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A new approach to grassland management for the arid Aletai region in Northern China

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Abstract. Land degradation in the arid Aletai Region in northern China is not only detrimental to animal production, but also reduces the ability to conserve water resources by destabilising the catchments of rivers which affects runoff, thus, threatening the sustainable use of these grasslands. A new approach to grassland management based on carrying capacity and ecological services value of grassland types, using an index of classification management (ICG), was designed to ensure the sustainability of grassland ecosystems. In this approach, grassland is classified into 3 management sectors. The first is conservation grassland, which is mainly devoted to ecological and social values; the second is the moderately productive grassland, dedicated to multiple benefits by rational use; and the third is intensively productive grassland, focusing on maximum economic effect. For the arid Aletai region, no intensively productive grassland was available. Conservation grassland occupied 2.5 million ha, accounted for 25.4% of grassland area, and included alpine meadow, mountain meadow, mountain meadow steppe, mountain steppe and flat meadow. In these grasslands, grazing should be eliminated to allow restoration of degenerated areas, protect grasslands with important ecological values from destruction, and to further improve the environment. Moderately productive grassland covered 7.3 million ha, and the grassland types were alpine steppe, mountain desert steppe, plain desert steppe, steppe desert, and plain desert. Agricultural measures, such as fertiliser and irrigation application, should be used to enhance the productivity of these grasslands.

Additional keywords: carrying capacity, classification, ecological services value.

Introduction

Grasslands are the most extensive terrestrial vegetation type in China (41% of the land area). They play a significant role in animal husbandry (Hodgson 1990) and in improvement of the environment (Brunson and Steel 1996). However, before the 1970s grasslands in northern China were extensively and continuously exploited according to farmers' personal preference, as they were in New Mexico, USA and many other parts of the world (Saunderson 1975; Suttie *et al.* 2005). In this traditional use pattern, farmers focused on economic return and neglected the sustainability of grassland. Continuous grazing was widely adopted in grassland management. This usually led to grazing pressure on grasslands exceeding their carrying capacity because of the need to maximise the economic benefits to meet farmers' increasing demand for income. Thus, overgrazing and poor management have contributed to grassland degeneration, soil erosion, salinisation, desertification and sand dune formation (Baumer 1982; Zhu and Liu 1989). There are 13 million ha of degraded land in northern China, 33% resulting from overgrazing and about 10% caused by mining (Li 1997*a*). Desertification and degeneration of grassland threaten people's subsistence and economic sustainability development (Guo *et al.* 2003*a*).

Based on floristics, structure and habitat, 10 grassland types were identified in the arid Aletai region by the China Grassland Classification System (Jia 1980). This system was based on vegetation features and habitats of grassland types but neglected the ecological function values and differences in management patterns (Chen 1995). Each grassland type has many different functions with the importance of each function varying among the different grassland types (Guo *et al.* 2004*a*). Furthermore, the ecological functions of grasslands are not consistent with those that lead to economic returns to people who use the grasslands (Ayling and Kelly 1997). Consequently, this classification system has

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not reflected appropriate management patterns for the Aletai grasslands with the result of increases in degraded grassland from about 23% of the total area in the 1960s to 70% by 1995; a more than 3-fold increase (Chen 1995) resulting from mismanagement. Decline and degradation reduces the ability of grassland to conserve water resources mainly through destabilization of river catchments (Guo *et al.* 2003*b*), which creates severe problems for the rational use of water sources (Ren *et al.* 1997).

Rational management of grassland relies on a comprehensive understanding of the different ecological functions of grasslands. One of these functions is the ecological services value of a grassland, and this has attracted much recent attention in China (Chen and Zhang 2000; Xie *et al.* 2001) because of increases in the frequency of flooding, dust storms, and serious soil erosion resulting from the destruction of vegetation. Consequently, the Chinese government has initiated a program of environmental restoration for all of China, and the rational use of grassland is an important component of this program. The best way of managing grasslands is still under debate worldwide, and many studies have shown that a reduction or cessation of grazing will mostly result in the restoration of degraded grassland (Smith *et al.* 1995). Baron *et al.* (2000) proposed improved methods of management compared with traditional grazing or hunting, but did not consider non-forage values of grassland (Brunson and Steel 1996). However, the suggestion of a reduction in the amount of livestock to be carried has met with extreme resistance from farmers, and this remains a very unpopular measure in China as well as in other areas, for example, Arizona and New Mexico (Voorthuizen 1978). Many farmers depend on animal production for their livelihood and there is a long history of free grazing land in China (Li 1997*b*; Tian and Liu 2003). This kind of disagreement has created a dilemma for grassland management in northern China and has lead managers and professionals to seek a new approach to grassland use. Such an approach in the coming decades must include meeting farmers' needs as well as improving the grassland environment.

