the number of different species. Because d_1 and W_1 are data collected from similar sampling times the standardized community density is different from a comparison of the community biomass. Annuals and biennials are pioneer plants and as they are only temporarily dominant they are not calculated.

7.5.5 Improvement in herbosa composition after the enclosure of degraded steppe

The enclosure of degraded steppe eased the impacts of livestock trampling and selective grazing and allowed the severely degraded steppe community to be restored and improved. Through the survival, competition and interaction within and between species, the community composition gradually changed. For example, *Artemisia frigida* + small herbosa plant communities gradually evolved into *Leymus chinensis* + *Stipa grandis* communities which are adapted to the local climatic conditions. The structure and function of the community changed. Community succession patterns can be classified into three categories, namely:

- the growing community;
- the declining community; and
- the perennial associated community.

The growing community refers to plant species which are sparse and poorly represented in the degraded community but whose density and function increase each year during the restoration succession. These plants include *Leymus chinensis*, *Stipa grandis*, *Agropyron cristatum*, *Achnatherum sibiricum*, *Allium* spp. and others. In particular, *Leymus chinensis* increased significantly during the eighth year following the steppe enclosure and became the dominant plant species in the community with a high importance value. The density and function of other species such as *Stipa grandis*, *Agropyron cristatum* and *Koeleria cristata* gradually increased during the restoration succession. This is because these plants species have a high competitive potential under natural conditions, although their community functions fluctuate due to annual changes in atmosphere precipitation and stored soil moisture.

The declining community includes plants that decreased in number and function as the succession developed. They include *Artemisia frigida*, *Artemisia pubescens*, *Cleistogenes squarrosa*, *Allium tenuissimum*, *Potentilla acaulis* and *Heteropapus altaicus*. These declining plant species lost their dominance and became the associated plant species in the community.

The role and function of the perennial species of xeric dwarf semi-bushes, such as *Artemisia frigida*, *Artemisia pubescens*, *Cleistogenes squarrosa*, fluctuate during the restoration succession but many remain as associated species. Other associated species include *Carex korshinski*, *Allium bidentatum*, *Allium ramosum*, *Potentilla bifurca*, *Melandrium apricum*, *Saposhnikovia divaricata*, *Thalictrum petaloideum*, *Potentilla verticillaris* and *Cymbarria davurica.*

According to the living forms and eco-biological features of the various plant species, they can be divided into nine categories, including: bush plants, semi-bush plants, tall herb plants, dwarf herb plants, rhizoma herb plants, rhizoma *Carex* spp., bulb weeds, axial root herbosa, and annual and biennial plants (Table 7.18).

Table 7.18 Changes of important values (%) of plant layers during the restoration succession of degraded steppe

Plant layers	1983	1984	1985	1986	1987	1988	1989	1990	1991
Bush plants	8.2389	8.5652	5.6438	6.0096	6.6583	6.8864	6.2914	6.8536	6.8707
Semi-bush plants	4.4388	13.3171	15.3832	14.533	13.2631	11.1231	9.577	9.1694	6.2874
Tall herbs	6.8338	10.0137	10.0226	11.6864	9.1432	8.9905	14.6043	16.4742	16.959
Dwarf herbs	10.9618	7.9078	7.4366	7.7779	9.0655	10.3198	9.7679	11.9528	11.734
Axial root herbosa layers	27.5846	20.6495	23.4866	20.3821	30.7006	16.0262	23.0311	17.8812	17.777
Rhizoma herbs	14.5933	18.4435	18.6421	17.7213	17.8191	21.3900	20.6193	23.6143	24.067
Rhizoma *Carex* spp.	0.6746	1.4265	0.8257	1.1481	1.0715	0.8795	1.2157	0.8476	0.8715
Bulb weeds	12.5054	11.8629	11.2094	12.0152	9.4052	12.6915	12.6915	12.3070	14.0276
Annual and biennial plants	7.1971	7.9138	7.35	8.7364	5.8736	4.3488	5.3018	4.8999	5.4047

The bush plants are mainly composed of *Caragana microphylla* which has a height of 20–30 cm. It is a dominant layer of the community and plays an important role in stabilizing degrading communities, because it is a grazing-tolerant plant.

