Australian Government

Australian Centre for
International Agricultural Research

Sustainable Chinese Grasslands

ACIAR MONOGRAPH 210

Sustainable Chinese Grasslands

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ACIAR

2020

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ACIAR MONOGRAPH SERIES

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Kemp, D.R. 2019. *Sustainable Chinese Grasslands*. Australian Centre for International Agricultural Research, Canberra, ACT. 328 pp.

ACIAR Monograph No. 210 (MN210)

ISSN 1031–8194 (print)
ISSN 1447–090X (online)
ISBN 978-1-922345-21-9 (print)
ISBN 978-1-922345-20-2 (online)

Technical editing by Lorna Hendry

Design by anthouse.com.au

Printing by New Millennium Print

Cover: The Qinghai–Tibetan Plateau is 3,000–5,000 metres above sea level and is part of the 400 Mha of grasslands in China that support the livelihoods of 16 million herders. Photo: D.R. Kemp

Back cover: Grassland in good condition at Taipusi, IMAR, after five years of very limited grazing. Photo: D.R. Kemp

Foreword

The vast grasslands of China cover approximately 400 million hectares and support the livelihoods of 16 million herders and their low-income pastoral households. The poor condition of these grasslands after centuries of grazing, with considerable off-site impacts such as soil erosion affecting air and water quality, was the focus of an international conference in 2001. Australian grasslands expert, Professor David Kemp, then from the University of Sydney, was invited to share his experiences at the conference.

After a few years of follow-up discussion and planning, in 2004 the Australian Centre for International Agricultural Research (ACIAR) commenced an applied research program supporting the restoration of degraded grasslands through better management, while improving the income of herder households. The program demonstrated the calibre of Australia's agricultural science and scientists, and the invaluable role of ACIAR in brokering and facilitating international agricultural research-for-development collaborations.

The program was developed with key grassland groups across northern and western China, with ACIAR bringing together the key research institutions in China within a broad, systems approach. Much of the fieldwork was funded by Chinese agencies, including the Ministry of Agriculture and the Ministry of Science and Technology.

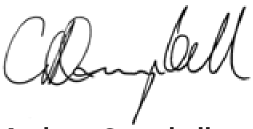
The editor of this book, Professor David Kemp, developed the program to restore degraded Chinese grasslands with Dr Bill Winter, an ACIAR Research Program Manager. The first ACIAR-supported project associated with the program, 'Sustainable development of grasslands in western China' (LPS/2001/094) finished in 2010. Modelling, farm demonstrations and field experiments indicated that a reduction in stocking rates could increase herder incomes and reduce pressure on the grasslands, enabling rehabilitation. However, further work was needed to understand the system changes that would consistently achieve sustainable outcomes.

The second phase of the program, from 2011 to 2018, had the goal of improving herder household incomes, alleviating poverty and rehabilitating degraded grasslands, while reducing environmental damage. The next ACIAR-supported project in the program, 'Sustainable Livestock Grazing Systems on Chinese Temperate Grasslands' (LPS/2008/048) provided leadership, mentoring, coordinating, modelling and analyses for a large number of Chinese-funded projects. The Australian team from Charles Sturt University's Graham Centre for Agricultural Innovation joined with groups from China Agricultural University, Inner Mongolia Agricultural University, Institute of Grassland Research (China Academy of Agricultural Sciences), Gansu Agricultural University/Gansu Academy of Agricultural Sciences and Lanzhou University to carry out the work.

Much has been learned since 2001. Herders have changed and continue to change their practices as they shift from a survival mode to one that is more production oriented. Our understanding of Chinese grassland systems has significantly improved and better guidelines for managing grasslands to achieve a sustainable and resilient state were developed, to the point where herders see a future in livestock production on grasslands.

Modest investment from ACIAR to support Australian scientists was matched by a much larger investment from China to support the on-ground activities through this program. The systems approach and multidisciplinary, integrative skills of the Australian scientists helped the Chinese research institutes, with their deep technical capabilities but more narrow focus, to work more effectively together on the complex challenges of improving rangeland management in China for multiple objectives.

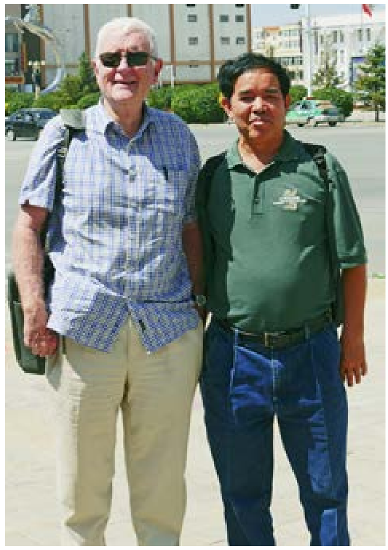
This monograph, *Sustainable Chinese Grasslands*, presents the current state of knowledge for managing these vast grasslands and what has been learned in the new century. The results apply not only to the 400 million hectares of grasslands in China but also to those in Mongolia, Russia and throughout Central Asia. The principles elicited here are also relevant to grasslands in many other developing countries.



Andrew Campbell
Chief Executive Officer, ACIAR

Professor David Kemp (third from left), Dr Bill Winter, former ACIAR Livestock Research Program Manager (fourth from left) and Chris Brittenden, former ACIAR Country Manager (far right,) with herders in eastern Gansu in 2002, during an early visit to plan the grasslands program. Photo: D.R. Kemp

Professor Andrew Campbell, Chief Executive Officer, ACIAR and Dr Nyima Tashi, President, Tibetan Academy of Agricultural and Animal Science, pictured at Lake Namtso in the Tibet Autonomous Region of south-west China. The lake is the highest saltwater lake in the world at 4718 metres above sea level, and is located on the Qinghai–Tibetan Plateau. Photo: D.R. Kemp



Professor David Connor and Dr Liu Guodao, reviewers of the last phase of the program in 2016. Photo: D.R. Kemp

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Acknowledgments

This monograph reports mainly on the second phase of a program supporting the restoration of degraded grasslands in China. The work discussed here was part of a large program, for which ACIAR provided the central coordinating role and valued funding.

ACIAR supported the program through an initial project, 'Sustainable development of grasslands in western China' (LPS/2001/094), which also received support from the Department of Agriculture, Fisheries and Forestry and the Australian Greenhouse Office. A second ACIAR project followed, 'Sustainable livestock grazing systems on Chinese temperate grasslands' (LPS/2008/048).

These were the first ACIAR projects to focus on the vast grasslands of China. The strong support from ACIAR CEOs, Dr Bob Clements, Mr Peter Core, Dr Nick Austin and Professor Andrew Campbell, and livestock research program managers, Dr Bill Winter, Dr Peter Horne and Dr Werner Stur, was much appreciated. They all share in the success of this work.

We particularly thank Professor Nan Zhibiao, whose foresight led to the establishment of this research program. A new direction was developed through the ACIAR project 'Strengthening incentives for improved grassland management in China and Mongolia' (ADP/2012/107). Now that there is a better understanding of rehabilitating grasslands and improving herder household incomes, this new phase is examining ways that these governments can use their funds to foster the desired changes.

The program had the key role of coordinating a range of other projects and activities designed to analyse the grassland and livestock system in northern and western China and obtain the data needed to analyse, model, plan and test solutions. This involved a considerable number of separate projects, experiments and farm demonstrations funded by Chinese sources, notably the Ministry of Science and Technology and the Ministry of Agriculture. At last count, the cost was around A$54 million for the life of this program. These contributions were essential for the success of this project. We thank all our supporters and collaborators for their major efforts at taking on and researching the many ideas generated and for obtaining all the funds needed for the success of this work.

We are continually grateful to the herders of China, who talked freely with us about what they did and the issues that confront them. Some are now leading their districts to greater and more prosperous outcomes and are at the forefront of demonstrating better grassland and livestock management practices to others.

Special thanks are due to the Rockefeller Foundation's Bellagio Centre for a fellowship, where planning and initial writing for this monograph commenced.

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David R Kemp is the Professor of Agricultural Systems at the Graham Centre for Agricultural Innovation at Charles Sturt University, Orange, New South Wales, Australia. He is the leader of the Australian-funded projects that supported the research reported in this monograph. Professor Kemp has researched the management of grasslands and forages, among other topics, throughout his career. For his work in China, Professor Kemp has been given the Golden Steed Award by the government of the Inner Mongolia Autonomous Region, the Dunhuang Award by the government of Gansu and the Friendship Award by the Chinese Government, for his and the group's contributions to development.

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Statue in honour of the first farmers to develop agriculture 9,000–10,000 years ago in Gansu, at the Gansu Grassland Ecological Research Institute of Lanzhou University.

The late, eminent Professor Zhu Xu and Dr Tian Qingsong, from the Institute of Grassland Research, Chinese Academy of Agricultural Science, at the Taipusi Grassland Research Station, examining progress in the rehabilitation of a typical steppe in IMAR. Photos: D.R. Kemp

Abbreviations

ACIAR	Australian Centre for International Agricultural Research
AGO	Australian Greenhouse Office
ANPP	above-ground net primary productivity
AR4D	agricultural research for development
ASR	actual stocking rate
CAAS	Chinese Academy of Agricultural Science
DAFF	Department of Agriculture, Fisheries and Forestry (Australia)
DM	dry matter
DMD	dry matter digestibility
DMI	dry matter intake
DS	dynamic sustainability
DSR	desirable stocking rate
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
FBA	feed balance analyser
GEPAP	Grassland Ecological Protection Award Policy
GGC	Grassland Growth Calibration
GHG	greenhouse gas
IGC	International Grassland Congresses
IMAR	Inner Mongolia Autonomous Region
IMAU	Inner Mongolia Agricultural University
IPCC	Intergovernmental Panel on Climate Change
IRC	International Rangelands Congresses
JIF	journal impact factors
LPO	linear program optimiser
LWG	liveweight gain
ME	metabolisable energy
Mha	million hectares
NPP	net primary production

NPV	net present value
NPVa	net present value as annuity
OCM	operating cash margin
OMMLP	optimised management models for household pasture livestock farm production
PERFECT	Productivity Erosion Runoff Functions to Evaluate Conservation Techniques
PFG	plant functional group
PLM	precision livestock management
SCA	Standing Committee on Agriculture
SDSR	short duration seasonal rotation
SE	sheep equivalent (equivalent to a 50 kg sheep)
SGM	Sustainable Grasslands Model
SGS	Sustainable Grazing Systems
SOC	soil organic carbon
SRe	stocking rate recommended by local officials
SRf	stocking rate that optimises financial returns for the herder
SRW	standard reference weight
SSR	sustainable stocking rate
SU	sheep unit (equivalent to a 50 kg sheep in moderate condition)

1 Sustainable Chinese grasslands

David Kemp, Zhang Yingjun, Wu Jianping, Hou Xiangyang, Hou Fujiang, Han Guodong

China's grasslands are part of the Eurasian grasslands, one of the world's largest land-based ecosystems that extend from eastern China to eastern Europe. The grasslands of China are vast (approximately 400 Mha), and some 90% are overgrazed and considered degraded, although only 10% (approximately 40 Mha) have become so badly degraded and desertified that they need serious intervention to restore them. The worst areas have had livestock grazing bans imposed. There has been considerable concern about the state of the grasslands (Li 1999; Ren et al. 2001; Lu, Fan & Liu 2002; Lu, Ly & Xin 2005; Hong 2006; Hong 2011; eds Kemp & Michalk 2011) and ongoing discussion about better policies (Gongbuzeren, Li & Li 2015).

Typically, the productivity of these grasslands has declined and the botanical composition has changed to the point that species of low nutritional value, either due to low palatability or being effectively inedible, have become an increasing and often dominant proportion of the plant community. The overall impression, though, is of resilient ecosystems where most native plant species remain, but their composition declines to a significantly less desirable state for functionality and sustaining livelihoods. It is very rare for exotic species to be found invading the grasslands.

A herder taking sheep out to graze on the desert steppe in spring. Photo: D.R. Kemp

The 16 million herders who depend upon grasslands for their livelihoods are among the poorest rural communities in China. Traditionally, they led a nomadic lifestyle. Human and animal populations were low, having only a moderate impact on the environment, and they acquired considerable skill in surviving in a climate that is considerably lower than 0 °C for up to seven or eight months of the year. Precipitation (50–600 mm) occurs primarily through the summer growing season, with a more variable period in early summer, which often sets the annual grassland productivity level, irrespective of the total annual precipitation.

The traditional practice is to take the animals out to graze every day of the year, irrespective of conditions. Adult animals lose 20–30% of their body weight every winter, often only regaining that weight loss by the end of summer after a period of compensatory gain. Mating is more successful in late summer and autumn, when animals are at their peak body condition for the year. Animals are often in poor condition at other times of the year and cannot get pregnant. Those animals that do get pregnant produce young in the middle of winter through to spring, when temperatures are very low and they are in poor condition. The young are weaned about the time that grassland growth commences in early summer, or during summer.

Traditional herder knowledge helps to ensure that animals survive through these tough local conditions, but this does not optimise production for the rapidly developing markets of China. Consumers want more animal products, not skin and bone (Kemp & Michalk 2011). Herders have traditionally believed that the more animals they have, the better their income will be. This has led to overstocking in recent decades.

Livestock productivity is generally poor. Animals are of low birth weight and grow slowly, often not reaching mature weights until about twice the age that would apply in Australia, Europe, New Zealand or other developed countries. Cattle and yaks typically only produce a calf every second year. Sheep produce a lamb in two years out of three, and there is considerable abortion among goats due to the stressful conditions. Meat, milk and fibre (wool, cashmere and yak hair) production per animal is considerably below what could be expected from better-fed animals. As the productivity per animal is low, so is the price per animal. When traders come, they purchase the best animals. As a result, the remaining animals are the least productive, as was found when the weights and condition of animals were regularly monitored on farms[1] (eds Kemp & Michalk 2011). Often flocks were found to have far more old animals than was reasonable for flock renewal. The flock or herd productivity declines over the years until there is a good season, an above average number of young are born, and rebuilding occurs. This is more akin to wild animal populations than a managed flock or herd.

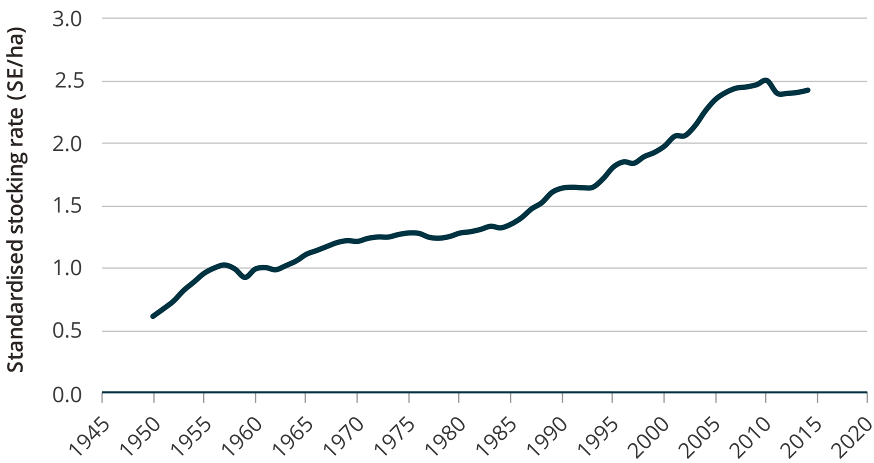

Figure 1.1 Standardised stocking rate (SE/ha), China, 1950–2014

Note: From 1950 to 2014, the stocking rate showed an average annual increase of 3%.
Source: FAOSTAT

Overgrazing of grasslands has been driven by major increases in people and animals since 1950, reflecting policies to utilise this apparently wasted resource. Old herders talk about their youth, when they were 'having trouble to see the cattle, but now they see the mice'. Analyses of local records has shown a fourfold increase in stocking rates since 1949 (Figure 1.1; Chapter 2). The data are shown as sheep equivalents to better illustrate grazing impacts. China now has one billion sheep equivalents of livestock using grasslands, particularly in summer.

The overall pattern in stocking rates shows four distinct phases. From 1950–57, there was a steep rise in numbers following the wars and conflicts of previous decades, presumably getting back to previous levels, though no earlier data are available. From 1958–84, there was a steady rise in numbers during the collective farm and commune era, when production systems were rebuilt. During that time, cattle were the main tools used on farms for producing crops and there was very little consumption of beef. From 1985, after then-President Deng Xiaoping introduced the 'responsibility' system, opening markets and allocating individual areas of land to farmers and herders, the response of the herders was to increase their grazing livestock by nearly twofold. Village leaders now identify that response as exacerbating overgrazing. From 2009 to 2015, there was a small decline in animal numbers, as herders, officials and research (like the programs discussed in this monograph) all indicated that a reduction in stocking rates was needed.

1 'Farm' is used in this publication for properties producing livestock. This terms covers the many different types of farms that have grazing livestock.

Understanding why herders do what they do, and what can be changed to improve their livelihoods, is critical to developing sustainable solutions (Chapter 6; Hou, Han & Li 2012; Hou et al. 2014). More detail on trends in livestock numbers, nationally and regionally, is presented in Chapter 2.

The data on livestock numbers in China provide useful indications for the level of stocking rate reduction needed to restore the grasslands. If the stocking rates in 1950 were the goal, a 75% reduction in overall stocking rates would be required. However, from the limited information obtained to date, it is considered that during the period 1958–84 grasslands were in reasonable condition and systems were sustainable. This means that a 50% reduction is a more practical target. Different targets will probably apply in different regions. The reduction required will depend upon the local availability of forage and supplements. Grassland areas are considered natural systems and government policies have limited any artificial pasture or fodder crops to < 0.7 ha per household. Better nutrition of livestock to sustain higher stock numbers would require production of more forage, hay, silage, grain, etc. in neighbouring districts. However, growing that food would compete with cropping for human consumption, which has priority in China. These considerations mean that livestock in grassland areas are and will be mostly dependent on grassland for food.

Animals grazing on the desert steppe in early winter at temperatures of –20 °C. The tall grass is toxic in summer and is left ungrazed under these harsh conditions. Photo: D.R. Kemp

The condition of some grassland areas was adversely affected by an expansion of cropping fostered under previous government programs. This was done in the belief that the soils and climate were better than they were (Ren et al. 2001). Cropping meant that soils remained bare through winter and spring. Wind erosion then removed much of the readily available nutrients in soil surface layers, reducing productivity. Many of the areas used for cropping in recent times are now returning to grazing, though the plant species present are not as frequent nor as productive as they are in natural grasslands. Restoration of these previously cropped areas often requires replanting. This is a separate issue to the main emphasis of this monograph of managing the grasslands to return them to more sustainable levels.

The decline in grassland productivity due to overgrazing through the year has meant that wind erosion and the frequency of dust storms have increased considerably. Historically, an average of one severe dust storm reached Beijing every four to five years. In recent times, there have been four to five dust storms in a single year. These dust storms can reach the Korean Peninsula and Japan. There is considerable concern about dust storms across northern China. Governments have been implementing a range of policies to reduce their incidence. The grasslands are only partly to blame, as dust also comes from construction, industrial and mining sites close to the northern cities. Unfortunately, some early policy responses resulted in programs to plant trees across the grasslands, where trees do not naturally occur, rather than seeking to better manage the grasslands. Those problematic policies may return as the responsibility for grassland management was transferred to the State Forestry and Grassland Administration in 2018.

Since the passing of the first Grassland Law in 1985, government policies have aimed to improve herder incomes and rehabilitate grasslands. Many local officials, following earlier directions from the Central People's Government, had encouraged more livestock as a way of improving incomes. However, with the passing of the Grassland Law, local governments commenced grazing bans in parts of the grasslands to aid rehabilitation. In the Inner Mongolia Autonomous Region (IMAR), 70 Mha was progressively closed to grazing. Grazing bans exclude all livestock and typically last for five years. Herders are compensated for not grazing. Compliance with these bans has become an increasing problem, and even when herders comply they are not always convinced that the grasslands benefit. Also, after a grazing ban, grasslands were being restocked at the old, high stocking rates. A subsequent Grassland Law was then introduced to allow local officials to implement lower stocking rates. Increasingly, the Central People's Government has strengthened its desire to improve the environmental values of the countryside, as President Xi Jinping noted in his 2017 address to the Party Congress. Some officials interpret this as meaning that all grazing will be banned in sensitive areas.

When this project was being developed, there was little evidence that a five-year grazing ban would restore the botanical composition of grasslands to a desired state, or if some grazing may help in that restoration, yet the impact on herder household incomes could be significant. Work done in the 1990s in IMAR within an AusAID project (Chen et al. 2002), using tactical rest ideas developed in Orange, NSW (Kemp & Michalk 1993; Kemp & Dowling 2000), showed that early summer rests could help restore C3 (temperate) perennial grasses (Kemp, Michalk & Virgona 2000). Normal grazing was then possible through summer, once some initial plant growth had occurred that reduced the risk of early-summer overgrazing. An early summer grazing ban is now commonly imposed by local officials, for which herders get a small payment, as part of the 'balance' program supported by the Central People's Government.