Classification management is an administrative and management approach to grassland ecosystems which can be an effective way to coordinate the sustainable use of natural resources. It is widely used for forest management in northern China (Hong and Hou 1999). Grasslands can be classified into 2 sectors on the basis of their potential in order to develop a sustainable pattern of use. This classification is based on the level of plant production, animal production and differences in ecological services produced by different grasslands. These 2 sectors are called 'productive grasslands' and 'conservation grasslands' (Guo *et al.* 2004*a*).

The objective of this research was to develop an approach to classification management for the arid Aletai grasslands that will ensure the sustainable utilisation of grassland resources and provide useful information for other regions with the same problems.

Classification management for grasslands

Each type of grassland should be managed to meet a specific need, and the relative importance of productive value, ecological value and social value of each grassland type is different. It is important to ensure that the ratio of productive grassland area to conservation grassland area is sufficient to meet local peoples' demand for the products of the different types of grassland. However, grassland functions vary with humans' management aims. Before the agricultural revolution, grassland was a virtually inexhaustible resource that supported our forebears. In an agricultural economy, grassland resources are thought of as the production bases of animal husbandry. Since the 1980s, ecological crises have obliged us to use grassland resources rationally for sustainable development. The most important grassland functions are the combination of social, ecological and economic values in the future. Current management of grasslands aims to maximise the economic benefits of animal husbandry, and usually causes some grassland degradation when they are stocked beyond their carrying capacities. This applies particularly to some grasslands whose very fragile habitats are easily destroyed, which, in turn, contributes to dust storms and other problems. There is an urgent need to conserve or restore the productive capacity of degraded grasslands. Classification management of grasslands involves their division into a productive sector based on productive value and a conservation sector based on the ecological service value of each grassland type identified from different features of the communities. Productive grassland is the production base for animal husbandry and may involve grass products such as hay and silage, whereas conservation grassland management focuses mainly on common-good effects.

Materials and methods

Study area

The Aletai Region, in China's Xinjiang province, lies between 45°00′ and 49°11′N and between 85°04′ and 91°04′E (Fig. 1). It covers 11.80 million ha, of which 83.4% is grassland. The available grassland is 9.8 million ha (Wu *et al.* 2003). This area is 24 times larger than the cropland and 15 times larger than the forestland in Aletai. The climate is cold temperate in the mountains and arid in the plain. The annual mean precipitation is 300–500 mm with an annual mean temperature of −4 to −2°C in the mountains, and at the foot of the mountains the annual mean precipitation is 130–150 mm and the annual mean temperature is 3.4–4.2°C. In the plains, the annual mean precipitation is 80–90 mm and the annual mean temperate is 6°C (Guo *et al.* 2004*b*).

Field survey

The following 10 grassland types; alpine steppe, alpine meadow, mountain meadow, mountain meadow steppe, mountain steppe, mountain desert steppe, plain desert steppe, mountain steppe desert, plain desert, and flat meadow,were identified from features of the plant communities and terrain (mountain, flat, plain) using a grassland map surveyed in 1990 (Appendix 1). A field survey was conducted during 1994–96, in which 94 survey sites were stratified in relation to the different grassland types throughout this region (Fig. 1). These survey sites were selected on the map, the latitude and longitude recorded and then located in the field. According to the spatial distribution and area of each grassland type, 4 and 15 typical survey sites were selected and marked for alpine steppe and plain desert, respectively, and 10 survey sites for each of the other 8 grassland types, all of which had suffered some degradation. In 1994, 0.1 ha was fenced at each survey site to exclude grazing. In 1995, 25 or 30 quadrats of 1 m^2 were randomly selected in each fenced area to collect quantitative data on the vegetation by throwing an object over the surveyor's shoulder and using where it landeds to locate a specified corner of the quadrat. The total number of quadrats was 2502. In this region, only 1 harvest was undertaken at the end of the growing season (Chen 1995), and comprised measuring the total foliage cover using 100 points (1 mm wire) and then collecting all plants rooted in each quadrat. Plant samples were separated into groups of species and dried and weighed in the laboratory. These data were used to calculate the carrying capacity of each grassland type in 1996. In 1994 and 1995, rainfall was 450 and 460 mm in the mountain region, 135 and 142 mm at the foot of the mountains and, 79 and 84 mm in the plains, and was similar to the mean rainfall over the past 20 years.