The semi-bush plants are composed of *Artemisia frigida* and *Kochia scoparia* which have heights of 13–18 cm. At the initial stage of steppe enclosure, they hold an important position in community. Later, their function is significantly reduced and they can be regarded as slowly declining species.

The tall herb plants are composed of *Stipa grandis* and *Achnatherum sibiricum* which have heights of 30–50 cm. Their growth is slow prior to the closure of the steppe and but as restoration progresses they became the dominant layer in the community.

The dwarf herb plants are composed of *Cleistogenes squarrosa*, and *Koeleria cristata* and their heights vary from 10 to 15 cm. At the initial stage of closure of the steppe, these plants are dominant in the degraded community. At the later stage of community succession, the function of *Cleistogenes squar-*

rosa was reduced and the function of *Koeleria cristata* was increased. They are associated components of the plant association.

The rhizoma herb layer is composed of *Leymus chinensis.* After enclosure of the steppe, this layer gradually replaced the function of semi-bush plants of *Artemisia frigida* and became the dominant layer of the community.

The rhizoma *Carex* spp. layer is composed of *Carex korshinski* which is one of the perennial associated plants in the community.

The bulb plant layer is composed of several *Allium* spp. plants and their heights vary from 15 to 30 cm. This layer is also one of the perennial associated plant layers in the steppe community.

The axial root herbosa layers have important functions in community structure and function. They are mainly composed of *Ajania* spp., and species from the Leguminosae, Rosaceae, Umbellifereae, and Ranunculaceae families. These plants increased gradually after the enclosure of the steppe and are characterized by their colorful flowers, thus making an important contribution to seasonal changes of the natural scenery in the community.

The annual and biennial plants are mainly composed of *Artemisia scoparia*, *Salsola collina*, *Dontostemon micranthus* and several other hellebore plants. There is a trend of a gradual decrease in the function of these plants during the community restoration succession, related to competition for survival space, moisture and nutrients among annual/biennial plants and perennial plants.

After enclosure of the steppe, the changes of community structure described above enable the degraded steppes to improve from poor steppes or grazing lands with low utilization values to useful rangelands (Chen and Wang, 1998).

7.5.6 Amelioration of loose soil on the degraded steppe

When the soil of degraded steppe is raked and loosened (scarified), the change in community composition and structure was accelerated (Table 7.19). The height of *Leymus chinensis* doubled to 40–50 cm, plant density increased from 44 plants$\cdot$m^{-2} to 185 plants $\cdot$m^{-2} and the above ground biomass increased by 49%. Additionally, the proportion of above ground biomass from herbosa plants increased from 43.5% to 57.2%. The proportion of above ground biomass from leguminous plants increased from 6.2% to 12.3% and the proportion of above ground biomass of *Ajania* spp. decreased from 41.14% to 16.6% (Chen et al., 2008).

After soil amelioration of the degraded steppe, 98% of the below ground biomass of the steppe community is concentrated in the top 40 cm of soil. The ratio of above ground to below ground biomass in the steppe community is normally 0.6, but this increased to 1.15 after soil amelioration, as the above ground biomass was greatly increased. It is thus clear that soil scarification in semi-arid climate conditions in the steppe zone is an effective solution to increase the community biomass.

Table 7.19 Comparison of quantitative nature of main plant community after eight years of soil raking and loosening

Plant species	Comparison(CK)			Loosen soil and light rake		
	H	DP	DW	H	DP	DW
Leymus chinensis	31	49.0	42.23	50	185.0	60.47
Agropyron cristatum	33	10.0	33.55	39	21.0	48.37
Cleistogenes squarrosa	8	2.0	4.08	11	8.0	1.54
Koeleria cristata	17	8.0	10.80	12	6.0	2.27
Stipa grandis	30	6.0	11.80	68	6.0	28.30
Artemisia pubescens	44	2.0	0.92	34	8.0	7.47
Artemisia scoparia	30	3.5	3.66	4	9.0	9.63
Artemisia frigida	17	3.0	4.81	11	4.0	4.22
Heteropapus altaicus	23	6.3	6.60	16	3.0	0.80
Allium bidentatum	25	3.8	0.80	21	12.0	5.53
Allium ramosum	26	2.0	0.67			
Allium tenuissimum	25	1.7	0.87			
Caragana microphylla	28.5	10.5	23.46	34	1.0	1.47
Melissitus ruthenica	32.2	20.0	9.37	20	5.0	5.66
Astagalus acaulis	6	1.0	0.11	13	3.0	9.23
Potentilla acaulis	4	1.0	4.02	3	1.0	1.50
Potentilla tanacetifolia	23	1.3	4.42	30	3.0	5.75
Potentilla bifurca	14.5	5.5	2.54	19	3.0	2.10
Others	33.2	2.4	5.95	27	9.0	3.05
Total		139.0			287.0	197.36