Through the 1980s and 1990s, there was a growing acknowledgment in China that the 300+ Mha of extensive grasslands in northern and western provinces were degraded to varying degrees. This was evident in a decline in growth of desirable plant species and an ever-increasing proportion of less-desirable species of low nutritive value. At best, these species might maintain an animal's body weight briefly in summer, but irrespective of how much the animal ate, it generally lost weight. Desertification increased. Cattle were less able to eat the short grass and were replaced by sheep and goats. Programs to cultivate grasslands to grow crops were not successful. These problems were acknowledged by researchers, herders and officials at all levels of government. Much of the past and current research in China investigates components rather than integrated systems. Studies needed to be done across a range of grassland types to identify better management practices. This monograph brings together the outcomes from a large program and is designed to find strategies that will help rehabilitate grasslands and improve herder incomes.

Building a program

In 2001, an international conference was held at Hailar in IMAR, organised by the China Agricultural Science Society and the Chinese Grassland Society. Several key speakers discussed the state of knowledge of grasslands at that time. Professor Nan Zhibiao from Gansu thought that some of the Australian approaches for managing grasslands sustainably could be useful, and invited Professor David Kemp to give a paper on the work done in central New South Wales and tour northern China to discuss ideas for research. Many discussions over the following few years culminated in a program funded by ACIAR that started in 2004. That program eventually comprised two large projects funded by ACIAR, with some additional initial activities funded by the Australian Department of Agriculture, Fisheries and Forestry (DAFF), and also by the Australian Greenhouse Office (AGO). The Australian components funded project design, analyses and coordination among six major groups working on grasslands in China. The fieldwork was funded by institutions from a range of Chinese Government programs.

The initial proposals were for grazing experiments designed to understand the interaction between grazing animals and the botanical composition of grasslands, and provide better estimates of livestock productivity. A modelling component was included that aimed at using the data from the experiments to investigate alternative grazing practices. Farm surveys would provide data for calibrating models and to help understand the grassland–livestock system. This included examining greenhouse gas production and wider sustainability issues from different grazing systems. The proposals expanded to include universities and institutes in Gansu, IMAR and Beijing. Given the extensive areas of grassland and the fact that some data was already available in China, the ACIAR program would focus on understanding the grassland–livestock system in several villages in a transect from due north of Beijing (in IMAR) through to western Gansu (Figure 1.2). Surveys of farms would provide data to calibrate models designed to evaluate the options available to herders to improve household incomes and help rehabilitate the grasslands. In addition, work would commence on understanding the governance issues for managing China's grasslands.

The initial part of this work was only specified for two years. Before that concluded, it was evident that not enough information could be collected in that time frame, and that other issues of interest (e.g. greenhouse gases, herder attitudes) had to be incorporated. The program was expanded to include modelling of greenhouse gas impacts and farm demonstrations. Funding for the expanded program came from ACIAR, the AGO, DAFF and Chinese agencies.

The first phase of the program demonstrated, first in models and then in farm demonstrations, that reductions in stocking rates could lead to improved net incomes from livestock with the prospect of consequent improvements in grassland condition (eds Kemp & Michalk 2011). It was acknowledged, though, that a wider test of on-farm changes was needed, as were experiments to investigate grassland management practices that could enable positive changes in the botanical composition of grassland from the increasing incidence of less-desirable species such as *Artemisia* to more productive, higher forage quality grasses. Did total grazing bans achieve the best outcome, or was tactical grazing better? Changes in the organisation of livestock production on farms were likely to be only part of the story. It was evident that better outcomes resulted when the markets sent signals to herders that emphasised per head production over increasing animal numbers. Better markets could encourage change with less need for government intervention.

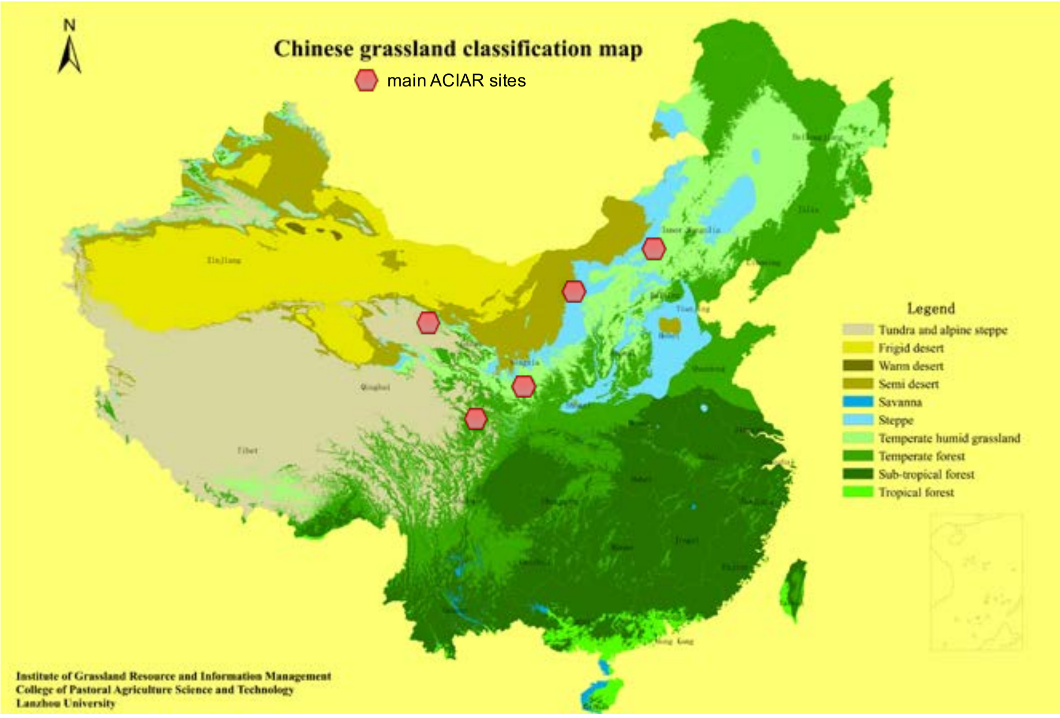

Figure 1.2 Map of the main vegetation types across China and the main initial study sites used in the ACIAR Sustainable Chinese Grasslands Program

All these components had to be documented. ACIAR agreed to a second major phase in this program, providing support to coordinate the planned work and help document the impact of various changes. The Chinese Government, through various national and local programs, provided funds for the comparison of experimental and control farms in nine regions across China, several projects to investigate grazing tactics and strategies on the main grassland types in northern and western China, and other work on improving the nutrition of livestock when grasslands are inadequate.

As these programs were large, and new to many involved, the success rate was variable. However, overall, far more is now known about managing the grasslands and the system changes that are required to deliver better household incomes and improved grassland condition.

We thank all our supporters and collaborators for their major efforts at taking on and researching the many ideas generated and obtaining all the funds needed for the success of this work. This monograph reports on 15 years of work investigating the improvement of grasslands and herder household incomes in northern and western China. The publications listed in Appendix 2 provide more detail on the work that was done.

Theory to practice

In developing the sustainable grassland management program for China, an initial step was to revisit the basic relationships underlying animal production of grazing animals. These relationships were the subject of much discussion in the 1960s and 1970s. A review of grazing experiments (Jones & Sandland 1974) suggested there is often a linear relationship between animal production per head and stocking rates (Figure 1.3). The initial formulation normalised the data, which means the underlying mathematical relationship may not be necessarily linear. However, if absolute values are used, the underlying relationship is clear. An important aspect of defining these relationships is that animal production per head (in growth, meat, milk, fibre) is the primary response. The productivity per unit area (hectare or mu) is then calculated from the production per head.

production/hectare = production/head x head/hectare

Many papers in the literature confound these terms and calculate them independently, although they are not independent measures. This often leads to differences in estimates of optimal stocking rates depending upon which measure is used (per head or per hectare). A further problem in the literature is the definition of optimal stocking rates at the point where the per head and per hectare curves intersect. This is clearly an artefact, dependent upon the scales used for each measure, and ignores other criteria that would define the optimum, such as grassland condition or economics.

Over the years, there has been an ongoing debate about the linear or curved nature of the response in per head production to stocking rates. A consideration of the results obtained in this program and of the literature suggested that curved responses often seemed to occur where there was some confounding. Examples include using animals of different ages, using mature animals that did not show much growth response, or combining data from different seasons (e.g. where grasslands were only growing and green for part of the period of measurement, while the rest of the period had effectively very different quantities and quality of forage). When the system under study showed reasonably consistent steady-state conditions, linear responses were evident.

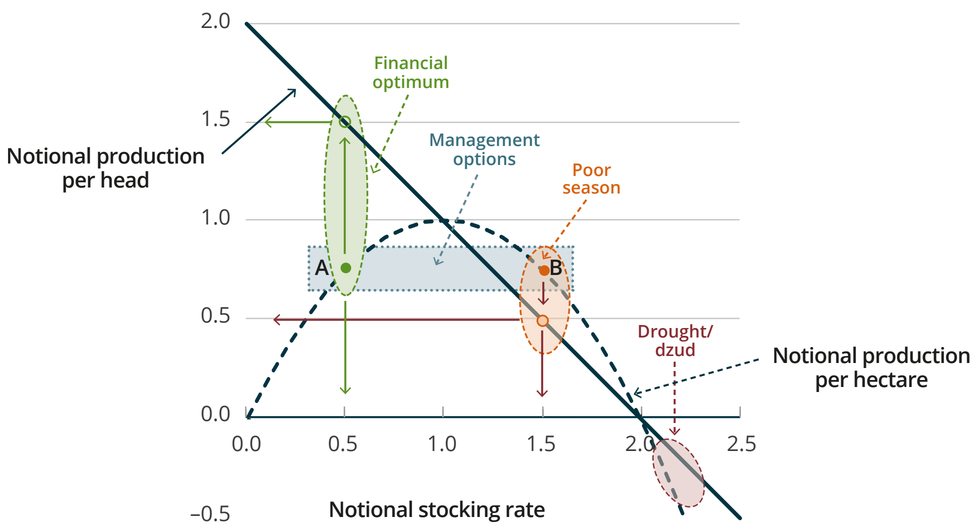

Figure 1.3 Basic animal production relationships between stocking rate, production per head and production per hectare

Source: Based on Jones & Sandland (1974)

Project meeting to review work, May 2006. Left–right: From Inner Mongolia Agricultural University, Professors Yun (Head of Grassland Department), Li (Vice-President), Wang (Head of Faculty of Ecology), Han (local project leader); from the Institute of Grassland Research, Dr Tian, Dr Yuan, Dr Xu (local project leader); Professor Kemp (project leader). Photo: Han Guodong

A further confounding problem is that, in the first year or more of a grazing experiment, the results will reflect the consequences of previous management at the site (Chapter 10; Zhang et al. 2015). It can take some time before the results more accurately reflect the treatments being studied. In China, grasslands are green and growing for three to four months over summer and animals have a reasonably consistent feed supply. It was therefore decided to restrict analyses of animal responses to stocking rates to the summer period. In autumn, winter and spring, the quantity and quality of forage available is often below maintenance requirements and animal responses need to be analysed differently. In those cold seasons, animal production is affected more by low temperatures and the quantity and quality of supplements they are given than by the available forage on grasslands.

The opportunities for improving animal productivity over summer derive from considering the basic relationships between stocking rates and animal production per head and per hectare (Figure 1.3) (eds Kemp & Michalk 2011). The simple case that applied in China (as shown in Chapters 8–10) was for a straight-line reduction in production per head with increasing stocking rates. The optimum point, based on financial analyses of the per hectare curve, is often around point A, where production per hectare and per head is 75% of the potential. At the top of the per hectare curve, the marginal gain (slope) for each additional animal is zero, though there are still costs for those additional animals. The net income is less than at the peak of the per hectare curve, and moves towards point A. The actual financially optimum position will depend upon the total effect of all fixed and variable costs, as well as income per animal, but from the perspective of this discussion and the experience gained with the models (Chapters 6 and 7), a reasonable position is around 75% of the peak of the per hectare curve, which translates to 75% of the per head response curve.

Livestock producers are often given a target production per hectare to aim for. These curves illustrate a problem that can arise. The production per hectare curve shows there are two positions (points A and B) where the same productivity applies per hectare. At point B, however, production per head is only 25% of the potential and the stocking rate is three times that of point A.

The stocking rate is a simple way of estimating the available forage per animal. The slow growth of animals to maturity in China strongly indicates that many are stocked at that higher level, a condition that also applies in poor growing seasons. In a drought or winter snow emergency (called *dzud* in Mongolia), animal production becomes negative as the notional stocking rate, relative to the forage supply, increases considerably. These curves indicate how the stocking rate could be substantially reduced and still achieve the same output of animal products per hectare, while moving closer to the point where net income per hectare, and therefore per farm, is maximised. In practice, the actual optimal position will vary, but the underlying response functions would retain a similar shape, with different scales.

Other analyses (Kemp, Badgery & Michalk 2015) indicated that, at point A, the grasslands would be in much better condition than at point B. To achieve production per head around 75% of the potential would require higher levels of green herbage mass in the grassland with a higher proportion of desirable plant species (Chapter 10). Economic modelling indicates that herder household net incomes would be increased if stocking rates were at point A (Michalk et al. 2011). This provides a mechanism where stocking rates could be reduced, animal productivity increased and grasslands rehabilitated, as there is less risk of overgrazing. These basic relationships were used in models (Chapters 6 and 7) to assess the cost–benefit responses of different stocking rates. The outcomes of the modelling were tested and substantiated in farm demonstrations (Chapter 4). Results from the grazing experiments were used to assess the form of the response in per head production to stocking rates and that supported the basic linear relationship (Chapters 8–10).

Many herders are not familiar with thinking about productivity per hectare, and better understand productivity per head. As with livestock producers in Australia, they talk more about how their animals perform than their output per hectare. Traditional herders lived a nomadic existence, and land was not necessarily the main constraint on livestock production. The constraint is more often how many animals they can manage with the labour available. For that reason, we translated the optimal values to per head production to provide better guidelines for herders (Chapters 4 and 5). By monitoring their animals, herders can better judge if their stocking rates are near the optimum, rather than developing new skills in thinking about stocking rates. In addition, the models estimated net incomes per household to reinforce the benefits of reduced stocking rates.

This program sought to identify various criteria that herders and officials can use to better manage their livestock and grasslands. Productivity and profitability per head are a primary measure that herders are more likely to monitor and use to optimise their household income. In addition, some simpler criteria are needed to manage stocking rates so that the grassland condition is optimised. Unless herders have accurate measures of the land area they are grazing, it is difficult for them to know and manage stocking rates. The grassland condition depends upon the balance between plant growth and animal demand. Animal demand varies with the size and physiological state of the livestock and is not easy to calculate accurately. However, the balance between animal demand and plant supply is clearly visible in the herbage mass. In experiments, the actual herbage mass in response to grazing pressures is regularly measured so that the herbage mass that optimises grassland functions and animal productivity can be assessed. Various studies sought to identify this optimal grassland herbage mass (Chapters 8–10). When the relevant values for herbage mass are known for any given grassland type, herders and officials can be trained to recognise that level and adjust their grazing and stock numbers accordingly.

The many different grassland types and environments across China mean that no single set of management criteria will apply to all areas. It is anticipated that the sustainable levels of herbage mass will probably range from high values in the higher rainfall meadow steppe to low values in the desert steppe. As an aid to officials in making judgements about sustainable levels of grassland utilisation, a long-term objective of this program is to use the data from grazing experiments to not only estimate the sustainable levels of herbage mass, but also estimate what that means in the sustainable consumption rates by livestock. The aim is to manage grasslands to improve and maintain a higher proportion of desirable plant species and maintain enough cover to reduce the risk of soil erosion.

Program structure

This large program had a transdisciplinary approach. The core aim was to improve the grasslands and the livelihoods of herders who depended upon them. All the work was evaluated from that perspective, as well as its contribution to understanding the system. The transdisciplinary nature of the work carried an expectation that all personnel had some understanding of the other components, so they could do better research and help solve the core problems more efficiently, although this varied among personnel. Capacity building was important in all components of the program. Central to the program design were the case study and satellite farms (Figure 1.4), which provided data to calibrate models and investigate what changes may be more useful, and ran the demonstrations to test the model outcomes.

As well as the data obtained from farms, additional data was required from experiments and literature to develop various models used to analyse farm options. Modelling and experiments proceeded in parallel. To keep the program's focus, regular meetings with herders and local officials discussed the program's progress. Training sessions were held with herders and officials to improve their skills as they moved from traditional practices to one that emphasised production for developing markets from which they could derive improved incomes. The cyclical nature of the program's design meant that there was no specific endpoint—a situation that applies to agriculture in general. Rather, the success of the program emerged when it was evident that sustainable changes in the livestock/grassland system were being adopted and herder livelihoods were improving.

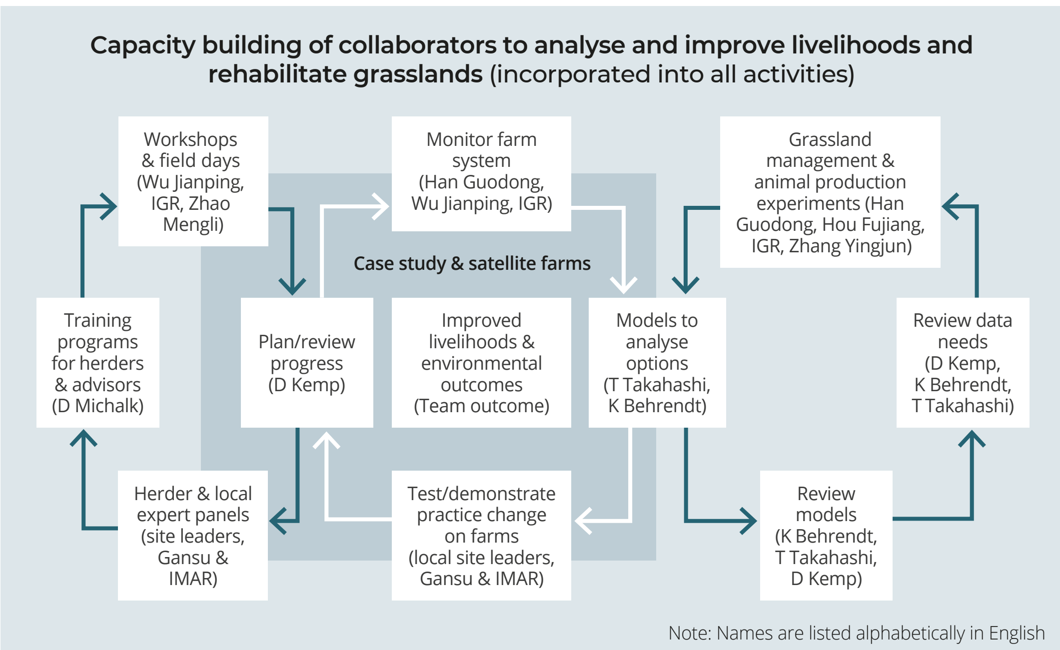

Figure 1.4 The Sustainable Chinese Grasslands Program aimed to analyse and improve the livelihoods of herders and rehabilitate grasslands

Working in China

Applied research programs such as those outlined in this monograph not only need to find appropriate solutions to problems, they must also develop the connections with herders and various authorities to deliver and help implement the practices identified. What were the processes that helped define the project and promote the results? This section outlines the main processes we used, though their implementation varied depending on how remote the study villages were. In some cases, we were able to visit sites regularly, but in others we worked with local researchers and students who did the required enquiries, surveys, training and contacts.

Initially, about three years were spent in discussion before the first phase of work officially started. These discussions clarified that farm surveys and modelling and field experiments were needed, and this fieldwork was funded and done by the Chinese groups. Once the project officially started, much time was spent interviewing farmers in each study village to understand how they worked and what the main parameters of their grazing–livestock system were. Repeat visits often applied, as it was important for the key people involved (researchers, herders and local officials) to get to know one another. Data had to be clarified during these repeat visits, as we built our understanding. We relied on herders recalling the biophysical and financial data we needed, as they did not keep written records. Regular visits were made at times when key pieces of information were more likely to be recalled. We worked with staff and students to help them understand how to use open-ended questions (e.g. 'What did you pay for a ram?') rather than leading questions (e.g. 'You paid ¥500 for a ram') to get better data. In China, leading questions are common and people politely give the answer expected.

We met with local officials and other interested people to outline what we were doing and keep them informed on progress in the project. Those contacts were at least annual and often more frequent. Similar contacts were made across the six layers of government in China. In Beijing, the team met with the Ministry of Agriculture and the Ministry of Science and Technology and other funding agencies. Our aim was to inform these groups of our progress and the implications for their programs. This had some influence on the Chinese national five-year plans and their annual updates. Officials and some herders visited Australia to see research and do 'paddock to plate' training programs, which helped them understand the key importance of more transparent marketing chains and understand how we carry out Australian research.

Extension staff from Australia helped run training programs with herders. This was a new, less formal approach for China. We met with small groups of herders on their farms. After some initial meetings, we asked officials to stay away so that the herders would talk more freely with the trainers. Separate meetings were held with officials to tell them what was discussed, how it was done and what we learned from the exchange with herders. This helped build a more accurate knowledge base of how livestock were managed.