Area of each grassland type

The edge of each grassland type, according to the map produced in 1990, was revised following the field survey during 1995 and this draft map obtained from the Xinjiang Grassland Bureau in 1996. Based on this new draft map and Landsat images in 1995, a new grassland type map was produced and digitised, creating a spatial database. The area of each grassland type was calculated by ArcDIS8.1 software (ESRI Inc., USA) in 1997.

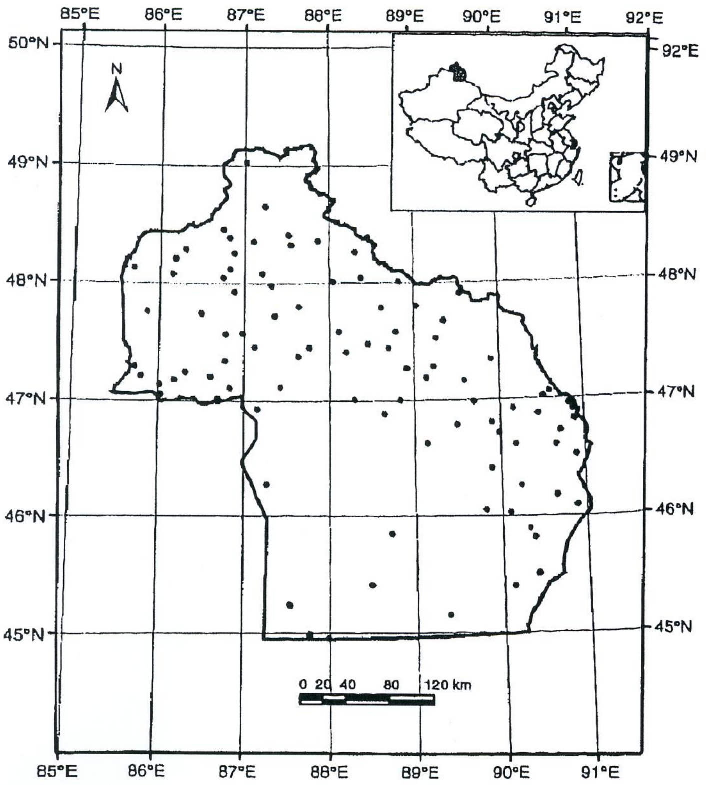

Fig. 1. Location of survey sites in the arid Aletai region of northern China.

Determining class and carrying capacity of each grassland type

Grasslands were divided into 8 classes according to dry matter productivity (DM) per year (MAPRC 1996) (Table 1).

One sheep with 40 kg live weight has been defined as 1 sheep unit in China, and the area necessary for grazing 1 sheep unit was used to indicate the productive ability of each grassland type. This area has generally been estimated by the equation:

$$PA = 1/\left(\frac{Y \times U}{I \times D}\right) \quad (1)$$

where PA is grassland area necessary to graze 1 sheep unit for each grassland type (ha/sheep unit) during the grazing period, Y is usable grass yield in a grazing season (kg/ha), U is usable percent of grassland, and was determined by

$$U = \frac{AI}{HB} \times 100\% \quad (2)$$

where AI is animal intake, HB is herbage biomass, AI and HB were measured by Chen (1995). The values for U are 45% for alpine meadow, alpine steppe, mountain meadow, 50% for flat meadow, mountain meadow steppe, mountain steppe, and 35% for mountain desert steppe, plain desert steppe, mountain steppe desert, plain desert. The daily intake for grazing livestock is I [4.0 kg per sheep unit (Ren 1998)], and D is the grazing period in days (here D is 185).