H: Height (cm); DP: Plant density (plants·m^{-2}); DW: Dry weight (g·m^{-2})

The evenness criteria (H) and the diversity criteria (D) of the community of degraded steppe were showed a general declining trend before soil amelioration. This trend can be expressed by the following equations:

$$H = 2.61 - 0.28t \ (t = \text{years after soil treatment, where } t \leqslant 8 \text{ and } r = 0.99) \text{ and}$$

$$D = 3.76 - \ln t \ (\text{where } t \leqslant 8 \text{ and } r = 0.99).$$

More than eight years after soil scarification, the trend in evenness criteria and the diversity criteria increased, and can be expressed with the following equations:

$$H = 0.97 \exp(0.06t) \ (\text{where } t \geqslant 8; r = 0.99)\text{and}$$

$$D = 1.14 \exp(0.08t) \ (\text{where } t \geqslant 8; r = 0.97)$$

It is thus clear that the increase or decrease in the diversity criteria is not related to a change in plant species richness, but is related to the plant species evenness and changes in the two criteria are consistent.

Both *Leymus chinensis* and *Stipa grandis* are poorly represented in the degraded steppe where *Artemisia frigida* and *Cleistogenes squarrosa* are dominant. Through soil amelioration, the growth of *Leymus chinensis* species was promoted, the evenness of community decreased and as result, community diversity also decreased. From the ninth year, the functions of the dominant plants of the hellebore and Ajania families were gradually replaced by herbosa plants, which are adapted to the zonal climate conditions so that evenness criteria and diversity criteria of the community increased (Hao et al., 2004).

7.5.7 Effect of burning on steppe degradation

Wild fires are an ecological phenomenon on the steppe that often occur during the winter and spring seasons. Fire has different effects on different species, so it can promote or control the generation and growth of plant species and affect the steppe quality and utilization value. Research has been conducted internationally on the effects of fire on the regeneration of forest and bush vegetation. Fire is used as one of the tools for managing the steppe, including for specific goals of bush clearance, insect control, grassland improvement, and the promotion of animal husbandry and its development.

Little research has been conducted in China on the effects of fire on the ecological and economic efficiency of typical steppe. However, some recent experiments on the effect of fire on *Leymus chinensis* steppe have been carried out. Experimental sites were established on enclosed and restored steppes of *Leymus chinensis* + *Stipa grandis* + *Achnatherum* spp. The enclosed steppe is an original steppe type which has been adapted to the local climate and soil conditions, while the restored steppe is a community type which mainly comprises *Artemisia frigida* + small herbosa following the enclosure of an over-grazed *Leymus chinensis* steppe. The soils of the two experimental sites are light loams and thick layer dark chestnut soils (Bao et al., 2000a).

The study examined the effects of fire on the composition, quality and utilization efficiency of *Leymus chinensis* steppe. The biomass, soil moisture and other parameters were measured every fifteen days during the growing season from May 15 to September 15.

Fire did not cause any obvious effects on the total production of the two experimental sites of the *Leymus chinensis* steppe. The maximum productivity value during the whole year occurred at the end of August and the maximum productivity was typically in the range of 180–200 $g \cdot m^{-2}$.

Fire promoted the growth of *Leymus chinensis* as a dominant plant in the community. During the maximum production period of the growing season, the production of *Leymus chinensis* inside the non-burned site was 30–50 $g \cdot m^{-2}$, which accounted for 70–80% of herb plants in the community. The effect of fire on the increase in production of *Leymus chinensis* is related to changes in the physical and chemical properties of the burned soil. *Leymus chinensis* is a nitrophilous rhizome geophyte and its newly generated sprouts grow under the topsoil so fire will not damage the growth of regenerating sprouts. In addition, fire can improve nutrient regime of the topsoil and can effectively control the growth of *Stipa grandis*, another dominant plant on the *Leymus chinensis* steppe (Bao et al., 2000b).