The work in this monograph has been the subject of many papers presented at conferences and meetings in China and in lectures to staff and students. We wanted to present work-in-progress as well as more complete results. As will be evident through this monograph, we developed various theories to help us understand, interpret and model the grazing–livestock system. These have become important in the subjects taught at collaborating universities in China. Further details on capacity building achieved are discussed in Chapter 11.

Monograph outline

This monograph reviews the work done in the large sustainable grasslands program since the early 2000s, with emphasis on the period 2011–18. A previous publication (eds Kemp & Michalk 2011) provides more detail on the background and earlier work.

The program was designed to provide sound evidence for the livestock and grassland management options to guide Chinese research and development agencies on how to alleviate poverty and reduce further environmental damage on degraded grasslands by improving household incomes from livestock production enterprises while reducing grazing pressures.

The program had two main objectives:

1. analyse the bio-economic sustainability of grassland livestock production systems options at household level
2. develop evidence-based advice for Chinese research and development agencies on practical options for reducing grazing pressures and improving net financial returns from livestock.

As part of these studies, a set of system components were investigated:

1. **Enterprise choice:** Which livestock enterprises are the most beneficial for net income and grassland sustainability?
2. **Animal management:** What changes are needed in the type, numbers and management of animals to achieve this?
3. **Animal nutrition:** What changes are needed in animal feeding strategies throughout the year?
4. **Grassland management:** How will these new livestock production systems improve the sustainability of the grassland?
5. **Infrastructure:** How will changes affect farm infrastructure and management?
6. **Finance and policies:** What are the additional strategies/policies that could be implemented to achieve greater household incomes and rehabilitate grasslands?
7. **Driving change:** What are the drivers of practice change that will bring about the changes identified?

These topics overlap and their interactions, as well as individual outcomes, will be considered in this monograph. These objectives and topics are then considered in the series of studies summarised in the following chapters.

- Chapter 2: Chinese livestock numbers and grassland impact
- Chapter 3: Changing animal practices and industry structures on grassland farms
- Chapter 4: Farm demonstrations—what are we learning?
- Chapter 5: Herder attitudes on stocking rates and implications for grazing management in northern China
- Chapter 6: Sustainability modelling
- Chapter 7: Modelling the sustainability of Qinghai–Tibetan Plateau grasslands
- Chapter 8: Desert steppe grazing management

- Chapter 9: Managing the typical steppe
- Chapter 10: Devising sustainable grassland grazing management practices for the future of Chinese grasslands
- Chapter 11: Capacity building as a driver to deliver benefits for sustainable grasslands
- Chapter 12: Future-proof sustainable Chinese grasslands

References

Chen, L, Michalk, DL & Millar, GD 2002, 'The ecology and growth patterns of *Cleistogenes* species in degraded grasslands of eastern Inner Mongolia, China', *Journal of Applied Ecology*, vol. 39, pp. 584–594.

Gongbuzeren, YL & Li, WJ 2015, 'China's rangeland management policy debates: what have we learned?', *Rangeland Ecology & Management*, vol. 68, pp. 305–314.

Hong, FC 2006, 'Zhongguo Caoye Kechixu Fazhan Zongti Zhanlue' (Comprehensive Strategy for the Sustainable Development of China's Grass Industry), in Q Du (ed.), *Zhongguo Caoye Kechixu Fazhan Zongti Zhanlue* (Strategy for the sustainable development of China's grass industry), China Agricultural Publishing House, Beijing.

Hong, FZ 2011, *History of Grassland in China*, China Agricultural Press, Beijing, pp. 221–233.

Hou, XY, Han, Y & Li, F 2012, 'The perception and adaptation of herdsmen to climate change and climate variability in the desert steppe region of northern China', *The Rangeland Journal*, vol. 34, pp. 349–357.

Hou, XY, Yin, YT, Michalk, DL, Yun, XJ, Ding, Y, Li, XL & Ren, JZ 2014, 'Herders' opinions about desirable stocking rates and overstocking in the rangelands of northern China', *The Rangeland Journal*, vol. 36(6), pp. 601–610.

Jones, RJ & Sandland, RL 1974, 'The relation between animal gain and stocking rate: derivation of the relation from the results of grazing trials', *The Journal of Agricultural Science*, vol. 83(2), pp. 335–342.

Kemp, DR, Badgery, WB & Michalk, DL 2015, 'Sustainable grasslands: resolving management options for livelihood and environmental benefits', in D Vijay, MK Srivastava, CK Gupta, DR Malaviya, MM Roy, SK Mahanta, JB Singh, A Maity & PK Ghosh (eds), *Sustainable use of grassland resources for forage production, biodiversity and environmental protection*, Proceedings of 23rd International Grassland Congress, New Delhi, India, Keynote Lectures, Range Management Society of India, Jhansi, Uttar Pradesh, India, pp. 259–269.

Kemp, DR & Dowling, PM 2000, 'Towards sustainable temperate perennial pastures', *Australian Journal of Experimental Agriculture*, vol. 40, pp. 125–132.

Kemp, DR & Michalk, DL 1993, 'Pasture management: introduction', in DR Kemp & DL Michalk (eds), *Pasture management: technology for the 21st century*, CSIRO Publishing, Melbourne, pp. ix–xi.

—— (eds) 2011, *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 189.

—— 2011, 'Livestock production styles and managing grassland ecosystems' in G Lemaire, J Hodgson, A Chabbi (eds), *Grassland ecosystems: productivity and environmental issues*, CABI Publishing, Wallingford, Ch. 1.6, p. 53–62.

Kemp DR, Michalk DL & Virgona JM 2000, 'Towards more sustainable pastures: lessons learnt', *Australian Journal of Experimental Agriculture*, vol. 40, pp. 343–356.

Li, B 1999, 'Steppe degradation in northern China and preventing measures', in RG Xu (ed.), *Collected Papers of Li Bo*, Science Press, Beijing.

Lu, XS, Fan, JW, Liu, JH 2002, 'Grassland resource', in QL Du (ed.), *Chinese grassland sustainability development strategy*, Chinese Agricultural Press, Beijing.

Lu, ZJ, Lu, XS, Xin, XP 2005, 'Present situation and trend of grassland desertification of North China', *Acta Agrestia Sinica* (Journal of Grassland), vol. 13, pp. 24–27.

Michalk, DL, Kemp, DR, Han, GD, Hua, LM, Nan, ZB, Takahashi, T, Wu, JP & Xu Z 2011, 'Redesigning livestock strategies to reduce stocking rates and improve incomes on western China's grasslands', in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 140–151.

Ren, JZ, Hu, Z, Zhang, Z, Hou, FJ & Chen Q 2001, 'Zonation of grassland industry for sustainable ecological and economic development in China', in F Hong F & J Ren (eds), *Prospects of Grassland Science and Industry for the 21st Century*, Chinese Grassland Society/China Association of Agricultural Societies, Beijing.

Zhang, YJ, Huang, D, Badgery, WB, Kemp, DR, Chen, WQ, Wang, XY & Liu, N 2015, 'Reduced grazing pressure delivers production and environmental benefits for the typical steppe of north China', *Scientific Reports*, 5, doi: 10.1038/srep16434.

2 Chinese livestock numbers and grassland impact

David Kemp, Wu Jianping, Lang Xia, Gong Xuyin, Li Ping, Han Guodong, Zhao Mengli, Karl Behrendt, Scott Waldron

Livestock have always been an important part of China's history, transport, mechanical power and food supply, vital for supporting the large population, especially herders who lived on the grasslands. However, for much of China's history, the 400 Mha of extensive grassland areas of the north and west had a low density of people and animals. People lived a largely self-sufficient existence, depending upon their livestock to satisfy most of their needs. Trade with other regions was restricted and limited to higher value items, as transport systems were rudimentary. Not all grasslands were grazed each year and a transhumanance system of annual movement by herders seeking forage for their livestock meant they had time to recover.

The grasslands of China had sustained herder households for centuries, but in the last century, the large increases in populations of people and animals have put this major resource under increasing pressure. It is now widely acknowledged that 90% of the grasslands are degraded to varying degrees and animal productivity is low. Overstocking was encouraged, as herders and officials considered that more animals would result in more income, which would support the increasing demand for food and other products from the increasing human population. It has now been realised that those policies and practices have not delivering the results desired and that degradation of the grassland resources is creating additional environmental problems, including the increasing frequency of dust storms. As discussed throughout this monograph, simply increasing animal numbers does not result in higher incomes for herder households. A better strategy is to focus on maximising net income per animal.

This chapter summarises the changes in livestock numbers since 1950, when statistics were collected for the animals that graze the grasslands. This provides a background to the chapters that consider more detailed impacts and solutions. Data is presented for sheep, goats, yaks, beef cattle, horses and camels, but not dairy cattle, buffaloes, pigs or poultry. The latter groups of animals are more common in the south-east of China, not on the grasslands. In more recent years, dairy cattle numbers have expanded in grassland regions, but they tend to be kept in feedlots and fed on specially grown forages. The ways grazing animals are managed have changed over time, but it is difficult to be very precise about how that may have changed grazing pressures on the grasslands. For example, a general trend has been to increase the amount of supplementary forage used and the time animals spend in sheds through winter. This trend has been driven, in part, by the declining forage available from grasslands and changing market demand for animal products (quantity and quality). The objective of this chapter is to estimate the general changes in grazing pressures that would have occurred.

Data is presented for China, the IMAR and Gansu, and four regions within those provinces where the research presented in this monograph was carried out. In IMAR, the counties investigated are Siziwang and Xilinhot. In Gansu, the counties are Sunan and Gannan/Maqu. From these seven different regions and scales, we can clarify the similarities and differences in livestock pressures on grasslands, and the implications of these for similar areas across China.

Livestock have always been important in pastoral areas of China. This ancient bronze shows an animal used for draught. In recent decades, the numbers of draught animals have declined, and beef cattle have rapidly increased. Photo: D.R. Kemp

China

Statistical issues

The available data on livestock numbers and products has some limitations that need to be kept in mind when considering these results. It is best to interpret the results in a broad sense. The problems in Chinese livestock collection and reporting systems have been previously documented (Waldron et al. 2007). In China's annual 'bottom-up' system, statistics are sent from villages up to national levels, based on subsamples and a series of technical assumptions (turnoff and carcass weights). These are corrected and retrospectively revised every 10 years in a complete agricultural census (1996–97, 2006–07). The early years of the 1950s would have been problematic, as the current Chinese government came to power in 1949 after many years of conflict.

The main national dataset used for China was obtained from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) (accessed April 2017). The available FAOSTAT data cover the period 1961–2014. Data from 1950 to 1961 were obtained from archived statistics originally maintained by the United States Department of Agriculture and now on a NASA website (accessed April 2017). Where that data overlapped that from FAOSTAT, any differences were trivial. This suggests that the same adjustments applied to the earlier dataset.

The data used was on numbers of sheep, goats, cattle (excluding dairy and buffalo, but including yaks), horses and camels—the species that utilise grasslands. The data on sheep and goats is sometimes separate and in other cases combined (sheep+goat), especially in the early years of available data. Herders often call all their small livestock 'sheep' and those collecting the data were not always able to separate them. In some cases, it appears that beef cattle and yaks may have been combined. Where clear differences applied, the separate data on species was used.

Changes in animal products (especially meat) over time could add additional information on how well those animals were being fed from grasslands. However, that data has limitations. Data on 'meat' animals (the term used in FAOSTAT) is more correctly termed 'turnoff' or 'offtake', which includes both slaughtered and transacted animals (which may not have then been slaughtered for meat) and the proportions vary through the years. The derived tonnes of meat from each species are based on estimated carcass weight constants. What was evident was that the same yield of meat per animal was often used over the years, even though seasonal conditions and management practices changed. In the early years, sheep numbers were not clearly distinguished from goats, and the weight of 'meat' per goat was often equal to, or greater than, that from sheep, suggesting there are some inherent errors. Sheep are typically 20–25% larger than goats, and it is highly unlikely that both species had the same meat yield. The calculated meat per head was not constant across all years, suggesting that there was some data collected that resulted in variable outputs over the years, but it was difficult to resolve this detail. The 'meat' produced by horses and camels was constant over the years (120 and 220 kg/head, respectively) and does not identify consumption, as some of the animals sold were not slaughtered. As horses and camels are a small proportion of the total number of animals, this is not a major issue for estimating the total effect from all grazing animals.

The definition of 'meat' animals is also problematic. When the number of animals in this category is expressed as a proportion of the total (within species) this was initially low (arguably realistic), but in later years it rose to 70–80% of the total for sheep and goats. It is unrealistic to expect that the national flock/herd could continue to increase each year if 70–80% were slaughtered. Fecundity is not that good in China and, even within the world's best systems, total animal numbers could only decrease with that slaughter rate. Even a slaughter rate of 40% for cattle is arguably unrealistic at a national scale, as this roughly suggests a life span of 2.5 years for the average head of cattle. Waldron et al. (2007) used data from IMAR that separates 'turnoff' into 'killed for self-use', 'sold for slaughter', and 'exchange only'. Their data reported that most sheep and goats were slaughtered, but that rate would still be too high. We have used the data on meat per 'turnoff' animals, but suggest it needs to be interpreted carefully until we can find a better clarification of what was counted. We use 'turnoff' in a relative sense to get an idea of changes over time. Meat output per total flock/herd is possibly a safer estimate of output.

Some data was available on wool production, but this used a constant term across the years and may not reflect the effect of grassland conditions. No data was consistently available on cashmere.

Waldron et al. (2007) expressed caution in interpreting a lot of the statistics, as sheep vs goat data are poorly differentiated and it is best to treat them as a single category, although this improved in recent years. Slaughter numbers are overstated, as noted above. For cattle, the proportion is much less, especially before 1978 when they were the main draught animals. They have since been largely substituted with machinery. Sheep and goat meat production are grossly overstated, while sheep and goat meat consumption (obtained from other data sources) is understated, leaving a large unexplained gap between estimates. The data presented needs to be considered conservatively, with the above caveats in mind.

Total livestock grazing pressure

The total livestock grazing pressure across China was estimated using the total number of animals in each category converted into sheep equivalents (SE). These estimates are similar to the Chinese sheep unit (SU). They are based on the estimated average differences in liveweight. One SE is equivalent to a 50 kg animal:

- 1 sheep = 1 SE
- 1 goat = 0.8 SE
- 1 cattle = 5 SE
- 1 yak = 3.5 SE
- 1 horse = 6 SE
- 1 camel = 10 SE

The area of grassland across China used in the national statistics has varied over the years. Initially this did not include any land that could not be cropped, although livestock would have grazed the extensive, non-arable land as well as crop residues and some forages. The common estimate from the early 1990s of 392,834,000 ha of grassland in China is held constant and was used to estimate stocking rates.

The cumulative SE for sheep, goats, cattle, horses and camels from 1950 to 2014, and the standardised national total stocking rate as SE/ha, are shown in Figure 2.1. The greatest contributors to total SE were cattle and the next largest category were sheep and goats. In recent decades, the proportion of cattle fed for part of their life in pens has increased, though it is difficult to estimate how many. The sheep and goat SE are shown separately, but as previously mentioned they are arguably best treated as one category (sheep+goat), particularly for the first few decades of this data.

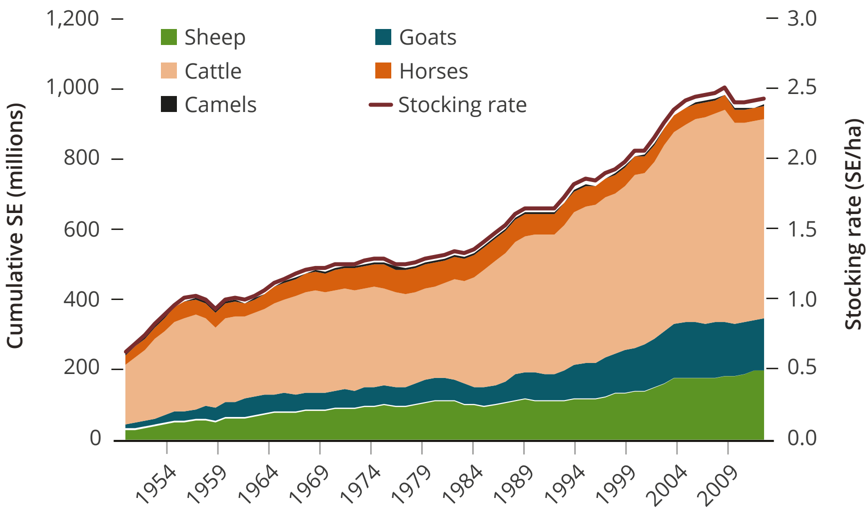

Figure 2.1 Cumulative SE and standardised stocking rate (SE/ha), China, 1950–2014

Source: FAOSTAT

In 1950, the stocking rate averaged 0.6 SE/ha. By 2014, this was 2.4 SE/ha, a fourfold increase in grazing pressure. China now has about one billion SE (380 million sheep and goats, 115 million beef cattle, 6 million horses and other grazing animals). The average rate of increase in the stocking rate from 1950 to 2014 was 0.027 SE/ha per year (mean of 4.5% per annum). The standardised stocking rate data for China (Figure 2.2) indicates there were approximately four different growth phases from 1950 to 2014: an initial rapid rise from 1950 to 1957, a slower rate of change from 1958 to 1984, another fast rise between 1985 and 2008, and a constant, or declining, period from 2009 to 2014. The break between these periods was based on inspection of the data, but in each case points could be varied a year or so without changing the general result.

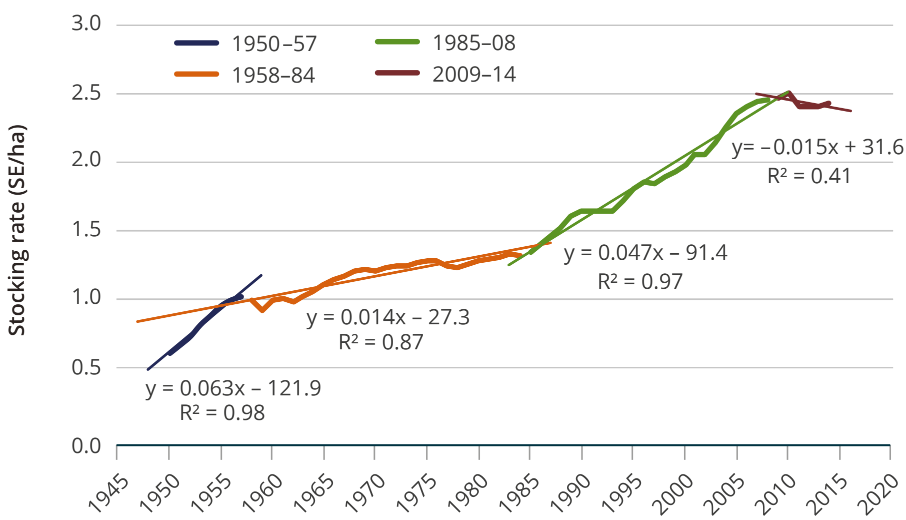

Figure 2.2 National standardised stocking rate (sheep, goats, cattle, horses and camels), China, 1950–2014

The rate constants and percentage change per year for the stocking rate data for these four periods are given in Table 2.1. The highest annual rate of increase was 7.5% p.a. from 1950 to 1957, the recovery period after the previous years of conflict. Data collection at that time may have initially underestimated actual numbers, as the state was only starting to collect this information, but the estimated growth rate is feasible for the likely grassland conditions at the time.

Change was slow (1.2% p.a. increase) in the collective period (1958–84), when agricultural activities were being reorganised and tightly regulated. The first few years of this period (1958–62) was the 'great hunger' during the Great Leap Forward, and the data show a decline in total SE during this period (Figure 2.1). During this time, cattle were primarily used for mechanical power and not consumption. Only yaks were consumed. There is an opinion among Chinese scientists that during this period the grasslands were in reasonable condition and stocking rates may have been sustainable. The stocking rates in that period were about half those of 2014, suggesting that a halving of current stocking rates is needed to restore them to a sustainable level.

Table 2.1 Rate constants and percentage change in total SE and stocking rates, 1950–2014

Period		Duration (years)	Slope (SE/ha/yr)	Mean total (SE)	Annual change (SE/yr)	Change per year (%)
1	1950–57	8	0.0628	328,532,750	24,669,975	7.5%
2	1958–84	27	0.0144	463,264,644	5,656,810	1.2%
3	1985–2008	24	0.0467	738,806,871	18,345,348	2.5%
4	2009–14	6	–0.0145	956,996,779	–5,696,093	–0.6%

When the individual responsibility system and markets were introduced, and herders started to have control over individual areas of land when decollectivisation started in the 1980s, there was a faster rate of increase in animal numbers and stocking rates (1985–2008, 2.5% p.a.). This was attributed to herders considering they could now have more animals, supported by local officials, as a way of improving their income. However, as argued in this monograph, that consideration is based more on maximising the number of animals that can survive than optimising production and net incomes. During this period, grassland degradation became widely recognised.