The carrying capacity (CC) (sheep unit) of each grassland type was determined by the following equation:

$$CC = PA \times A \quad (3)$$

where A is the area of each grassland type.

Value of annual ecosystem service of each grassland type

Based on the value of ecological services of ecosystems (Costanza *et al.* 1997), Xie *et al.* (2001) calculated the ecological services value per unit of all the grassland types in China using the equation

$$P_{ij} = (b_j/B)P_i \quad (4)$$

where P_{ij} was the value of annual ecosystem services per unit, $i = 1, 2, 3, \ldots, 15, 16, 17$, indicating gas regulation, climate regulation, disturbance regulation, water regulation, water supply, erosion control and sediment retention, soil formation, nutrient cycling, waste treatment, pollination, biological control, refugia, food production, raw materials, genetics resources, recreation, and cultural, $j = 1, 2, \ldots, 29, 30, 31, 32$, indicating the 32 grassland types in China. The results of these calculations indicated that P_{ij} was 58.6, 181.9, 339.9, 303.0, 157.0, 74.7, 94.1, 95.9, 86.6, 356.8 for alpine steppe, alpine meadow, mountain meadow, mountain meadow steppe, mountain steppe, mountain desert steppe, plain desert steppe, mountain steppe desert, plain desert and flat meadow, respectively. Vegetation cover is related to the conservation of water resources and soil erosion. In this study, vegetation cover of each grassland type was used to

Table 1. Grassland class limits as determined by annual dry matter production in the Aletai Region of northern China

Class	DM (kg/ha)	Class	DM (kg/ha)
1	>4000	5	1000–1500
2	3000–4000	6	500–1000
3	2000–3000	7	250–500
4	1500–2000	8	<250

modify the ecological services value per unit of all grasslands by the equation:

$$P'_{ij} = (c_j/C)P_{ij} \quad (5)$$

P'_{ij} was the annual ecosystem services value per unit of grassland type in the arid Aletai region, i was the same as above, $j = 1, 2, \ldots, 9, 10$, indicating the 10 grassland type in the Aletai region (see above); c_j was the mean cover of j grassland type; C was the mean vegetation cover of all 10 grassland types. C and c were measured by vertical foliage projection for each quadrat expressed as a percentage.

The total ecological services value of j grassland type was defined by the following equation:

$$V_j = \sum_{i=1}^{17} A_j P'_{ij} \quad (6)$$

where V_j is the total ecological services value of j grassland type and A_j is the area of j grassland type.

Determining the pattern of classification management

Carrying capacity reflected the goods provided by the different grassland types and was designated the productive index. The annual ecological services value indicated the importance of each grassland type with respect to conservation value and was defined as the conservation index. Grazing 1 sheep unit meant grazing 1 sheep with 40 kg live weight. The productive index was the carrying capacity in sheep units and was converted into money based on the price of 1 sheep with 40 kg live weight in the market. Price of live sheep per kg was US$1 in China, so that 1 sheep unit was US$40. For a comprehensive estimate for each grassland type, the index of classification management (ICG) was defined by the following equation:

$$ICG_j = \frac{40 \times CC_j}{40 \times CC_j + V_j} \quad (7)$$

where IGC is the index of grassland classification, CC_j is the carrying capacity and V_j is the annual ecological service value of each grassland type. A grassland type with a higher IGC should be placed in the productive sector and one with lower IGC should be placed in the conservation sector. According to the advice of 10 experts from 5 provinces in northern China, a grassland type should be placed in the intensively productive sector when the ICG was over 0.75 and into the conservation sector when ICG was below 0.25. Grassland with ICG between 0.25 and 0.75 should be placed in the moderately productive sector.

Results and discussion

Area and class of each grassland type

Some grassland types covered extensive areas (Fig. 2), and the herbage biomass varied among the different grassland types (Table 2) with a mean value for all types of 2753 kg/ha. Mean herbage biomass for mountain meadow, mountain meadow steppe and flat meadow were above this overall mean, but those for the other grassland types were below it.

No grasslands produced less than 500 kg/ha (Class 7). The area of Class 1 grassland was 1.164 million ha, or 11.9% of the Aletai grasslands, and grasslands in Classes 3 and 4 accounted for 71.2%. These latter classes are unfavourable for intensive grazing because of their low productivity, but moderate grazing is practicable. Classes 5 and 6 made up 17.0% of the Aletai grassland and consisted of seriously degraded grassland and low productive grassland but they played a very important role in the regional environment as typical and natural ecosystems (Guo *et al.* 2003*b*) and should be protected from further degeneration in the future (Zhu and Liu 1989).