The yield of burned *Stipa grandis* steppe is lower than the yield of unburned *Stipa grandis* steppe. The yield of *Stipa grandis* in unburned steppe is similar to the yield of *Leymus chinensis* (peak biomass above ground is 30–50 $g{\cdot}m^{-2}$). However, the biomass of the burnt *Stipa grandis* is only 10–30 $g{\cdot}m^{-2}$. Burning in autumn has an obvious controlling effect on *Stipa grandis*. *Stipa grandis* is a chamaephyta and its generating sprouts are grown on the topsoil where they are damaged by fire.

In the burned community, herbosa plants maintain vigorous photosynthesis and the increase and accumulation of organic matter lasts to the end of growing season. At the end of the growing season, the yield of herbs on the burned steppe is higher than on the unburned steppe and the difference can be as high as 30–40 $g{\cdot}m^{-2}$. During the second half of August and early September (harvest and forage storage season), the total yield of herbs from *Leymus chinensis* steppe is 300–375 $kg{\cdot}ha^{-1}$. The increased production of these nutritious herbs improves the quality of steppe community. It can also be seen from the experiments, burning in spring has more beneficial effects on the production of *Leymus chinensis* than burning in autumn.

The yields of *Allium* spp. plants before and after burning were almost the same, or slightly increased before burning. *Allium* spp. plants are geophytes and burning does not cause any damage to their generating sprouts. These plants are usually associated with *Leymus chinensis*, *Stipa grandis* and other dominant plants, and *Allium* spp. are less important as competitors for moisture and nutrients. Fire does not cause significant effects on the yield of *Allium* spp. plants.

Fire does have an obvious effect on the growth of species of the Compositeae family by decreasing yield. In the typical communities of *Leymus chinensis* steppe, Compositeae species include *Serratula centauroides*, *Artemisia pubescens*, *Artemisia frigida* and other chamaephyta. Fire damages the generating sprouts of these plants. On the unburned steppe, the yield from Compositeae species was 10–15 $g{\cdot}m^{-2}$ and on the autumn burning steppe, the yield is also 10–15 $g{\cdot}m^{-2}$. Fire can restrict the growth of *Artemisia* spp. and promote the growth of *Leymus chinensis* thus enabling an increase in steppe productivity.

Caragana microphylla is a bush on the *Leymus chinensis* steppe. Fire, especially in autumn, restricts the growth of this bush. On the unburned steppe, the yield of *Caragana microphylla* was 20–50 g/m^{-2} compared 5–20 g/m^{-2} on the burnt site. If the flames are higher than the bush height of *Caragana microphylla*, the fire will cause direct leaf scorch and kill the generating sprouts so that the yield in the following year is reduced. Although *Caragana microphylla* can control wind erosion of the soil and maintain snow on the steppe during winter and spring seasons, its presence affects forage production. Thus, burning is used to control the density of *Caragana* spp. and improve the utilization efficiency of the forage harvest.

The sharp thorns of *Stipa grandis* can penetrate the skin of livestock and damaging the leather industry. Burning can also reduce the cover of *Stipa grandis* and reduce damage from the thorny plant, helping the leather making industry by reducing the amount of scaring on animal hides.

The study of the effects of fire on steppe improvement contains two aspects, namely, the biological features of the various plants and the effects of burning on soil condition. Experiences from China and abroad show that the difference in location of the generating sprouts of the various plants affects their reaction to fire. Therefore, burning the steppe will promote the growth of some species and cause decline in others and altering the succession and community composition. Steppe fires can also change the soil structure and nutrient regime. First, the steppe fire clears plant litter above ground and alters the moisture regime, especially snow accumulation. It affects the light and temperature regimes of the land surface. Steppe fires can also accelerate the decomposition of soil organic matter on the steppe, and promote the vigorous growth of *Leymus chinensis* during the mid to late growing season leading to higher yield of improved quality forage. Fire has potential as a tool to speed up the restoration process of degraded steppe if appropriately used in a planned and controlled way consistent with local conditions and management aims (Bao et al., 2001).