From 2009 to 2014, the data indicates a small decline in grazing pressure, although this may in fact represent no real change as this period is short. Future data will show if the increasing animal numbers have now reached a limit and will be consolidated. The current poor state of many grasslands will limit the number of animals that herders can manage. By 2009, officials were changing their attitudes from emphasising increasing animal numbers to improve product output and herder household incomes, to focusing more on improving the output of animal products. The work reported in this monograph has encouraged that change.

From 1950 to 2014, there was no uniform pattern of change for the major herbivores. When the number of cattle is related to the number of sheep+goats over the whole period (Figure 2.3), there was an average increase of 0.25 cattle for each extra sheep+goats. This was a 42% higher rate of increase for cattle than for sheep+goats, when expressed as SE.

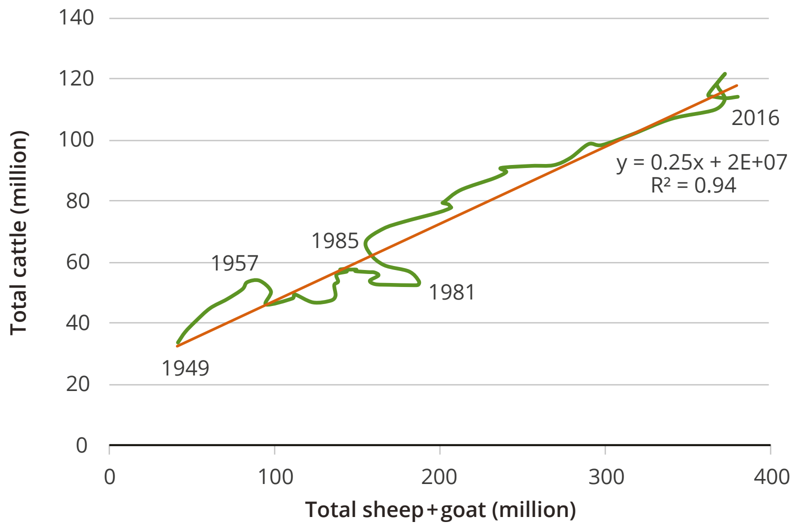

Figure 2.3 Total number of cattle vs total number of sheep+goats, China, 1950–2014

There were some differences in the relationship between cattle and sheep+goat numbers over the years. From 1949 to 1957, during the recovery period, cattle numbers increased by 60% then almost stopped, whereas sheep+goats doubled. This could indicate an increase in cattle used as draught animals. Between 1957 and 1981, a period when regulations were introduced to limit their use for draught purposes, cattle numbers showed very little change, while sheep+goats (the main meat source from herbivores) again doubled. Sheep+goats then declined by 30 million until 1985, while cattle numbers rapidly increased when they could be used for consumption. From 1986 to 2005, there was a reasonably constant rate of increase in cattle and sheep+goat numbers. In recent years (2006–14) there have only been small changes in cattle and sheep+goat numbers. The periods when the relative changes in cattle and sheep+goat numbers varied broadly relate to the different periods of changes in stocking rates (Figure 2.2).

These shifts among animal species would have affected the grasslands. Cattle tend to be less selective of plant species when grazing, which could mean that in the first period (1949–57) plant composition changes may have been small. When sheep+goat numbers were increasing relative to cattle, larger effects on plant species may have been seen.

Livestock productivity

The amount of animal product (especially meat) per head can provide additional information on how animals were being managed and the productivity of the underlying grassland resource. However, this data needs to be carefully appraised (see Waldron et al. 2017 for a more complete discussion of the issues). It was assumed that any of the basic statistical problems noted earlier apply in a reasonably constant way through the adjusted datasets, and that the patterns of change do provide some useful information, even if the absolute values are not correct. Data on meat production are available from 1961 from FAOSTAT. This data had been adjusted following more detailed surveys in 1996–97 and 2006–07.

Preliminary analyses found that meat production per head, using the estimates of the 'turnoff' number of animals, gave results that were inconsistent. The proportion of those animals did not vary in any logical way between years. For example, sheep+goats in the 'turnoff' category, as a proportion of the total, varied from 9% in 1961 to 21% in 1979, 67% in 1997 and 76% in 2014. If most animals were slaughtered, these numbers are unrealistic. Flocks and herds could not be sustained at that level of loss. For example, in 2014, this implies a lifetime of 1.3 years per sheep+goat. Similarly, the numbers for cattle varied from 1% in 1961 to 40% in 2014. We know that livestock production in China is not very efficient. It takes two to three years for a ewe to produce a lamb, and four years before a cow has a calf. This can only sustain low rates of slaughter.

More useful results were obtained by deriving meat outputs per animal using the total number of animals in the national flock/herd. Meat output per head for all sheep+goats (Figure 2.4) and all beef cattle (Figure 2.5) show a similar sequence to the earlier data on stocking rate changes over time. The increasing output of meat per head probably reflects, in part, an increasing proportion of flocks and herds being sold for slaughter, though probably not to the high proportions indicated by the 'turnoff' numbers.

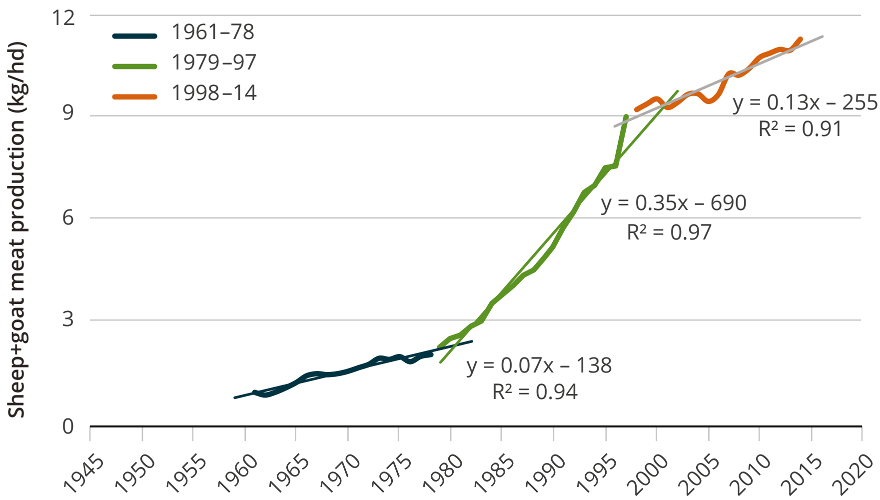

Figure 2.4 Meat production per head for all sheep+goats, China, 1961–2014

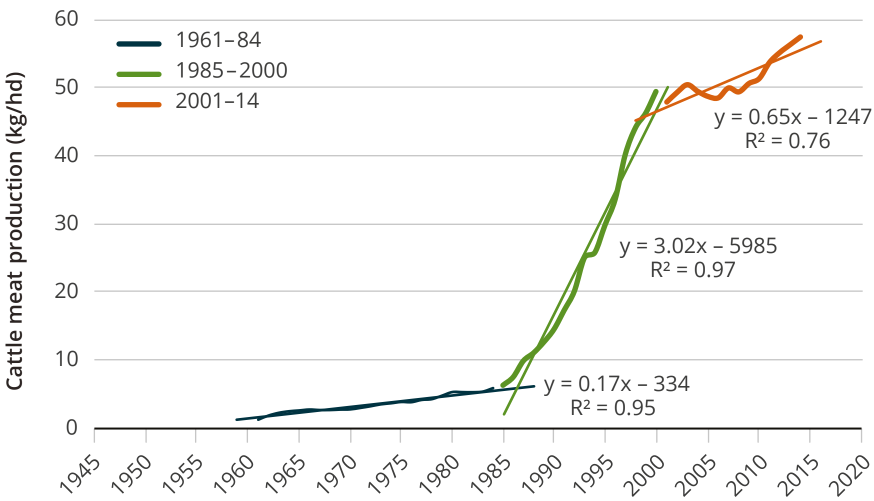

Figure 2.5 Meat production per head for all beef cattle, China, 1961–2014

The rates of change in meat produced per head for sheep+goats and cattle were initially low from 1961 to 1978 (4.8% and 4.9% of the average output at that time, respectively) (Table 2.2). This difference in timing arguably reflects the slower breeding cycles of cattle and the limited change in total cattle numbers during this period (Figure 2.3).

Table 2.2 Meat production per head, China, 1961–2014

Period	Duration (years)	Rate (kg/hd/yr)	Average (kg/hd)	Gain per year (%)
Sheep+goats				
1961–78	18	0.071	1.5	4.8%
1979–97	19	0.35	4.9	7.2%
1998–2014	17	0.13	10.0	1.3%
Cattle				
1961–84	24	0.17	3.5	4.9%
1985–2000	16	3.02	24.5	12.3%
2001–14	14	0.65	51.4	1.3%

Between 1985 and 2008 there was a rapid increase in total SE across China (Figure 2.1). This broadly aligns with the periods of rapid increase in meat output per head for cattle and sheep+goats (Figures 2.4 and 2.5). Increased meat output per sheep+goats started earlier than for cattle, probably due to the faster breeding cycles of sheep+goats. However, there was a decline in meat output per head after 1997 for sheep+goats and after 2000 for cattle (11 and 8 years respectively), before the rate of increase in animal numbers slowed from 2009. The significantly slower rate of increase in meat output per head after 1998 for sheep+goats and 2001 for cattle, while animal numbers increased, suggests some fundamental system changes, which could include a deterioration in the underlying grassland resources. The slower rate of change in meat output per head for the period 2001–14 suggests that some limits are being reached. The capacity for increasing the food supply for animals is limited, as is the proportion of flocks and herds that can be sold for slaughter. These data support the view that since 2000 there has been increasing off-take of meat to satisfy an increasing demand for red meat by Chinese consumers. This is also driven by higher prices.

Inner Mongolia Autonomous Region

IMAR is one of the major grassland (64 Mha) provinces of China. Herding has been a traditional practice here for millennia and IMAR has been in the forefront of developing sustainable grazing practices. The problems of degraded grasslands have been widely acknowledged. In recent years the whole province has been subject to partial or total grazing bans. Data on livestock numbers for 1947 to 2015 have been assembled from the yearbooks and related sources to investigate the changes. Unfortunately, it has not been feasible to build a consistent dataset on meat output to compare IMAR with China.

Sheep+goats have been the major livestock group in IMAR from 1947 to 2015, contributing about half of the SE (Figure 2.6), similar to cattle+horses. In general, there was a steady increase until around 2002 and a subsequent rapid rise. Cattle numbers also increased after 2002. The data do not always separate beef from dairy cattle. In 2002, dairy cattle were 24% of the total, rising to 39% in 2006, then declining in proportion to 21% by 2015. Dairy cattle are now managed in feedlots and are not grazed to the same extent as other species. Horses+donkeys+mules comprised a similar level of SE as cattle from the mid-1960s to about 2000, but they have since declined because of policy changes. By 2015 there were 82.7 million sheep, 24.7 million goats, 11.3 million cattle, 2.1 million horses+donkeys+mules and 0.2 million camels in IMAR.

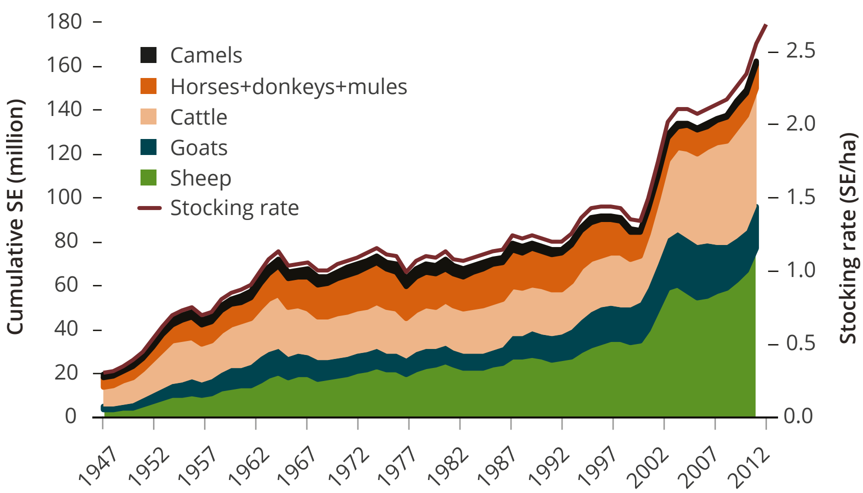

Figure 2.6 Cumulative sheep equivalents and standardised stocking rates, IMAR, 1947–2015
Source: Inner Mongolia Autonomous Region Yearbooks

The total grazing pressure in many areas is high. These sheep on the desert steppe are in good condition at the end of summer, but there is no more grassland growth for the next nine cold months to sustain them under traditional management practices. Photo: D.R. Kemp

Stocking rates have dramatically increased from 0.3 SE/ha in 1947 to 2.5 SE/ha in 2015, an increase of 8.8x. From 1947, there was an initial steep increase to 1 SE/ha. That remained relatively constant from 1965 to 1987, then increased slowly to 1.3 SE/ha by 2002. This was followed by a steep rise to 2.5 SE/ha by 2005, initially due to more dairy cattle but subsequently due to both beef cattle and sheep. There was a pause after 2005, then stocking rates again increased until 2015. In recent years, it is unlikely that the dairy cattle grazed the grasslands to any great extent. In 2015, if the 21% of cattle that were dairy did not graze, this would only reduce the stocking rate to 2.3 SE/ha, which is still more than an eightfold increase in grazing pressure since 1947.

The long initial period for increasing livestock numbers from 1947 until 1965, which applied to China as a whole (Figure 2.1), probably reflects the initial low herder population density in IMAR and the effects of migration into grassland regions. The collective period in China's history limited change until 1987, but afterwards herders had more individual control and more people moved onto the grasslands. Animal numbers in IMAR increased rapidly, like elsewhere in China. It is not clear how much of this increase was due to an increase in animals per household or an increase in herder households. In Taipusi, an old herder commented that when he was young there were three households where he lived, but now there are 66. The available land has decreased, while animal numbers have dramatically increased.

There were some interesting shifts in the relative changes in sheep+goats vs cattle numbers from 1947 to 2015 (Figure 2.7). Over this 68-year period, cattle numbers increased by 0.08 for each unit increase in sheep+goat—approximately 40% that of sheep+goats when expressed on an SE. This indicates the general dominance of sheep and goats in IMAR. Sheep and goats have become more important over time as the available grass becomes shorter and cattle are less able to graze. There were five phases in this interaction:

A. 1947–55: both sheep+goats and cattle numbers increased at nearly equivalent SE rates (0.18 cattle numbers per 1 sheep+goat number)

B. 1955–2002: an increase mainly in sheep+goats, with very small increases in cattle

C. 2002–06: cattle numbers increased faster relative to sheep+goats and there was a belief among some herders that cattle were more profitable, which was supported by government programs and continued into the next phase

D. 2006–12: decrease in sheep+goats (mostly in goats) and a significant increase in cattle numbers

E. 2012–15: marginally larger increase in numbers of sheep+goats compared with cattle, though both increased at higher rates than in previous phases.

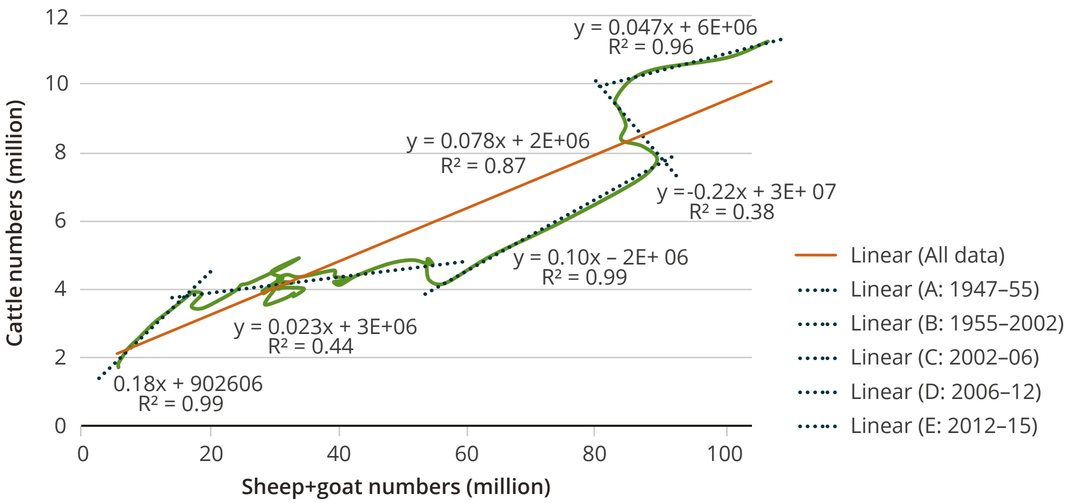

Figure 2.7 Relationship between numbers of cattle and numbers of sheep+goats, IMAR, 1947–2015

Statistics for the five phases are summarised in Table 2.3. The changes in animal numbers in each phase varied considerably, from a decline of 0.96x in sheep+goats in phase D to a 3.3x increase in sheep+goats in phase B. The annual rate of change in phases A, C and E for sheep+goats was around 0.4 per year, suggesting a high retention rate and maybe reduced sales. This could also reflect animals coming into IMAR from other provinces. Rates of increase in sheep+goats relative to cattle were higher in phases A, C and E, averaging 0.37 over these phases compared to 0.02 and –0.22 in phases B and D.

Table 2.3 Number of sheep+goats and cattle, IMAR, 1947–2015

Phase	End year	Number of years	Number of sheep+goats	Change in phase	Change per year	Number of cattle	Increase in phase	Increase per year	Slope
	1947		5,708,000			1,746,000			
A	1955	8	17,244,000	3.02	0.38	3,942,000	2.26	0.28	0.18
B	2002	47	56,752,200	3.29	0.07	4,195,500	1.06	0.02	0.02
C	2006	4	90,026,000	1.59	0.40	7,801,000	1.86	0.46	0.10
D	2012	6	86,054,000	0.96	−0.16	10,158,000	1.30	0.22	−0.22
E	2015	3	107,365,000	1.25	0.42	11,260,000	1.11	0.37	0.05

Note: The 'Slope' column shows the relative change in sheep+goat numbers for each unit change in cattle.

Siziwang

Siziwang is a desert steppe region, north of Hohhot in IMAR. Grassland degradation problems were recognised in the 1990s by local herders and officials. Inner Mongolia Agricultural University began long-term research into better grassland management and, when the program discussed in this monograph commenced, Siziwang was chosen as one of the key study sites.

Data have been obtained from various yearbooks to examine the general patterns of change in livestock numbers in Siziwang. Unfortunately, it was not possible to find data for 2001 and 2002, though this gap arguably does not affect the general patterns or conclusions. Sheep and goat data are treated as one group, due to the general problems of poor separation in the data. Horses, donkeys and mules are also in one group. The relative proportions of horses, donkeys and mules have varied over the years, but overall numbers are small relative to sheep and goats. Cattle numbers are generally low. In recent years, dairy animals have become a larger proportion of the cattle group.

Siziwang is an area of 1.7 Mha. In 2016, it had 1.1 million sheep+goats, 36,000 cattle, 1800 horses+donkeys+mules and 8,000 camels. Cattle numbers were around 60,000 in the 1960s, as were horses+donkeys+mules in the 1970s. Camel numbers reached a peak of about 11,000 around 1980. Many herders in Siziwang are Mongolian, and they have a strong horse culture, although the number of horses greatly declined as the grasslands degraded. The total SE in Siziwang ranged from 358,000 in 1949 to 1,756,000 in 1989. These numbers have declined by 30% to 1,231,000 in 2016 (Figure 2.8). Cattle numbers declined significantly by 2008, and the increase since then has mostly been in dairy animals. The significant number of camels indicates the dry nature of grazing lands.

Stocking rates in 1949 were 0.2 SE/ha, rising to 0.7 SE/ha in 1960. They were then relatively steady at 0.7 SE/ha until 1985, rose to an average of 0.9 SE/ha from 1988 to 2008, then declined sharply to an average of 0.6 SE/ha from 2009 to 2016. This later decline in stocking rates aligns with the period when the results from the ACIAR program were being implemented in the district, recommending a 50% reduction in stocking rates. The decline in cattle and other large animal SE numbers agrees with the comments of old herders that cattle can no longer be adequately fed on the short grasslands.