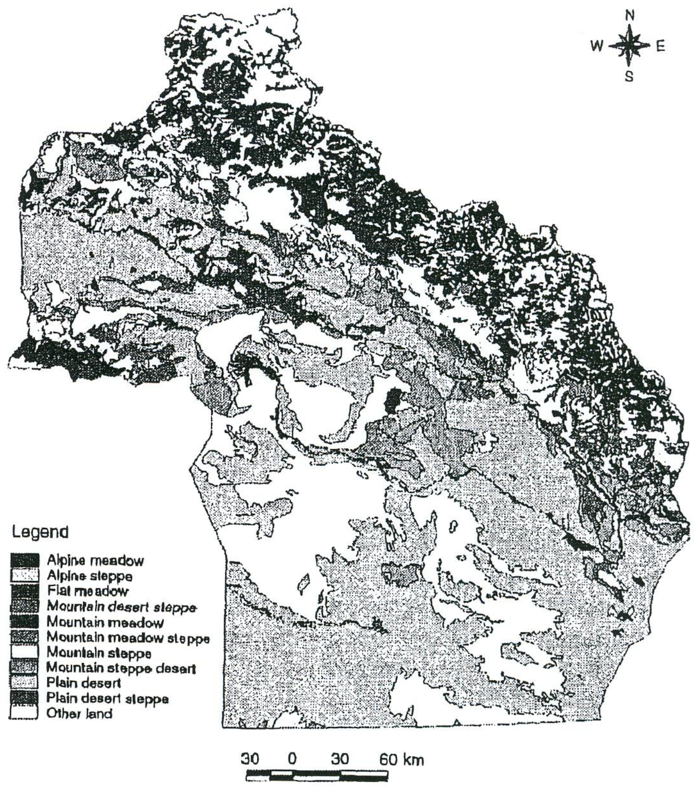

Fig. 2. Area of grassland type surveyed during 1995 in the arid Aletai Region of northern China (other land indicates uses such as crop land, rivers, roads, residents, forest land); AS, alpine steppe; AM, alpine meadow; MM, mountain meadow; MMS, mountain meadow steppe; MS, mountain steppe; MDS, desert steppe in mountains; PDS, desert steppe in plains; MSD, steppe desert; PD, plain desert; FM, flat meadow.

Table 2. Yield and class of 10 grassland types in the arid Aletai Region of northern China

Grassland types	Survey site (number)	Yield (kg/ha)	Class
Alpine steppe	4	1335	4
Alpine meadow	10	2694	3
Mountain meadow	10	5895	1
Mountain meadow steppe	10	4270	1
Mountain steppe	10	1330	5
Mountain desert steppe	10	900	6
Plain desert steppe	10	912	6
Mountain steppe desert	10	879	6
Plain desert	15	1395	4
Flat meadow	10	7920	1

Carrying capacity of each grassland type

Yield determined carrying capacity (Voorthuizen 1978). However, its utilisation rate varied from one grassland type to another owing to plant composition and nutrient value (Chen 1995), so the actual productive ability of grassland has been better defined as area for grazing 1 sheep unit as described by Ren (1998). The lower the area required for grazing 1 sheep unit, the higher the productive ability of the grassland. The actual productive ability of the Aletai grassland differed between grassland types (Table 3) and for flat meadow and mountain meadow, 0.19 and 0.27 ha were sufficient to graze 1 sheep unit for 1 year. However, the required areas were over 2.3 ha for mountain steppe desert, plain desert steppe and mountain steppe desert.

Carrying capacity also varied among grassland types. The carrying capacity of plain desert was greater than that of other grassland types, and contributed 73.7% of the total carrying capacity of the arid Aletai region. Therefore, this grassland type will be the main grazing land in the future. Although flat meadow, mountain meadow and mountain meadow steppe had a greater ability to carry grazing animals, the carrying capacity of these grasslands made up only 2.27% of the total in the Aletai region because of the smaller area and the level of degradation.