References

Bao Y J, Li Z H, Liu Z L. 2000a. The simulated experimental research on the fire effects on Leymus chinensis steppe. Grassland of China, 1: 7-11.

Bao Y J, Li Z H, Liu Z L. 2000b. Influence of fire factor on *Leymus chinesis* population in Inner Mongolia steppe. Grassland of China, 3: 1-6.

Bao Y J, Ning Z, Li Z H, Liu Z L. 2001. Influence of fire factor on *Stipa grandis* population in Inner Mongolia steppe. Grassland of China, 1: 17-22.

Chen Z Z, Wang S P. 1998. Optimized productive paradigms of grassland animal husbandry in typical steppe. Beijing: Meteorological Press.

Cheng J Z, Lee X Q, Liu Z L, et al. 2008. Spatial variation of C and N contents of plant communities in the steppe of north China: Implication for the abnormal C/N ratio in the surface soil. GeoChina, 37(3): 265-274.

ERDUNBUHE. 2002. Desertification and its control strategies in Inner Mongolian Plateau. Hohhot: Inner Mongolia University Press.

Hao D Y, Gao X, Liu Z L, et al. 2004. Determination of plant community organization on steppe ecosystem health evaluation in Inner Mongolia. Acta Ecologica Sinica, 24(8): 1672-1678.

Hao D Y, Liu Z L, Wang W, Liang C Z. 1997. Research on the restoring succession of the degenerated grassland in Inner Mongolia. A mathematical model for plant community succession. Acta Phytoecologica Sinica, 21(6): 503-511.

He J P, Kang S A. 1994. Application of principal components analysis to evaluate the study of grassland soil fertilities. Journal of Inner Mongolia Agricultural University, 16(2): 52-57.

Liu Z L, Wang W, Hao D Y, Liang C Z. 2002. Probes on the degeneration and recovery succession mechanisms of Inner Mongolia steppe. Journal of Arid Land Resources and Environment, 16(1): 84-90.

Liu Z L, Wang W, Liang C Z, Hao D Y. 1998. The regressive succession pattern and its diagnostic of Inner Mongolia steppe in sustained and superstrong grazing. Acta Agrestia Sinica, 6(4): 244-251.

Ren T, Hao D Y, Shi X, et al. 2001. The influence of regression on the typical steppe in Inner Mongolia. Journal of Arid Land Resources and Environment, 15(3): 48-51.

Shi X, Hao D Y, Ren T, et al. 2001. The problems of selecting sampling in dynamic diagnosis of typical steppe. Journal of Arid Land Resources and Environment, 15(2): 80-84

Tilman D. 1985. The resource ratio hypothesis of succession. American Naturalist, 125: 827-852.

Tilman D. 1994. Competition and biodiversity in spatially structured habitats. Ecology, 75(1): 2-16.

Wang L X, Liu Z L, Liu H M, et al. 2008. Assessment of typical steppe ecosystem health in Inner Mongolia. Acta Ecologica Sinica, 28(2): 544-550.

Wang W, Liu Z L, Hao D Y. 2000a. Mechanism of degradation succession in Eymu chinesis+Stipa garandis steppe community. Acta Phytoecologica Sinica, 24(4): 468-472.

Wang W, Liang C Z, Liu Z L, Hao D Y. 2000b. Analysis of the plant individual behavior during the degradation and restoring succession in steppe community. Acta Phytoecologica Sinica, 24(3): 268-274.

Wang W, Liu Z L, Hao D Y, Liang C Z. 1996a. Research on the restoring succession of the degenerated grassland in Inner Mongolia. I. Basic characteristics and driving force for restoration of the degeneration grassland. Acta Phytoecologica Sinica, 20(5): 449-459.

Wang W, Liu Z L, Hao D Y, Liang C Z. 1996b. Research on the restoring succession of the degenerated grassland in Inner Mongolia. II. Analysis of the erstoring processes. Acta Phytoecologica Sinica, 20(5): 460-471.

Wang W, Liu Z L, Hao D Y, Liang C Z. 1996c. Research on the restoring succession of the degenerated grassland in Inner Mongolia. IV. Analysis of plant population dynamics during restoring succession. Journal of Arid Land Resources and Environment, 13(4): 44-55.