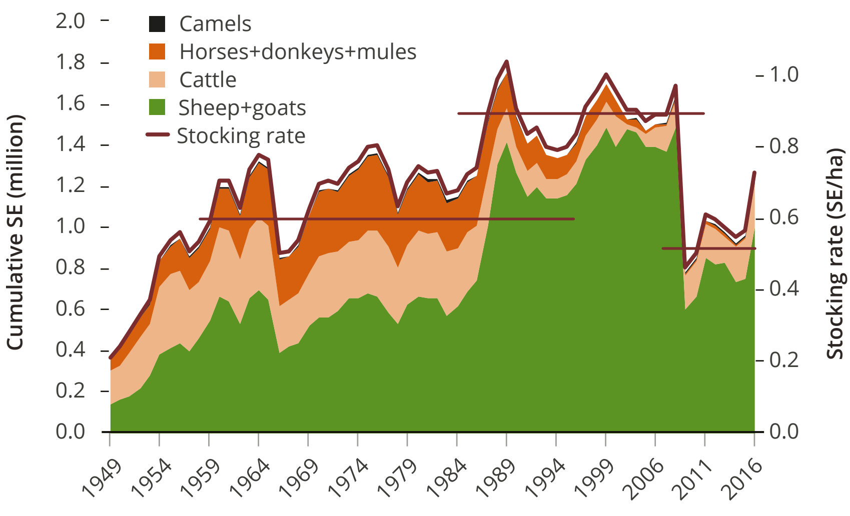

Figure 2.8 Livestock numbers and stocking rates, Siziwang, IMAR, 1949–2016

Note: Horizontal bars denote average stocking rates for the periods 1960–85, 1988–2008 and 2009–16.

Since 1949 there have been significant changes in the proportions of the major livestock groups (Figure 2.9). From 1949 to 1985 there was a close linear relationship and a general increase in both cattle+horses+camels and sheep+goats, except for a significant decline in the 1960s (Figure 2.8). On an SE basis, large animals only increased at 66% of the rate for small animals. From 1985 to 1989 there was a 38% decline in large animals while small animal numbers doubled. This suggests that, during that period, the viability of large animals was doubtful and the existing grassland conditions were considered more favourable for sheep and goats. From 1989 to 2008 the numbers of small animals oscillated between 1.2 and 1.5 million, while larger animals continued to decline. From 2008 to 2009, sheep+goat numbers dropped by 60% and cattle remained steady. This was when general prices for sheep and goats declined. Since 2009, sheep+goats have increased to about 1 million SE. Since 2008, the numbers of large animals have been relatively steady.

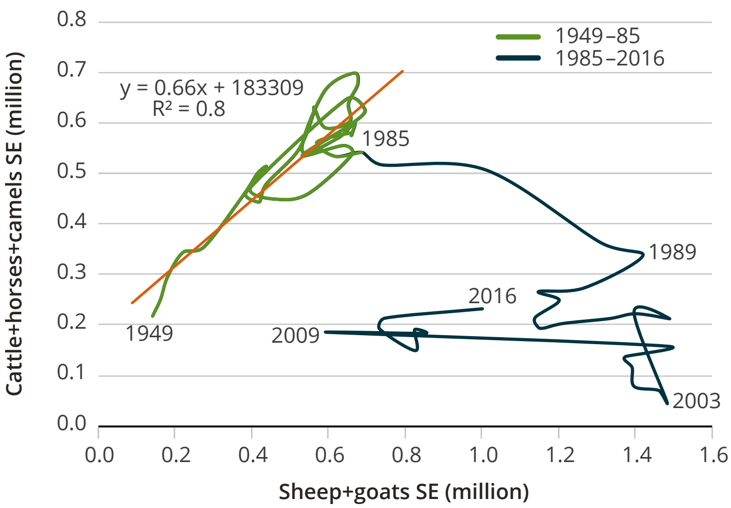

Figure 2.9 Numbers of large animals (cattle+horses+camels) relative to small animals (sheep+goats), Siziwang, IMAR, 1949–2016

Note: Fitted line is for the period 1949–85.

The pattern in changing livestock numbers and stocking rates in Siziwang is different to the general patterns found for China and other regions. In Siziwang there was more variability in the data. This is partly due to Siziwang being a smaller region with smaller animal numbers, so the effects of variable seasonal conditions are more obvious. Across China, seasonal effects are smoothed out as changing climatic conditions are not uniform. In Siziwang there was a longer initial period of recovery after 1949, which may reflect the low initial density of people and animals and the gradual migration of others into the region because of policy changes. In Siziwang there was a steady rise in animal numbers until 1960, whereas across China the initial rapid rise only lasted until 1957.

The relatively stable animal numbers from 1960 to 1985 in the collective period reflected the situation across China. As discussed earlier, this is possibly the period when stocking rates across China were generally sustainable. That was followed by a period of higher animal numbers from 1988 until 2008, when the grasslands were overgrazed. Since 2008, the stocking rates have been reduced by 30%, arguably in response to the research presented in this monograph and because the extent of overgrazing was recognised and accepted as a problem. It is interesting that current stocking rates are below the average from 1960 to 1985. That could suggest that stocking rates in the collective period were above sustainable levels, or that the stocking rates from 1988 to 2008 did significant damage that reduced what might be sustainable to less than what may have been possible in previous decades. It is reasonable to expect that a few decades of lower stocking rates might be needed before the grasslands can sustainably carry the animal numbers of 1960–85.

Xilinhot

Xilinhot is a region in the middle of IMAR where the grasslands are typical steppe, tending to drier conditions, and where livestock production is a major activity. Throughout the study period, grasslands have been the major source of food for livestock, though since around 2015, hay production from the grasslands has become significant. That hay is used across IMAR. The county boundaries have changed over recent decades, which creates some problems when building a dataset about what has changed since the late 1940s. A consistent dataset was assembled from a few sources for 1986–2015 (Figure 2.10). Some boundary changes in 1985 resulted in significant changes in land area and livestock numbers for earlier periods. The available data on animals was either collected in June or December, or both. The June animal numbers would better reflect the grazing pressure on the grasslands. There were significant statistical relationships between animal numbers in June and those in December. These relationships were then used to fill in the gaps in data for June.

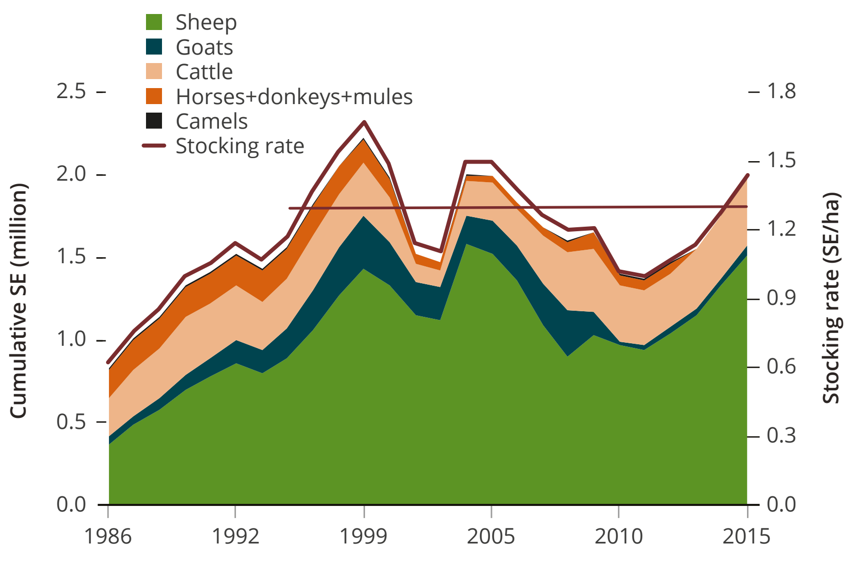

Figure 2.10 Livestock numbers and estimated stocking rates, Xilinhot, IMAR, 1986–2015

Note: Horizontal line shows average stocking rate for 1996–2015.

While the data for Xilinhot is limited, it does cover the time after the collective period, which ended in 1978, when livestock numbers in other regions started to increase rapidly. A rapid increase in animal numbers and stocking rates also occurred in Xilinhot, reaching a peak in 1999. There was a general decline until 2011 and then animal numbers and stocking rates increased until 2015, almost returning to the previous peak of 1999. The declines and recovery in animal numbers from 1999 reflect a combination of seasonal conditions, grazing bans (often imposed for five years) and fluctuating markets.

The stocking rate in 1986 on 1.3 Mha of grasslands was 0.6 SE/ha. In 1999 this nearly trebled to 1.7 SE/ha before declining to 1.0 SE/ha in 2011 then increasing to 1.4 SE/ha in 2015. From 1996 to 2015, the average stocking rate was 1.3 SE/ha, over twice that of 1986. Most of the animals in Xilinhot were sheep, with declining numbers of goats, horses and camels. Cattle numbers remained relatively constant throughout this period, though there was an increasing proportion of dairy cattle within that group. In 2015, there were 1.3 million sheep, 0.3 million goats, 0.08 million cattle, 0.01 million horses+donkeys+mules and only 330 camels.

Gansu

Gansu in western China has a highly variable range of environments, from deserts to ancient irrigation districts, semi-arid farming regions on the limit of rain-fed cropping and alpine meadows along the northern Sunan and eastern sides of the Qinghai–Tibetan Plateau. Livestock are found throughout the diverse agro-ecosystems. Sheep and goats are found throughout Gansu, but camels are mainly kept in the deserts and yaks are kept in alpine areas. Cattle graze where grassland growth is better, or in feedlots. There is an estimated 1.6 Mha of grasslands.

Gansu has a similar pattern in livestock numbers (Figure 2.11) to the other sites discussed. There was an initial increase from 1949 to the mid-1950s, a decline in the early 1960s (at the time of the 'great hunger'), a steady rise until the mid-1980s, then a steady rate of increase from the mid-1980s until 2016. The SE numbers of cattle+yaks, and sheep+goats were similar in 2016. Unfortunately, the lack of data on horses, mules, donkeys and camels makes it harder to examine the total impact, but it is likely that the numbers of those animals has probably declined, as has occurred elsewhere. That would mean that the rate of increase in total SE and SE/ha would be a little less than for cattle, sheep and goats. Yaks are included in cattle numbers. Potentially, the mean stocking rate would be at least 3.5 SE/ha, up by 3.9x that of the 0.9 SE/ha for 1949—approximately the same increase as for the whole of China. In 1988, there were 2.4 million horses, donkeys and goats, and 0.04 million camels. By 2016, Gansu had 5.2 million cattle, 1.1 million yaks and 24.3 million sheep+goats.

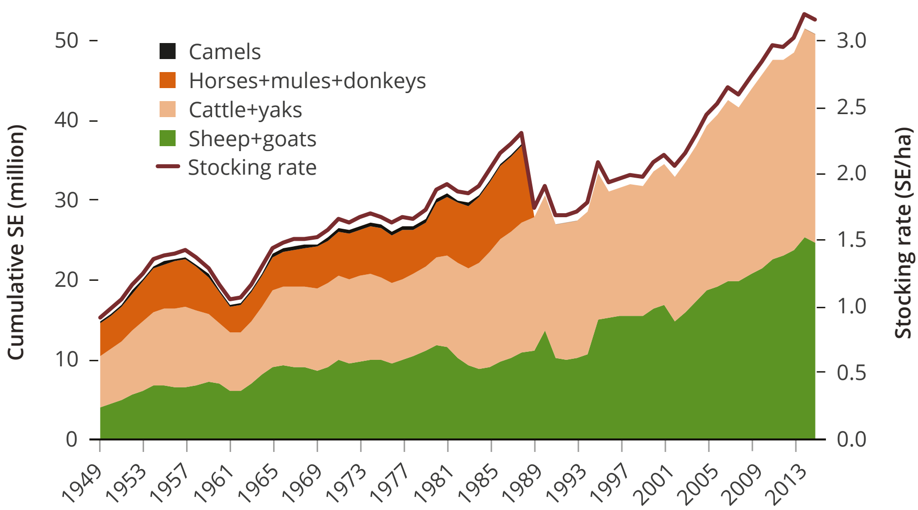

Figure 2.11 Livestock numbers and stocking rates, Gansu, 1949–2016

Note: Data for horses+donkeys+mules and camels were not available for 1989–2016.

The number of cattle and the number of sheep+goats both increased at similar rates, when expressed on an SE basis, from 1949 to 2016 (Figure 2.12). This represents approximately five extra sheep per extra head of cattle. The main exception to this trend was between 1980 and 1995, when cattle numbers initially increased while there was a decrease in sheep+goats. There was a second decrease in sheep+goats in 1991, before numbers moved back to the common trend. Equal grazing pressures over time across Gansu, for cattle and for sheep+goats, suggests that the grassland condition on average remained suitable for both large and small herbivores. Some areas would have only been suitable for sheep+goats, while others could support cattle. The relative areas of each probably did not change. By 2000, overgrazing was widely acknowledged.

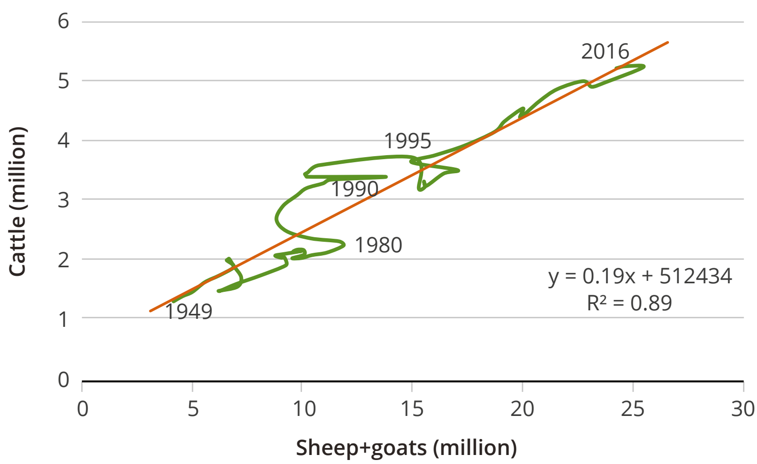

Figure 2.12 Number of cattle relative to sheep+goats, Gansu, 1949–2016

Sunan

Sunan is on the northern edge of the Qinghai–Tibetan Plateau, which covers about 40% of China. Grazing land varies in altitude from 2000–4000 m with moderate rainfall and a four-month growing season. The grasslands are broadly classified as alpine meadows. Herders practice traditional grazing patterns of having winter, spring/autumn and summer grazing areas, determined by altitude, that are now fixed and allocated to individual households. Sheep, followed by yaks and goats, are the main livestock species. This region has the Gansu alpine fine-wool breed, based in part on Australian merinos, though inter-breeding with local animals has resulted in reduced quantity and quality of wool. Sunan has 1.2 Mha of grasslands, though an unknown but significant part of that is not grazed, as it is inaccessible and very dry, especially at lower elevations.

Livestock numbers (as SE) and stocking rates have increased sevenfold since 1949 (Figure 2.13). There was an initial rapid increase until 1960, a slower rise until the mid-1980s, a decline until the mid-2000s then a rapid rise in the next decade. In 2016, total livestock numbers and stocking rates were similar to those of the mid-1980s. Both horse and goat numbers have declined over recent decades. Local authorities decided in the 2000s to remove goats from most areas. It was considered that the goats were doing more damage than sheep, though this could have simply been due to overstocking and not a species effect. The cashmere market had declined but fine wool remained more profitable, justifying the greater reduction in goat numbers. However, fine-wool production is marginal, as most herders have bred their sheep with local breeds and both wool yields and quality has declined.

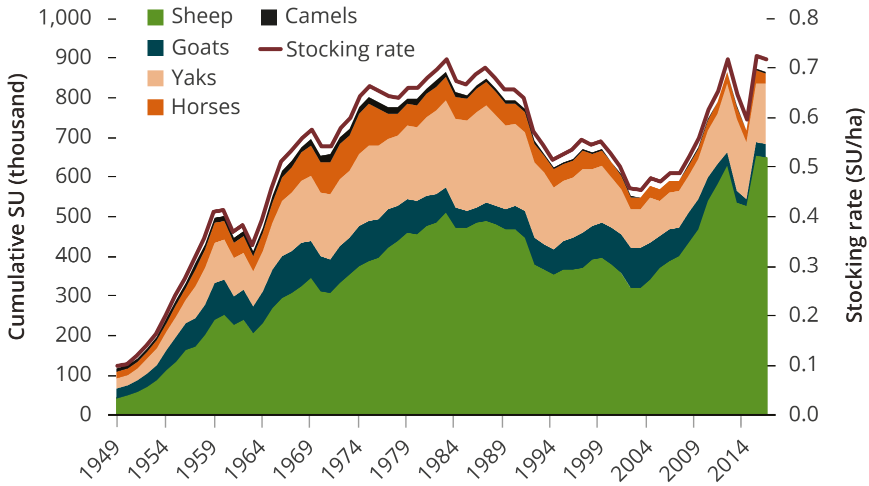

Figure 2.13 Livestock numbers and stocking rates, Sunan, Gansu, 1949–2016

From 1949 until the 1980s there was a relative constant ratio between small and large animals in Sunan (Figure 2.14). Through the 1990s there was a decline in small animals, but not much change in the large animal numbers. This continued until around 2000. After 2000, the number of small animal increased in general, while there was a relatively smaller change in the large animal population. By 2016 the total number of SE had returned to similar numbers to that of the 1980s.

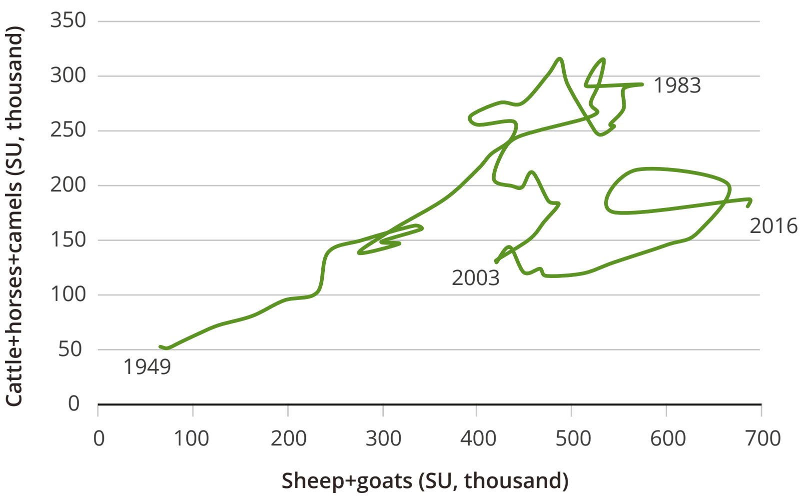

Figure 2.14 Number of cattle+horses+camels relative to sheep+goats, Sunan, Gansu, 1949–2016

Maqu

Data on livestock numbers for Maqu, Gannan, on the Qinghai–Tibetan Plateau in Gansu have been obtained for 1949–2016 from the Chinese yearbooks. The livestock included are sheep, yaks and horses. There is a gap in the data for horses from 1991–2002, but as they are a minor part of the total animal biomass this does not affect the general results. The land area of Maqu is 0.89 Mha, most of which is used for grazing through the year. Higher altitudes are grazed in summer. Maqu is the major source (approximately 45%) of water for the Yellow River.

The total number of sheep, yaks and horses increased from 191,400, 34,500 and 14,900 respectively in 1949 to 451,300, 473,300 and 20,000 respectively in 2016. The total SE increased from 418,800 in 1949 to 2,464,500 in 2016, with most of that coming from increase in yak numbers (Figure 2.15). The average stocking rate (SE/ha) increased from 0.5 in 1949 to 3.2 by 2008 then declined slightly to 2.9 by 2016—an average increase of about sixfold over the period, about twice that of China as a whole. The overall stocking rate rose steeply (approximately 50%) from 2009–12 after reasonably constant values from 1985. It is not clear what the main drivers of these large changes were, though the introduction of the individual responsibility system through the early 2000s was probably important.

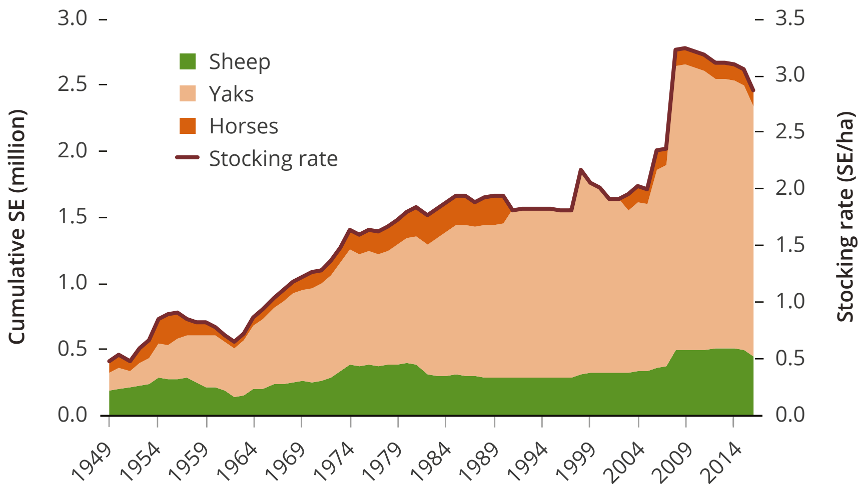

Figure 2.15 Number of sheep, yaks and horses and average stocking rates, Maqu, Gannan, 1949–2016

Sheep have often been the most profitable animals on the Qinghai–Tibetan Plateau, and their products were more readily traded with other districts. However, through the 67 years from 1949 to 2016, sheep numbers only increased 2.2×, whereas yak numbers increased 13.7×. The changes between sheep and yaks show some variable trends (Figure 2.16). For a brief period from 1949 to 1954, sheep numbers increased faster than yaks. Until 1962, sheep declined as yaks slowly increased, followed by a faster increase in sheep numbers until 1980, then a decline in sheep while yaks increased. From 2003, there was a steady increase in yak numbers at 1.3× the rate for sheep. Overall, there was an average rate of increase of 1.3 yaks for every extra sheep. In SE terms, this average was 5.2 yaks for every sheep. Yaks have cultural significance to Tibetans, and this may be more important than increasing incomes.