Ecological services value of each grassland type

This study showed that the ecological services value per unit area varied among the different grassland types, and that the total annual ecological value of the grassland ecosystem was US$999 million in the arid Aletai region (Table 4). The ecological services value of plain desert was only 15.94% of the total, even though it made up 65.91% of the Aletai, because of its lower ecological services value per unit area. Mountain meadow contributed the largest ecological services value to the study region. The ecological services value of flat meadow with higher ecological services value per unit area, accounted for only 16.32% because of its smaller area. The ecological services value of alpine steppe and plain desert steppe was less than 1%. These results showed that the ecological services value per unit area was not consistent with total services value for the different grassland types, illustrating the importance of grassland type when selecting areas for environmental improvement.

Table 3. Area of grazing 1 sheep unit and carrying capacity for each grassland type in the arid Aletai Region of northern China

Grassland types	Area for grazing 1 sheep unit (ha/sheep)	Carrying capacity (1000 sheep unit)
Alpine steppe	1.2320	0.7885
Alpine meadow	0.6104	29.8913
Mountain meadow	0.2789	18.2903
Mountain meadow steppe	0.3466	5.6357
Mountain steppe	1.1128	93.6532
Mountain desert steppe	2.3492	72.6608
Plain desert steppe	2.3183	7.6272
Mountain steppe desert	2.4053	114.9012
Plain desert	1.5156	983.1546
Flat meadow	0.1869	6.4593
Total	–	1333.0621

Index and pattern of classification management for grassland

Calculations indicated that ICG was different among the grassland types (Fig. 3). No grassland type had an IGC that was greater than 0.75 and, therefore, within the scope of the intensive productive sector. The 5 grassland types with ICGs below 0.25 were placed in the conservation sector, and were alpine meadow, mountain meadow, mountain meadow steppe, mountain steppe and flat meadow. For alpine steppe, mountain desert steppe, plain desert steppe, steppe desert and plain desert, ICGs were between 0.25 and 0.75 so these grassland types placed in the moderately productive sector.

Table 4. The value of annual ecosystem services of each grassland type in the arid Aletai Region of northern China

Grassland types	Service per unit (US$/ha. year)	Service value (1000× US$/ year)	Composition of service value (%)
Alpine steppe	77.54	49.63	0.05
Alpine meadow	309.47	15154.78	15.17
Mountain meadow	417.65	27389.26	27.41
Mountain meadow steppe	320.76	5215.50	5.22
Mountain steppe	172.14	14486.97	14.50
Mountain desert steppe	42.36	1310.29	1.31
Plain desert steppe	53.36	175.50	0.18
Mountain steppe desert	81.58	3897.00	3.90
Plain desert	24.56	15929.08	15.94
Flat meadow	472.13	16317.02	16.32
Total	–	99925.09	100.00

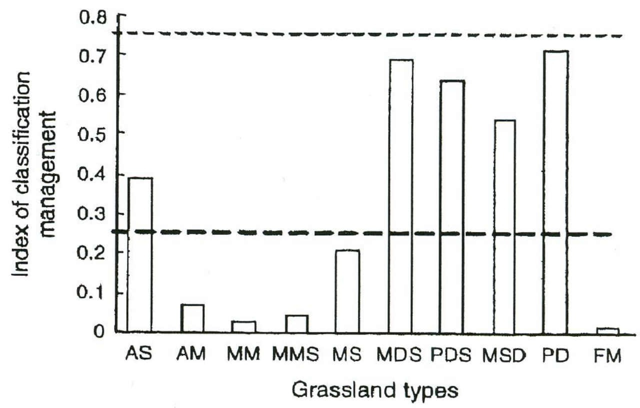

Fig. 3. Index of classification grassland of each grassland type in the arid Aletai Region of northern China.

Grasslands in the conservation group had a significant ecological function, a low productive capacity or were severely degenerated, and would be unfavourable for plant and animal production in their current condition. The management of these grassland groups should emphasise their ecological effects and not their possible economic productivity in the future. These grasslands occupied 2.50 million ha, including 25.4% of the available grasslands in the arid Aletai region, and are found mainly in the headstreams of inland rivers or near residential areas. They play an important role in regulating runoff to inland rivers, but most are in a state of degradation because of overgrazing (Wu *et al.* 2003) which reduces the water flow of rivers and aggravates the problems of water resource utilisation. Grazing should be stopped to allow restoration of degraded grassland for regulating runoff to rivers, and improving the ecological environment.