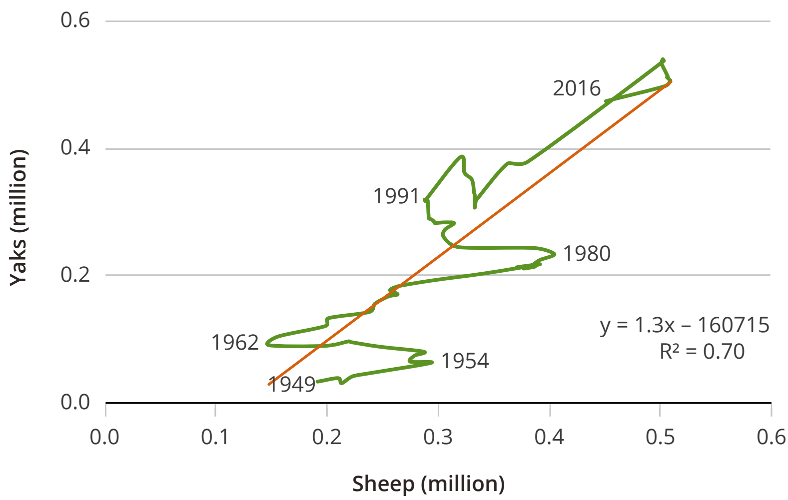

Figure 2.16 Number of yaks relative to sheep, Maqu, Gannan, 1949–2016

In Gannan, sheep have been more profitable over the years, but as pressure has increased on the available land, yaks are often kept in preference to sheep for cultural reasons. Photos: D.R. Kemp

There have been several major phases and policy changes that have influenced grassland management on the Qinghai–Tibetan Plateau (Hong 2011). Before 1949, population densities were low and livestock was managed by tribal leaders and temples. Between 1949 and 1958, tribal leaders owned the livestock, but they were allocated to and managed by individual herders. Cooperatives were then formed and these became larger over time, while population densities remained low. In Maqu, from 1949–54, there was a rise in total animals (74% increase in SE), mostly sheep rather than yaks, and then an overall decline in total SE for a few years (Figure 2.15).

People's communes dominated the period from 1958–78. Herders joined the communes and herds became large. It is now acknowledged that management was not generally efficient. From 1954 to 1962 there was a 50% decline in sheep numbers in Maqu, while yaks increased by 40%. From 1962 to 1980 sheep numbers increased by 275% and yaks by 266%. This suggests some major changes in local policy around 1962.

The Householder Contract System for farmers and herders was implemented in stages from 1978–2009. From 1985, all livestock were progressively distributed among individual herder households under the Pasture Household Contract Responsibility System. From the late 1980s, contracts for most grasslands were signed by communities and by the early 2000s most herder households were operating as individual family businesses. It has been argued that, as regulations were minimal, overstocking and overgrazing became severe in this period, but after 1980 in Maqu, sheep numbers had declined by 28%. By 2003 (the turning point in Figure 2.16), yaks only increased by 31% and the average stocking rate had only increased from 1.8 to 2.0 SE/ha. The data presented here show that increased stocking occurred in the commune period (1962–80) (Figure 2.15) but the effects only became evident later, after higher stocking rates had been maintained for some years. Stocking rates exceeded 1 SE/ha from 1966 (twice the 1949 stocking rate).

In 2002, the State Council of China enacted the Grassland Law. Since 2009, this has brought in regulations for grasslands to reduce overgrazing and rehabilitate and/or maintain grasslands. In Maqu, from 2003 to 2015, sheep numbers have increased 35%, yak numbers have increased 54% and average stocking rates have risen by 50% from 2 to 3 SE/ha. It is not clear how the Grassland Law is being applied.

Discussion

Throughout the recent history of China, livestock numbers and stocking rates have shown some common features when analysed at a national, provincial or local level, for regions where grasslands have been commonly used to feed livestock. There were four phases evident in most of the datasets examined.

1. **Recovery:** From the late 1940s through the 1950s there were significant increases in animals and stocking rates. This period was after the extensive conflicts of previous decades. The populations of people and animals on the grasslands during this time were generally low and grasslands were considered to be in reasonable condition. The perception of productive grasslands at this time resulted in an expansion of cropping into many grassland areas, with adverse results (Ren et al. 2001).
2. **Collective:** Through the 1960s and 1970s, agriculture across China was organised into collectives and production was regulated from the central government. Large animals were for production and not consumption, except for yaks and dairy products. During periods like the Great Leap Forward, there were food shortages and a noticeable decline in animal numbers often occurred. Slow increases in animal numbers and stocking rates were seen. Discussions among herders and officials suggest that during this phase the grasslands were in reasonable condition and stocking rates may have been sustainable.
3. **Expansion:** After deregulation of production and markets in 1978, when herders progressively attained user rights over their own areas of land, there were rapid increases in animal numbers and stocking rates. This is the period when overgrazing became widely acknowledged. Developing markets increased demand for more animal products, especially red meat, throughout China (Zhou et al. 2012; Mao et al. 2016). Herders and officials thought that more animals were the pathway to improved animals, but animal production is typically optimised at lower stocking rates where animal production per head is higher (eds Kemp & Michalk 2011).
4. **Restoration:** Acknowledgment of overgrazing resulted in a cessation of increasing animal numbers and stocking rates through the 2000s. The timing of this phase varied depending upon local conditions. Policies were introduced, typically for five years, to impose short-term grazing bans in early summer (Chen, Michalk & Millar 2002) and/or limit animal numbers. Much research was initiated to identify sustainable practices.

For much of China's 400 Mha of grasslands the objective is now to restore them to sustainable states, where the focus is on production of animal products rather than maximising the number of animals that can survive (Kemp & Michalk 2011). An important driver of this change are environmental problems such as the dust storms that have increased across northern China. Many other aspects of the grassland–livestock system will need to change, as discussed in this monograph, but the actual practices used will vary from region to region depending upon local circumstances. Typically, a 50% reduction in stocking rates is arguably required to allow the grasslands to recover. As desirable plant species return to the grasslands, some small increases in stocking rates are possible, but these will need to be carefully managed. Animal numbers and stocking rates through the collective period provide an indication of sustainable levels. To go above these levels will require significant increases in the supplementary food supply. Increasing the productivity of grasslands above their inherently low levels is unlikely to be profitable.

References

Chen, L, Michalk, DL & Millar, GD 2002, 'The ecology and growth patterns of *Cleistogenes* species in degraded grasslands of eastern Inner Mongolia, China', *Journal of Applied Ecology*, vol. 39, pp. 584–594.

Hong, FZ 2011, *History of Grassland in China*, China Agricultural Press, Beijing, pp. 221–233.

Kemp, DR & Michalk, DL (eds) 2011, *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings* 134, Australian Centre for International Agricultural Research, Canberra, pp. 189.

—— 2011, 'Livestock production styles and managing grassland ecosystems' in G Lemaire, J Hodgson, A Chabbi (eds), *Grassland ecosystems: productivity and environmental issues*, CABI Publishing, Wallingford, Ch. 1.6, pp. 53–62.

Mao, YW, Hopkins, DL, Zhang, YM & Luo, X 2016, 'Consumption patterns and consumer attitudes to beef and sheep meat in China' *American Journal of Food and Nutrition*, vol. 4(2), pp. 30–39.

Ren, JZ, Hu, Z, Zhang, Z, Hou, FJ & Chen Q 2001, 'Zonation of grassland industry for sustainable ecological and economic development in China', in F Hong F & J Ren (eds), *Prospects of Grassland Science and Industry for the 21st Century*, Chinese Grassland Society/China Association of Agricultural Societies, Beijing.

Waldron, S, Brown, C, Longworth, J & Zhang, CG 2007, *China's livestock Revolution: agribusiness and policy developments in the sheep meat industry*, CABI Publishing, Wallingford, Ch. 2.

Waldron, S, Luong, P, Smith, D, Phan, SH, Dong, X & Brown, C 2017, 'Macro developments in the China and Southeast Asia beef sector', *Animal Production Science*, vol 59(6), pp. 1001–1015.

Zhou, ZY, Tian, WM, Wang, JM, Liu, HB & Cao, LJ 2012, *Food trends in China*, Report to the Australian Government Department of Agriculture, Fisheries and Forestry, pp. 58.

3 Changing animal practices and industry structures on grassland farms

Wu Jianping, Gong Xuyin, Lang Xia, David Kemp, Taro Takahashi, David Michalk, Hou Xiangyang, Zhang Xiaoqing

China has 400 Mha of grasslands (Kemp & Michalk 2011; Kemp et al. 2013), of which 300 Mha are in the north and west of the country, directly supporting 16 million people (Michalk et al. 2011) plus many more indirectly. From 1950 to 1980, China's human population rapidly increased throughout much of the grassland areas. As a result, livestock numbers also increased to support the growing population and sustain the livelihoods of herder households. Prior to 1980, livestock production by herders focused on subsistence for households and the local communities and grazing practices maintained a transhumant, annual migration system on the extensive grasslands. Traditional practice was that grasslands would be rested at intervals, allowing time for species to adapt and recover. The amount of forage available for livestock was greater than it is today. These processes of recovery have declined significantly as livestock densities increased from 1950 (Chapter 2).

After 1980, policies focused on increasing livestock production to satisfy increasing demands for livestock products such as milk, meat, fibre and hides. These livestock products traditionally come from pastoral areas. Increasing numbers of cattle, yaks, sheep and goats in pastoral regions resulted in continuous overgrazing and led to over 85% of China's grasslands being degraded by the early to mid-1990s. During this period, the frequency of severe sandstorms in spring increased significantly every year as a result of overgrazing. Starting in the 1990s, research began on identifying sustainable solutions for rehabilitation of the grasslands. Government policies changed with the implementation of the Grassland Law, designed to protect and restore vast areas of grasslands, reduce dust storms and recover desirable plant species and biodiversity. Subsidies for fencing came in from the mid-1990s, and grazing bans were progressively introduced from the early 2000s.

The skills of traditional herders have been built on surviving in a very harsh climate, and the primary use of livestock for household consumption as a 'bank', which can be sold when needed, and only selling a small proportion of their flock or herd. Herders had limited knowledge and skills of how to optimise the output of animal products to increase household incomes within the constraints of limited grassland and other fodder resources. In the early 2000s, the sustainable grasslands program supported by ACIAR started with the goals of identifying practices that rehabilitated degraded grasslands and improved the livelihoods of herders. As discussed through this monograph, the initial work sought to better understand the herder livestock system on grasslands to improve knowledge, supported by modelling the energy balance of livestock, and investigate changes that could improve the efficiency of animal production while reducing the grazing pressure on grasslands.

This chapter reviews some of the changes in animal management practices coming from the ACIAR program that improve the efficiency of animal production and are viable within the herder livestock production systems. Similar changes in practices are likely to be useful in other countries throughout the Eurasian grasslands. In the ACIAR program, the main region where many of the animal management studies were done was Sunan, Gansu, in western China. Sunan is on the northern edge of the Qinghai–Tibetan Plateau, where the mountains are up to 5,000 m high and the grasslands are alpine meadows. Many of the herders are Tibetan, grazing fine-wool sheep. Flock sizes are often only around 100 adult animals and the herders have summer, autumn/spring and winter grazing lands. Additional aspects of livestock management were studied in IMAR.

Challenges

Grassland degradation is now common across most of the grasslands of China. This has resulted in lower productivity and carry capacity, severe soil erosion, loss of biodiversity and other detrimental effects. In the past few decades, the estimated average grassland production and carrying capacity has decreased about 30% in the most of China's north-western regions, while the livestock (sheep, goats and cattle) population doubled (Chapter 2). As overgrazing of grasslands has increased, the available forage for livestock has significantly reduced. The condition of livestock is now often poorer than was traditionally been case. In part, this is due to an imbalance in the forage available in summer and winter grazing areas, but it mostly results from major increases in animal numbers (Chapter 2). There has been the belief that the path to increasing household incomes is through more animals. However, as demonstrated through this monograph, improving the efficiency of production and focusing on productivity per head provides a better way of optimising household incomes, while reducing the grazing pressure on grasslands.

Traditional livestock management had not been focused on maximising animal products for sale (Kemp & Michalk 2011). A household's assets were largely tied up in its 'bank' of livestock for domestic use and status, and prices for animals did not vary much with animal size or output. Households therefore aimed to maximise animal numbers and only a small proportion of a flock was ever sold. Flock and herd sizes were very dependent on seasonal conditions and there was very little feeding of hay or other supplements. The limited hay made was used for animals that were in poor condition, rather than for the general herd. That meant animals were fed supplements only after declining in condition, rather than for maintenance. When heavy winter snowfalls occurred, often after a summer with poor grass growth, animal deaths were high. This is referred to as a snow emergency in northern China, or dzud in Mongolia. Work on monitoring flock structure and condition (Kemp, Han & Junk et al. 2011) found that flocks often had a very uneven age structure. Often the best animals were sold to traders, which meant the remaining flocks were increasingly dominated by less productive and older animals. Renewal occurred after bad seasons, when the poorer animals died. This increased the forage supply per head for the remaining animals in subsequent years, which resulted in higher birth rates and renewed the flock, but with an uneven age structure. This is similar to wild animal populations and is largely unplanned. Improvements in productivity can be made by culling less-productive animals, better feeding of the remaining animals. Herders can market the animals they wish to sell, rather than traders dictating which animals they wish to buy (Kemp, Han & Junk et al. 2011).

Chinese government policies have had the twin aims of rehabilitating the degraded grasslands and alleviating poverty among herders (Kemp et al. 2013). These were also the aims of the program discussed in this monograph. Reducing stocking rates leads to higher production per head over summer, while at other times of the year more supplement per head is needed to maintain animal liveweights (eds Kemp & Michalk 2011). Research is needed to determine relative responses, and the data obtained can be used in models to find optimal farm level solutions. Alongside these issues are policies of total or seasonal grazing bans that aim to rehabilitate grasslands. For severely degraded grasslands, a total ban on grazing is reasonable, as there is almost no forage available for animals. Seasonal bans also have their place, as research has shown the value of allowing early-season growth of grasslands for increasing the total growth over summer (Chen et al. 2002). But for many grasslands where degradation is in the early stages and where changes in plant species have occurred, reduced and tactical grazing practices could be more useful than a total grazing ban. Livestock management and feeding strategies need to be developed in ways that help relieve pressure on the grasslands throughout the year.

Demand for animal products has increased in recent years. This has led to many small cropping farmers increasing the number of animals they raise, which in turn has depressed livestock prices. The animals raised by cropping farmers tend to scavenge for food and are poorly prepared for markets. This exacerbates the profitability of livestock production for herders who do not have other options. Herders then continue to increase their animal numbers, which has further adverse consequences for grasslands. Grain prices are guaranteed in China and these prices are higher than herders could normally afford, and higher than in countries like Australia and the USA. It is difficult for herders to use opportunity feedlots or provide better supplements through winter. The quantity and quality of individual animals drops, and herders are unable to get better prices. While these trends reflect the developing markets in modern China, they reinforce the need to develop more efficient livestock production systems, especially for herders who are solely dependent on livestock for their livelihoods.

Marketing of livestock (left) and their products (right) has been largely negotiated between single traders and herders, without any transparency. There are often many traders in the marketing chain and margins are small. Better marketing systems are needed to incentivise herders to improve their productivity. Photos: D.R. Kemp

Modelling

The ACIAR program used several staged methods to develop new practices that herders could use. Farm surveys were done to provide data on typical farms in each study region. The data obtained were used in models (Chapter 7; Takahashi, Jones & Kemp 2011) to understand current constraints and investigate alternative practices. The results from modelling various options were tested in on-farm experiments.

The livestock production system on grasslands in China is primarily limited by energy (feed) supply (Yang et al. 2012b). An estimate of the metabolisable energy (ME) balance per SE provides a clear picture of the scale of changes often needed (Figure 3.1). Estimates of actual energy intake in comparison with that required for maintenance show large gaps exist for 7–8 months (typically October to April) each year. These graphs do not include energy estimates for maximising production, as it was found that those curves were typically double that for maintenance and could not be realistically achieved with all the constraints on farms in China. Researchers, officials and herders in China could better understand the value of minimising the gap between actual and maintenance energy levels, which helped to devise improved practices.

The typical energy balance patterns found across China showed major deficits through winter (Yang et al. 2011). The only time that maintenance requirements were exceeded was in summer (Figure 3.1), when animal growth occurs. Animals typically lose 20–30% of their liveweight through the cold months and then regain that weight in summer. Liveweights of mature animals in September are often only marginally better than the year before. This means that much of their summer growth is compensatory gain, which is achieved at a higher level of efficiency than growth requiring structural body changes (e.g. bone growth). The peak in actual energy requirements occurred primarily around lambing. In Figure 3.1, this started in January, when temperatures were well below 0 °C and actual energy intake was only a third of that required for maintenance. These curves indicate the need for better feeding practices through the cold months of the year, and that changing lambing dates closer to summer (e.g. May) would better align energy demand and supply.

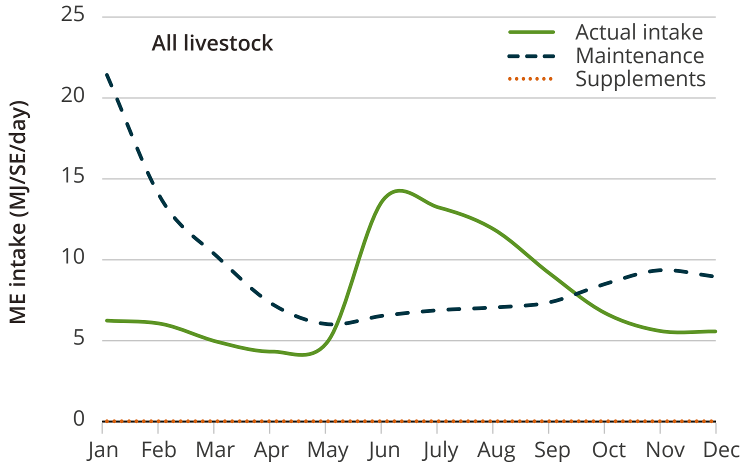

Figure 3.1 Metabolisable energy (actual and maintenance) for fine-wool sheep on a typical farm, Gansu, before the demonstration farms started

Flock and herd structures in China tend to have uneven age patterns and retain poor performing animals. A model was developed to estimate the net income (gross margin) for each individual animal in a flock or herd and rank animals from best to worst (Yang et al. 2012b). Curves for cumulative net income (Figure 3.2) typically showed a rise then fall. The final point (A) is the net income from livestock for the farm. The decline in the later part of these curves reflects the fact that some animals cost more to keep than they earn in income. Extrapolation from point A to point B shows how retaining only the better animals would result in the same farm net income, but with fewer animals. Often a 50% reduction in animal numbers achieved this. The animals ranked between point A and point B are the primary group for culling. But, as this system is feed-limited, if half the animals are removed the remaining animals can increase their food intake and production, resulting in the dashed curve. Livestock net income could then exceed that achieved at point B, or the same net income would be sustained at point C. This model greatly improved the understanding of the benefits of culling the least productive animals—ewes that did not successfully produce a lamb or animals that did not grow. This model only considers selection within the existing animals, but further gains could be made by introducing animals with higher genetic merit and improving the food supply at critical times during their life cycle.

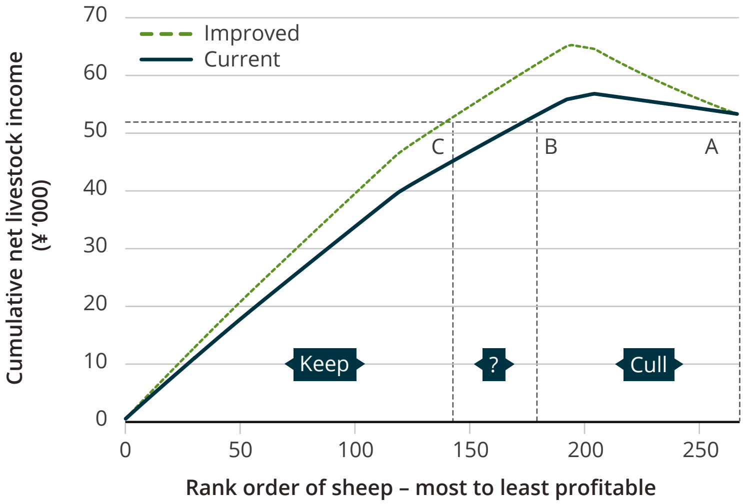

Figure 3.2 Ranking of net income (gross margin) per sheep on a demonstration fine-wool sheep farm, Gansu, using the *PhaseONE* model

Note: In China, the unit of currency is the Renminbi (RMB) denoted by the symbol ¥, not to be confused with the Japanese yen, which uses the same symbol.

Other models were used to determine optimal average stocking rates over time, using a dynamic model responding to variable grassland management tactics (Chapter 7). The theory of animal production from grassland (Chapter 1) provided the central ideas about how reductions in stocking rates could raise incomes while aiding rehabilitation of the grasslands. The models incorporated functions to analyse the effects of climate (precipitation, temperature and wind) on productivity, which were then used to analyse feeding practices and the use of warm sheds through the cold months. The ideas developed from these models were then considered and the more useful ones, both in terms of financial and sustainability gains, were tested in on-farm studies. These studies were used to develop practices that could be readily used on farms.

Changing animal practices

Animal management practices used by herders have evolved over time, but have focused more on managing the survival of the maximum number of animals than on achieving more animal product. Herders are willing to consider new practices when they can see the benefits (Wu et al. 2011). In this section, we present the results of testing new practices that herders have now adopted.

Lambing time

Lambing has traditionally occurred in mid winter, as ewes are in the best condition to get pregnant at the end of summer. A winter-born lamb is weaned in early summer when grass growth is commencing. While that pattern makes some sense ecologically, it suffers from the problem of ewes experiencing a huge energy deficit during lambing and early lactation (Figure 3.1). Milk production is consequently very limited, and both ewes and lambs are well below optimal liveweights throughout the whole winter.

The impact on energy balances of varying lambing times, and the value of providing supplements during critical periods, were modelled for a study village in Sunan, Gansu. Farms graze areas from 2,000–3,500 m in altitude through the year. The options modelled were traditional lambing in January with no supplements (Figure 3.1), or lambing in April, May or June with supplements. January lambing, with supplements, still resulted in a 50% energy deficit during lambing and early lactation (Figure 3.3). April lambing, with supplements, resulted in much smaller deficits during lambing and early lactation (Figure 3.4). The agreement between maintenance requirements and actual energy intake was closer when lambing occurred in May (Figure 3.5) and June (Figure 3.6).

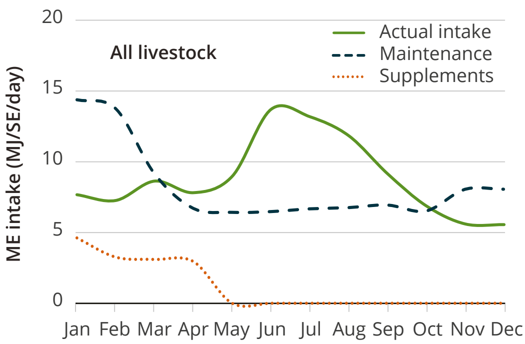

Figure 3.3 Metabolisable energy (actual and maintenance), January lambing with some supplements fed at local rates, demonstration farm, Sunan, Gansu

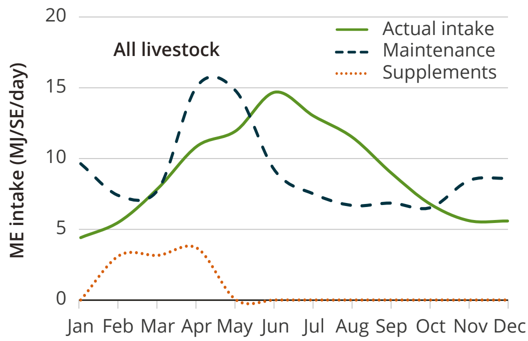

Figure 3.4 Metabolisable energy (actual and maintenance), April lambing with some supplements fed at local rates, demonstration farm, Sunan, Gansu

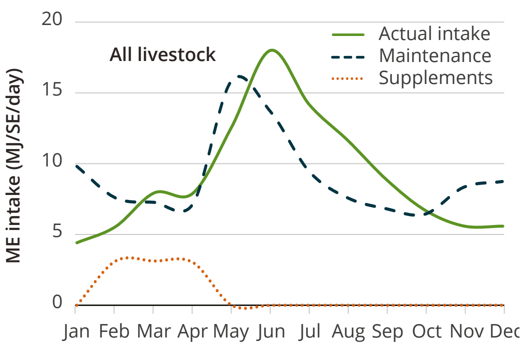

Figure 3.5 Metabolisable energy (actual and maintenance), May lambing with some supplements fed at local rates, demonstration farm, Sunan, Gansu

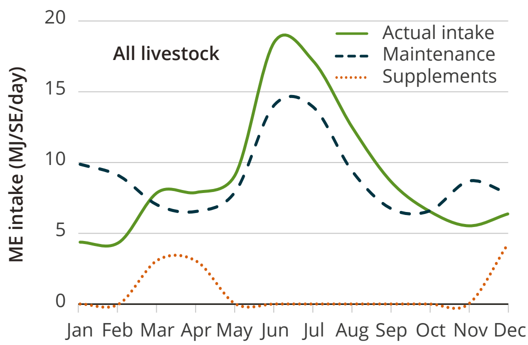

Figure 3.6 Metabolisable energy (actual and maintenance), June lambing with some supplements fed at local rates, demonstration farm, Sunan, Gansu

Where the agreement between energy demand for maintenance and actual supply was closer, it was anticipated that ewes would produce more milk and lambs would be larger and grow faster. These predictions were discussed with local herders and it was decided to trial lambing in April and May on demonstration farms. It was thought that June lambing would create problems in producing lambs large enough to be sold in early autumn.

Lambs born in January typically weigh 2–3 kg at birth and have slow growth rates until mid summer, when grass growth is significant. This demonstration found that April-born lambs were larger and reached higher weights at sale in early autumn (Table 3.1). May-born lambs had significantly higher birth weights, but significantly lower weights at sale in early autumn. The demonstration household strongly preferred April lambing because of the heavier sale weight in autumn. They have now adopted this practice, as have others in the village.

Table 3.1 Lamb growth and survival in response to lambing time, demonstration farm, Sunan, Gansu

Lambing months	Number (head)	Birth weight (mean ± SD, kg)	1-month weight (mean ± SD, kg)	2-month weight (mean ± SD, kg)	Sale weight (mean ± SD, kg)	Survival rate (%)
April	94	3.1 ± 0.6(b)	8.2 ± 1.5(a)	16.3 ± 2.8(a)	28.8 ± 4.1(b)	98
April	121	3.1 ± 0.5(b)	8.4 ± 2.7(a)	16.9 ± 2.1(a)	27.7 ± 3.0(b)	98
May	71	3.4 ± 0.7(a)	8.6 ± 1.7(a)	17.4 ± 2.4(a)	23.7 ± 4.2(a)	95

Note: Different letters in the same column indicate significant difference ($p < 0.05$).

These lambs at Sunan were born in April (spring), weaned early and grazed over summer on fresh grassland. Their growth rates exceeded those of lambs traditionally born in January (winter) and weaned in early summer.
Photo: D.R. Kemp

Warm sheds

Government programs have constructed many warm sheds, especially in IMAR. The plastic roof is south-facing and can be removed in summer. Some sheds have heating from methane digesters that use collected dung and urine. New designs have a solid and well-insulated roof. Photo: D.R. Kemp

Winters across northern and western China are very cold. Temperatures can be –20 °C to –30 °C. Traditional shelters have been used to provide some protection from the cold wind and snowstorms, but the benefits are marginal. Enclosed warm sheds have been developed to protect animals from the cold and trap heat. The best sheds now use plastic or glass roofs (facing south) and/or higher-quality insulation to trap heat and minimise heat loss. Most farms use modified traditional sheds to create a warmer environment for livestock. A warm shed compensates for the lack of food. An on-farm comparison of traditional sheds and warm sheds, where there was some insulation and air flow was restricted, demonstrated that warm sheds halved weight loss and increased conception and lambing rates significantly (Table 3.2).

Table 3.2 Fine-wool sheep performance, Gansu

Group	Number of sheep	Weight		Weight change		Fecundity	
		Before winter (mean ± SD, kg)	After winter (mean ± SD, kg)	kg	%	Conception rate (%)	Lambing rate (%)
Warm shed group I	230	45.8 ± 4.9	40.2 ± 4.3	–5.6	12.3	97*	97**
Warm shed group II	110	40.3 ± 4.6	34.3 ± 4.4	–6.0	14.9	99**	96**
Control (traditional) shed	120	41.9 ± 5.1	30.5 ± 5.0	–11.4	27.2	88	79

Note: * = significant at 0.05; ** = significant at 0.01 (compared to control).

The effect of winter temperatures on ewes and lambs was investigated in more detail to define the temperature responses of sheep (Zhang et al. 2016). Two groups of lambing ewes were monitored in adjacent sheds in Taipusi, IMAR. One group was in a shed modified to make it warmer through winter, and the other group was in a shelter. The animals were fed a ration with more protein and energy than would have been normal practice, but was still below maintenance requirements through winter. The ration was deemed to be financially viable for herders. The data were reanalysed to define temperature responses for ewe and lamb growth rates (Kemp et al. 2018).

These results show that, even though the ewes were fed a better diet than normal, ewe liveweights started to decline at temperatures below –8 °C (Figure 3.7). Lamb growth rates were closely related to the weight loss of ewes (Figure 3.8), reinforcing the need for better ewe nutrition in late pregnancy and through lactation. The warm sheds only provided a small benefit over the conventional shed. In support of the earlier results, there was a higher lambing rate in the warm shed but no significant differences in liveweights. In part, this was due to more respiratory problems among the warm shed animals, who were at a higher density than the traditional shelter. Other experience in using warm sheds through western China (Wu JP, personal communication) has found there is a need to have 20–30% lower animal densities than official recommendations to allow for better ventilation and animal movement, and to improve the food supply.

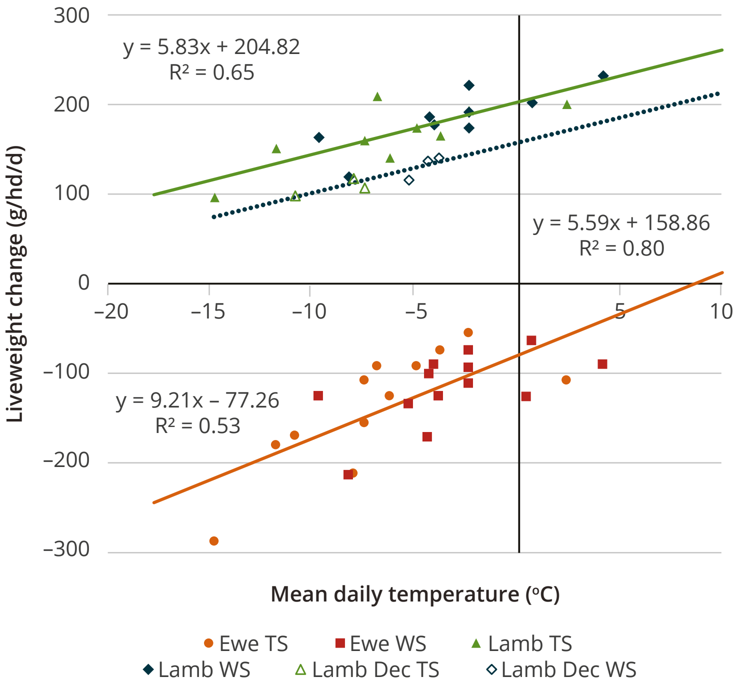

Figure 3.7 Relationship between daily lamb growth rates and ewe weight and mean daily temperatures in a traditional (TS) or warm (WS) shed

Note: The dotted line designates lambs in the first month after birth.
Source: Kemp et al. (2018)

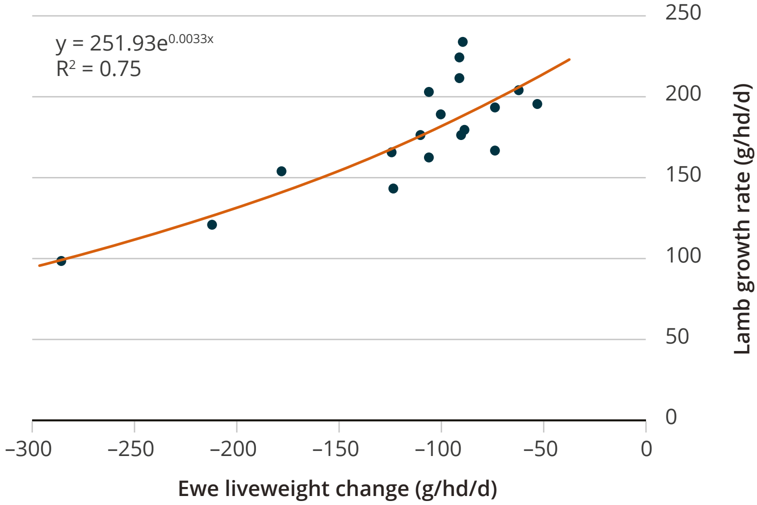

Figure 3.8 Daily lamb growth rates and ewe weight (Jan–Mar), combined data from traditional and warm sheds

Source: Kemp et al. (2018)

Supplementation of ewes

Traditional practice has resulted in ewes being grossly underfed through winter. This has major effects on their body condition and liveweight and the weights and growth of lambs. Demonstrations examined the effects of improved energy supplements for the condition of ewes and lamb birth weights. The traditional practice of lambing in mid winter was followed. Ewes were fed a supplement for 0, 1 or 2 months prior to giving birth. There was no effect on the ewes' condition scores, but lamb birth weights were directly affected. The supplement fed resulted in only a marginal improvement in quantity and quality than the herders would have otherwise used.

Table 3.3 Ewe body condition score (at lambing) and lamb birth weight in response to supplements, farm demonstration, Sunan, Gansu

	Period supplement fed to ewes before lambing		
	0 (mean ± SD)	1 month (mean ± SD)	2 months (mean ± SD)
Ewe body condition score 2 months before lambing	3.1 ± 0.3(a)	3.2 ± 0.4(a)	3.1 ± 0.2(a)
Ewe body condition score at lambing	2.4 ± 0.3(b)	2.9 ± 0.3(a)	3.1 ± 0.4(a)
Lamb birth weight (kg)	3.4 ± 0.4(c)	3.8 ± 0.4(b)	4.2 ± 0.5(a)

Notes:

- Different letters in the same row indicate significant difference ($p < 0.05$).
- Supplement fed was 0.06 kg maize + 0.15 kg beans + 0.09 kg wheat bran per ewe per day, providing a total of 3.3 MJ and 80 g crude protein.

Improving the nutrition of animals is vital for sustaining production and improving herder incomes. This allows grasslands to be managed to optimise the proportion of species with higher nutritive value (Liang et al. 2015) while reducing stocking rates and pressure on the grasslands, which will then reduce environmental problems such as dust storms (Wang et al. 2011) and greenhouse gas production (Dong et al. 2011).

Maize stubble (left) is commonly fed, unchopped, to livestock in winter, which reduces the rate of weight loss. However, more and better-quality meadow hay (right) is now being made in IMAR, which can minimise weight loss in livestock through winter if used well. Photos: D.R. Kemp

Precision management

The model developed to decide which animals to keep and which to cull (Figure 3.2) was applied to a demonstration farm in Sunan, Gansu with Gansu alpine fine-wool sheep. The application of the model in 2010, three years after selection for better animals had begun (Figure 3.9), indicated a small number of inefficient animals (between points A and B), although there was a higher proportion of old animals in the flock than would be ideal to sustain production levels. The demonstration farm started in 2007, but insufficient data had been collected on each animal to use the precision management model at that time. An analysis of the possible gains from selection suggested that considerable improvements were possible. The dashed line in Figure 3.9 shows the modelled gains from selective culling of the least productive sheep.

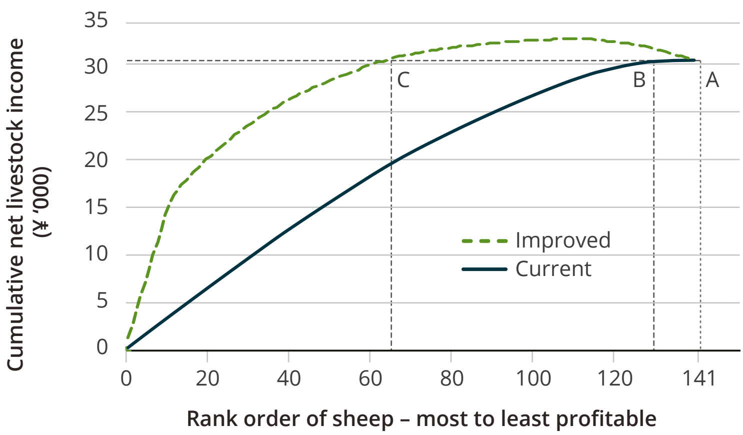

Figure 3.9 Cumulative gross margins for demonstration farm, Sunan, Gansu, 2010

A more intense selection program was then implemented (Yang B et al. 2012a). The results showed that in 2014 there were no animals that did not return a positive net income (Figure 3.10). The cumulative net livestock income was close to the ideal straight line. Further evaluation of the remaining animals suggested some gains were still possible. The same total net livestock income could be achieved with about 10 fewer animals (point C). The net income from livestock in 2014 was about 50% higher than in 2010. This resulted from improving the quantity and quality of livestock products and a general increase in market prices.

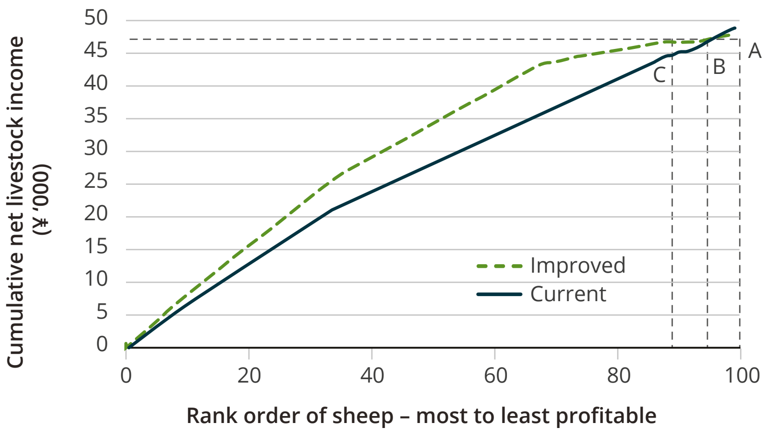

Figure 3.10 Cumulative gross margins for demonstration farm, Sunan, Gansu, 2014

The progressive improvement trends in the demonstration farm are evident in several key measures (Table 3.4). From 2007 to 2014, the flock size was reduced from 161 to 120 animals. The liveweights, body condition scores and wool production all increased, as did lamb birth weights and lamb sale weights. Overall, there was a substantial increase in farm income. The reduction in animal numbers allowed more forage for the remaining more-efficient animals. Small improvements in the supplements fed enabled animals to respond effectively.

Table 3.4 Sheep production using precision management and supplements, demonstration farm, Sunan, Gansu, 2007–14

Year	Sheep number (head)	Liveweight before mating (mean ± SD, kg)	Body condition score (mean ± SD)	Wool production (mean ± SD, kg)	Lamb birth weight (mean ± SD, kg)	Lamb sale weight (mean ± SD, kg)	Income (yuan)
2007	161	38.5 ± 4.8	2.8 ± 0.5	2.9 ± 0.2	3.1 ± 0.7	25.7 ± 3.5	31,729
2010	149	42.6 ± 5.9	3.2 ± 0.3	3.3 ± 0.3	3.5 ± 0.6	26.5 ± 5.3	34,995
2014	120	43.1 ± 6.1	3.6 ± 0.2	3.7 ± 0.7	3.5 ± 0.7	29.0 ± 4.5	46,463

The demonstration farm at Sunan was able to achieve a 25% reduction in animal numbers, with a 50% increase in net income. These changes were mainly from culling poor performing animals, selecting and breeding from the more productive animals within existing flocks, improving feeding practices (Gong et al. 2011) and using warm sheds through winter. The control farm did not receive any particular support, but nor were they constrained in what they could do. It was not considered ethical to restrict their development. Practices changed on control farms over time as they observed the demonstration farms and varied their practices with changing seasonal and market conditions.

Changes in body weight of animals on the control farms increased over the years, but less than for the demonstration farms (Table 3.5). On the demonstration farms in 2015, all classes of sheep were about 2 kg heavier than on the control farms, and there was an increase from 2008 in the body weight of ewes (8 kg), lambs (6 kg) and wethers (12 kg). These gains were measured at the time of the annual sales in early autumn and resulted in higher incomes for herder households. The responses on the control farms support the view that when the practice changes are clearly evident and can be implemented by herders, they will be adopted. Wool growth has shown small increases, more so on the demonstration farms (Table 3.6), as have reproductive rates (number of ewes with a lamb) and lamb weaning (survival) rates (Table 3.7).