In the arid Aletai region, grasslands in superior sites have been converted into crop land for wheat, rice and cotton production, so that intensive productive grassland was not available at the time of these surveys. The area of moderately productive grassland was 7.31 million ha (about 74.6%), and should be managed for multiple uses. Residents in the study area have depended on animal production for their livelihood for many centuries. The low density of population means moderate grazing intensities are possible. These grasslands are found mainly in the dry plain regions and in mountainous areas with little degradation. Plain desert is considered unsuitable for grazing in Australia but it is an important component of animal production in the Aletai region. The large area and low population pressure differs from the situation in Australia, USA and New Zealand, so a rational moderate management strategy is needed in the future. To sustain the animal production, measures such as fertiliser application and irrigation will be have to be used to improve the productivity of grasslands and establishing perennial legumes such as alfalfa and will increase the carrying capacity of flat meadows.

Summary and conclusions

This study indicated that each identified grassland type differed in carrying capacity and ecological services value. To aid grassland management in the future, grasslands have been divided into conservation, moderately productive and intensively productive sectors through the index of classification management. The Aletai grasslands were divided into moderately productive grassland and conservation grassland, but the intensively productive grassland sector was not present in the region. Cessation of grazing was recommended in conservation grasslands to restore degenerated areas, protect grasslands with important ecological values from further degradation and further improve the environment. The enhancement of moderately productive grassland by fertiliser applications, irrigation, and sown pasture to increase farmers' income may be used to compensate for the loss of the production from conservation grassland.

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Appendix 1. Community features of grassland types in the arid Aletai Region of Northern Xinjiang

Grassland type	Dominant species	Usually associated species	Height (cm)	Coverage (%)
Alpine steppe	*Festuca kryloviana*	*Festuca valesiaca, Poa altaica, Kobresia* sp. *Trisetum spicatum*	16–24	40–60
Alpine meadow	*Carex melanantha*	*Poa alpina, Carex stenocarpa, Anthoxanthum odoratum, Ptilagrostis mongholica*	12–30	65–90
Mountain meadow	*Aopecurus pratensis*	*Anthoxanthum odoratum, Bromus inermis, Dactylis glomerata, Poa sibirica, P. angustifolia, Hordeum brevisubu*	40–90	55–98
Mountain steppe	*Festuca valesiaca, Stipa szowitsiana*	*Leymus angustus, Carex liparocarpos, Potentilla bifurca, Agropyron cristatum, Hyssopus cuspidatus, Echinops ritro, Kochia prostnata*	20–35	40–60
Mountain desert steppe	*Festuca ovina, Stipa capillata, Artemisia gracilescens*	*Kochia prostnata, Stipa szowitsiana, S. glareosa, Artemisia terrae-albae, A. borotalensis, A. sublessingiana*	14–32	15–40
Mountain meadow steppe	*Festuca valesiaca, Bromus inermis, S. pennata*	*Achillea millefolium, Agropyron cristatum, Phlormis oreophila, Fragaria vesca, Leymus angustus, Polygonum alpinum, Medicago falcate, Vicia sepium*	20–40	55–90
Plain desert steppe	*Stipa glareosa, Artaemisia graeilescena*	*Anabasis salsa, Carex melanantha, Cleistogenesia prostnata, Ceratocarpus arenarius, Ceratoides lateens, Halogeton arachnoideus*	8–20	15–40
Plain desert	*Anabasis salsa, Haloxylon ammodendron*	*Cleistogenesia prostnata, Arisitida prnnata, Kochia prostnata, Suaeda salsa, Nanophyton orinaceum*	4–45	10–55
Mountain steppe desert	*Artemisia* sp.	*Leistogenes squarrosa, Stipa glareosa, Ceratoides lateens, Anabasis eriopoda, Ceratocarpus arenarius*	7–34	20–40
Flat meadow	*Calamagrostis epigeigia, Achnatherum spiendens*	*Elytrigia repens, Hordeum bogdanii, Leymus multicaulis, Phragmites australis, Medicago falcate, Melilotus albus, Glycyrrhiza uralensis*	9–150	30–100