Table 3.5 Body weights of Gansu fine-wool sheep, control and demonstration farms, Sunan, Gansu, 2008–15

	Control farms			Demonstration farms		
Year	Ewes (mean ± SD, kg)	Lambs (mean ± SD, kg)	Wethers (mean ± SD, kg)	Ewes (mean ± SD, kg)	Lambs (mean ± SD, kg)	Wethers (mean ± SD, kg)
2008	32.4 ± 5.3	23.1 ± 3.3	39.2 ± 8.2	33.3 ± 4.5	24.4 ± 5.3	39.5 ± 10.8
2010	34.6 ± 7.2	28.4 ± 3.6	43.5 ± 11.8	36.5 ± 5.3	29.4 ± 3.7	45.5 ± 5.0
2015	37.8 ± 4.9	28.0 ± 3.9	47.6 ± 4.3	41.3 ± 8.5	30.4 ± 3.1	49.3 ± 6.3

Note: Weights measured at the end of summer, at time of sales.

Table 3.6 Wool yield of Gansu fine-wool sheep, control and demonstration farms, Sunan, Gansu, 2008–15

	Control farms			Demonstration farms		
Year	Ewes (mean ± SD, kg)	Lambs (mean ± SD, kg)	Wethers (mean ± SD, kg)	Ewes (mean ± SD, kg)	Lambs (mean ± SD, kg)	Wethers (mean ± SD, kg)
2008	2.9 ± 0.5	2.2 ± 0.4	3.1 ± 0.7	2.9 ± 0.6	2.3 ± 0.5	3.2 ± 0.8
2010	3.3 ± 0.8	2.7 ± 0.5	3.2 ± 0.8	3.3 ± 1.0	2.7 ± 0.5	3.7 ± 1.0
2015	3.0 ± 0.6	2.7 ± 0.3	3.1 ± 0.4	3.5 ± 0.8	2.8 ± 0.5	3.5 ± 1.3

Table 3.7 Reproduction and lamb weaning rates, control and demonstration farms, Sunan, Gansu, 2008–15

	Reproduction rate (%)		Lamb weaning rate (%)	
Year	Control farms	Demonstration farms	Control farms	Demonstration farms
2008	83	82	75	76
2010	85	89	81	83
2015	96	99	96	99

Changing industry structures of farms

The examples in this chapter show how it is possible to change practices on farms to increase production by reducing animal numbers, while using better selection and feeding practices to maintain or increase household incomes. These techniques will contribute to solving the collective problems of reducing stocking rates, rehabilitating grasslands and improving herder household incomes. An important consideration, however, is that the grazing industries of China are in transition. These changes will require not only the continuing development of markets but also government support with appropriate policies. The need for government policies to support the emerging and likely future trends in livestock production will be critical for the improvement of herder household incomes. Policies need to support the trends that will reduce grazing pressures on the grasslands and facilitate rehabilitation.

Market development is critical. Herders need to obtain real price increases for better-quality animal products to stimulate positive changes. These changes are occurring, but in many regions there are still many traders along the value chain who make only small losses or gains (Waldron, personal communication). This leads to herders continually borrowing money in order to survive. The more efficient and transparent the markets are, the more likelihood there is that herders will receive appropriate signals from consumers that they can use to optimise their production system and incomes. At present, herders get some price signals that encourage larger quantities of animal product per head, but not always enough to improve their financial position. Herder associations are being formed to promote the development of market power among herders when negotiating with traders. This will improve market information and aid the development of more effective markets. Developing premium lamb and beef products, branded as Natural Meat, is another recent strategy designed to realise a higher value of products from grass-fed animals. Government policies need to promote better market systems and the components that help.

Traditional preferences in Chinese pastoral areas have been for meat with a high fat content (left), but health conscious consumers now prefer more lean meat. Modern hot pots (right) are very popular and allow meat of traditional quality to be used in the cities. Photos: D.R. Kemp

Many herders do not see a useful future in herding for their children and are encouraging them to seek employment elsewhere. As these herders get older, they often find it more profitable to lease their land to neighbours. They semi-retire with just a few animals for household needs, or move into nearby towns. Herders who rent their land are able to increase their area for grazing, and while they may increase their flock or herd size, their net stocking rate declines. This is a useful change for grassland management and animal production per head. However, the impacts of these changes are not uniform. The rented land is often overused and the herders' own land is lightly used. Land is often only rented for a year at a time, which means there is no incentive to better manage the rented land. Policy changes are needed to enable the transfer of land between herders in ways that encourage sustainable management. In several of the villages where the ACIAR program was active, more collective action by herders to achieve sustainable grassland management was becoming evident.

Demonstrations have shown the merit of culling the least productive animals and improving the nutrition of those remaining. This is the first step in the process of flock/herd improvement. Herders who have been involved in these demonstrations are keeping records of animal production and finances, and there are strong indications they will continue to do so. These practices will help herders better understand their livestock businesses. Better knowledge of the productivity of their animals means herders can more readily identify the better breeding stock when they introduce improved genetics, and can target feeding practices to optimise returns. Initially, it was a challenge to introduce ear tags to enable better recording of performance. When the benefits were demonstrated, the value of ear tags was evident. Ear tags are now required in China for management of diseases, such as foot and mouth. Precision livestock management is seen as a vital new area for research in China.

The work discussed in this chapter has shown the benefits of improving the quantity and quality of supplements. Herders now make more hay and purchase more straw from cropping areas. However, the nutritive value of much of this hay and straw is, at best, at maintenance levels. There is a poor understanding of energy and protein requirements of livestock. Training in nutrition and demonstrations on farms have been very important in educating herders. Research is needed to identify ways of improving the yield of digestible nutrients through the cold months of the year to improve animal productivity per head and financial returns from livestock. The vast amount of straw in China is potentially a valuable resource for livestock, if the quality can be improved.

Many of the examples in this chapter came from Sunan, on the northern edge of the Qinghai–Tibetan Plateau. This site was the main focus for more detailed animal management studies of the ACIAR program, but there are limits about what can be done locally (which also applies in other parts of China). The climate at Sunan is cold and there are no significant areas of crops grown to improve animal nutrition. To improve animal nutrition, productivity and thence returns to herders, the solutions will require wider county level strategies. At lower altitudes, there are the irrigation districts of the Hexi corridor, along parts of the old Silk Road. Either the fodder and grains grown in the irrigation areas could be transported to the plateau, or animals could be moved to feedlots at lower altitudes, closer to the crops. The latter solution is more financially viable, because of respective transport costs and because the climate is warmer from autumn to spring. Animals can be finished in a shorter time in feedlots, significantly reducing the grazing pressures on grasslands, and most animals can be finished before winter becomes severe. The local government has helped to fund these feedlots and some herders are now growing the crops used. The principle of separating breeding and finishing areas means different groups can specialise. This will be an increasing trend in many parts of China's grasslands.

References

Chen, L, Michalk, DL & Millar, GD 2002, 'The ecology and growth patterns of *Cleistogenes* species in degraded grasslands of eastern Inner Mongolia, China', *Journal of Applied Ecology*, vol. 39, pp. 584–594.

Dong, HM, Li, Y, Kemp, DR, Michalk, DL & Takahashi, T 2011, 'Reducing methane production from livestock: can more efficient livestock systems help?', in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings* 134, Australian Centre for International Agricultural Research, Canberra, pp. 115–127.

Gong, XY, Wu, JP, Zhang, LP, Yang, L, Feng, MT, Zhao, HJ & Du, XL 2011, 'Influence of feeding patterns on production efficiency of sheep in the cold season', *Pratacultural Science*, vol. 28, pp. 141–145.

Kemp, DR, Han, GD, Hou, FJ, Hou, XY, Li, ZG, Sun, Y, Wang, ZW, Wu, JP, Zhang, XQ, Zhang, YJ & Gong, XY 2018, 'Sustainable management of Chinese grasslands: issues and knowledge', *Frontiers of Agricultural Science and Engineering*, vol. 5, pp. 9–23, doi: 10.15302/J-FASE-2018204.

Kemp, DR, Han, GD, Hou, XY, Michalk, DL, Hou, FJ, Wu, JP & Zhang, YJ 2013, 'Innovative grassland management systems for environmental and livelihood benefits', *Proceedings of the National Academy of Sciences of the United States of America*, vol. 110 (21), pp. 8369–8374, doi: 10.1073/pnas.1208063110.

Kemp, DR, Han, GD, Junk, G, Langford, C, Michalk, DL, Millar, GD, Takahashi, T, Xu, Z & Zhao, ML 2011, 'Demonstration farms to improve grasslands and household incomes in western China: what can be done, what are we learning?' in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 152–161.

Kemp, DR & Michalk, DL (eds) 2011, *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 189.

—— 'Livestock production styles and managing grassland ecosystems' in G Lemaire, J Hodgson & A Chabbi (eds), *Grassland ecosystems: productivity and environmental issues*, CABI Publishing, Wallingford, Ch. 1.6, p. 53–62.

Liang, JY, Jiao, T, Wu, JP, Gong, XY, Du, WH, Liu, HB & Xiao, YM 2015, 'The relationship between seasonal forage digestibility and forage nutritive value in different grazing pastures' [Chinese with English abstract], *Acta Prataculturae Sinica*, vol. 24(06), pp. 108–115

Michalk, DL, Kemp, DR, Han, GD, Hua, LM, Nan, ZB, Takahashi, T, Wu, JP & Xu, Z 2011, 'Redesigning livestock strategies to reduce stocking rates and improve incomes on western China's grasslands', in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, 140–151.

Takahashi, T, Jones, R & Kemp, DR 2011, 'Steady-state modelling for better understanding of current livestock production systems and for exploration of optimal short-term strategies', in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 26–35.

Wang, ZW, Han, GD, Jones, R, Kemp, DR, Li, ZG, Takahashi, T & Zhao ML 2011, 'What are the solutions for dust and biodiversity on China's grasslands?', in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 128–138.

Wu, JP, Michalk, DL, Kemp, DR, Yang, L & Gong, X 2011, 'Talking with China's livestock herders – what was learnt about their attitudes to new practices?', in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 162–176.

Yang, B, Wu, JP, Yang, L, Gong, XY, Kemp, DR, Feng, MT & Sun, L 2012a, 'Establishing precision management techniques for sheep and feed balance research in pastoral areas', *Acta Agrestia Sinica*, vol. 20(3), pp. 589–596.

Yang, B, Wu, JP, Yang, L, Kemp, DR, Gong, XY, Taro, T & Feng MT 2012b, 'Metabolic energy balance and countermeasures study in the north grassland of China', *Acta Prataculturae Sinica*, vol. 21(2), pp. 187–195.

Yang, L, Wu, JP, Jones, R, Kemp, DR, Ma, ZF & Takahashi, T 2011, 'Changing livestock and grassland management to improve the sustainability and profitability of Alpine grasslands in Sunan County, Gansu Province', in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 69–79.

Zhang, XQ, Kemp, DR, Hou, XY, Langford, CM, Wang, K & Yan, WH 2016, 'Effects of shed modifications on ewe reproductive performance and lamb growth rate in Inner Mongolia', *The Rangeland Journal*, vol. 38, pp. 479–487.

4 Farm demonstrations: what we are learning

Li Zhiguo, Han Guodong, Zhao Mengli, David Kemp, Wang Zhongwu, Yuan Qing, Li Jiangwen, Wang Ruizhen, Andreas Wilkes, Wang Jing

Household livestock grassland farms in China

The Eurasian steppes comprise one of the world's largest groups of ecosystems, widely distributed across Asia and Europe. In China, there are 400 Mha of grasslands, occupying 42% of the country and making up 12% of the world's grasslands (Department of Animal Husbandry and Veterinary Medicine 1996; Kang et al. 2007). China's major agro-ecosystems are separated into the pastoral area (west and north), semi-pastoral area (central region) and cropping area (south). Most of China's grasslands are in the northern and western semi-arid, arid and cold regions, including the high Qinghai–Tibetan Plateau. Seventy-five per cent of China's grasslands and 70% of the grazing livestock are in six major pastoral areas within the provinces and regions of Tibet, IMAR, Xinjiang, Qinghai, Sichuan and Gansu (Department of Animal Husbandry and Veterinary Medicine 1996). IMAR is a major pastoral province with 70 Mha of grasslands. It has been in the forefront of identifying better livestock and grassland management practices.

In IMAR and other provinces, before 1947, the grassland was owned or managed by herders, serfs, feudal lords, tribes or temples. Livestock production was nomadic to semi-nomadic and primarily focused on satisfying household needs. Since 1950, various reforms in grassland areas have aimed to improve production and herder household livelihoods, often assuming more animals will result in more income. However, both the human and animal populations have increased dramatically since 1950 (Chapter 2), leading to overutilisation of the grasslands and declining productivity. Many herder households are among the poorest people in China. It has been estimated that the average grassland productivity has decreased by 30–50% (Wang 2006), while the frequency of dust storms has increased.

At the beginning of the 1980s, the *Double Rights* and *One System* policy was implemented. This meant that, while the ownership of grasslands belonged to the nation, herders had contracted rights of use and were responsible for management of the grasslands. Collective farms and other group structures were abolished. The household farm is now the basic unit for grassland management and grazing livestock production (Ding 2008). Herders are moving from primarily satisfying household needs to marketing more livestock products in response to increasing demand (Ren 2013). Rising prices for livestock products have helped to improve herder incomes (Wang et al. 2014), although that has led to oversupply and price reductions. The livestock production system is characterised by low costs and low income (Mou 1998; Li et al. 2015), utilising natural grasslands as the main forage source.

With increasing human population and livestock numbers, the capacity of existing grassland resources to support resilient and high-quality herbage and animal production is under threat (Estell et al. 2012). In IMAR, there are now more farms, with more animals producing more products from the same areas of grassland (Figure 4.1). Sheep and goats are primarily grazed on grassland and the meat output per head has not changed much. Beef production per head has increased, though this is because more animals are now finished in feedlots. The natural grasslands are declining in productivity, primarily because of grassland degradation aggravated by reduced rainfall caused by climate change. Overgrazing has been the main factor driving grassland degradation. Livestock keepers, who are faced with a variety of economic constraints and incentives, may consider that it is in their personal best interest to overstock (Pope & McBryde 1984), though this could change as markets pay more for the amount of animal product, rather than a common price for all animals. In China, a number of factors, including increasing household expenditures, slow growth in net incomes and expectations of volatile income streams, have led households to prioritise short-term income gains over investment in sustainable use of environmental resources (Ning & He 2006).

The twin common aims across the grasslands of China are to overcome degradation and improve the livelihoods of herder households. Other chapters in this monograph focus on the development of technologies that will further these aims. However, any technologies developed need to be effectively demonstrated on farms. This chapter discusses the work done in a large, extensive national program to trial new practices on farms so that herders can see the benefits and costs of various alternatives. How do herders manage change and what are the results when they do? Much of this work has been done in IMAR.

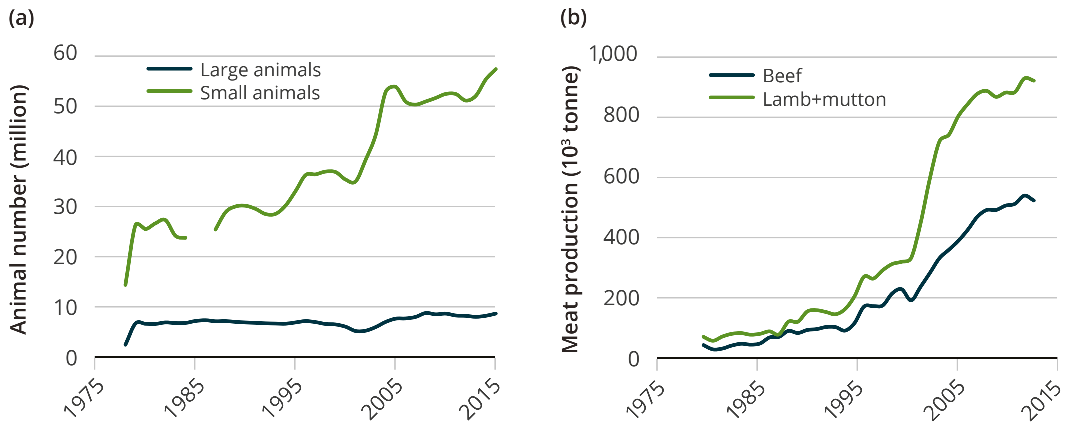

Figure 4.1 (a) Number of large (cattle+horse+donkey+mule+camel) and small (sheep+goat) animals, and (b) meat production from beef and lamb+mutton, IMAR, 1978–2015

Source: Inner Mongolia Autonomous Region Statistics Yearbook, 1978–2015

Grassland management and improvement programs

Grasslands and grazing have sustained the livelihood and culture of herder households for centuries (Wu et al. 2003). Traditional herders followed extensive nomadic animal production systems, were isolated in small groups away from urban centres and developed a deep traditional knowledge about how to survive in a harsh climate (Yang 2007). Historically, herding populations were much smaller than today and herders avoided grassland areas that were in poor condition, allowing them time to recover. The knowledge and skills of herders were focused on survival. Today, herders are part of a market economy and want the same goods and services, such as vehicles, phones, education and health services, that most people do. Herders need to build skills in optimising animal production to supply more of the animal products that consumers are willing to pay for. To do this, they need to change from keeper/survival mode to one focused on production (Kemp & Michalk 2011). As shown in other chapters, it is possible to achieve a win–win outcome where grasslands are improved and net household income is increased. Herder households need to become adaptive and flexible, better at managing risk and more able to adjust to changing environments and markets (Li 2015).

Building the knowledge and skills of herders became a core part of the program of the farm demonstrations. Key components of building knowledge have been to shift the herders' focus from gross to net profit, and helping them identify if they can achieve the farm size and animal numbers they need to be financially and ecologically viable. In doing this, it is acknowledged that some herders can change and will remain in animal production. Others, for various reasons (age, ability or family reasons), are unable to change what they do and will remain at similar levels of production, or may move into urban areas to be closer to families, if that is possible. Traditional knowledge helps to keep animals alive through the harsh winters, but improving the quantity and quality of animal products requires an understanding that starving animals are inefficient and that it can be profitable to feed them for production rather than just for survival. Demonstrations play a vital role in showing herders what can be done and provide data they can use to assess the viability of new practices. A further value of farm surveys and demonstrations is that they provide data to calibrate models (Chapter 6). Herders will always have their own ideas on what practices are viable for improving their livelihoods. Their suggestions may not always be correct, but it is important to include their suggestions in the farm demonstrations.

The general philosophy underlying the farm demonstration research program is that reorganising the livestock production system, and considering the developing markets of China, is preferable to relying entirely on government support programs. Reorganisation within a farm is more likely to build sustainable outcomes, as herders are in control and have learned how to exploit change to improve what they do. To sustain herder livelihoods and improve grasslands, changing farm practices need to be resolved first. More effective ways of using government support programs can then be identified. In practice, the reverse has often applied.

Since 2002, central and local governments have adopted many policies and measures to promote grassland recovery and conservation and promote economic development in pastoral regions (e.g. relocation of households from degraded areas, forage reseeding, grazing bans and fencing). However, these measures are all expensive, compliance has not been ideal and, while they may be sustained through a few five-year plans, there is no ultimate guarantee they will be permanent (Han, Wang et al. 2013; Wang, Yang et al. 2014).

During the 12th five-year plan (2011–15), the central government provided subsidies for herders in grassland areas of IMAR (70 Mha) for grazing prohibition (typically for five years at ¥90/ha[2]), animal balance (partial grazing ban at the start of summer to allow better regrowth of the grassland and reduced stocking rates at ¥22.5/ha), means of production (for diesel at ¥500/farm) and forage seeds (¥150/ha). Since 2016, the subsidy has only been for grazing prohibition and animal balance, and the payments are ¥112.5/ha and ¥37.5/ha respectively. Grazing prohibition means no animals grazing on the banned area over the whole year. Animal balance is based on reducing the number of sheep units[3] and supplementary feeding. This reflects the early work in this program, which indicated that reduced stocking rates could maintain household incomes and help grasslands recover (Kemp & Michalk 2011). A standard system is used to estimate sheep equivalents (SE), i.e. 1 sheep = 1 SE, 1 goat = 0.8 SE, 1 cattle = 5 SE, 1 horse = 6 SE and 1 camel = 10 SE. These are based on the estimated average differences in liveweight from a 50 kg animal. These payments have clearly helped improve grassland areas since 2010. It is likely that further changes in herder practices will be needed in the future.

Farm demonstration research program

The farm demonstration research program was broadly divided into two main components: initial studies and more intense studies in Siziwang, which was then expanded into a national program across the main grassland provinces of China. Similar methods were used in each case. A common emphasis was assessing the benefits of reduced stocking rates on household incomes, on the assumption that reduced stocking rates would aid in rehabilitation of the grasslands. In short- to medium-term studies in these harsh environments, it was not realistic to expect rapid grassland improvement.

2 Currency is shown as yuan (¥). At the time of this work, the exchange rate was approximately ¥1 = $A0.21.

3 China uses 'sheep unit' as a measure of livestock and is a lactating ewe rather than the easier-to-use sheep equivalent.

Dr Takahashi (on right) with students from Inner Mongolia Agricultural University interviewing a Siziwang herder as part of the initial farm surveys. Photo: D.R. Kemp

Farm household survey design

Farm household surveys were done to better understand the biophysical and financial aspects of the livestock–grassland system, first to model management changes, then to monitor the effects of the changes being tested. Initially, this research was novel in China. Early work in Siziwang was done in part to resolve effective techniques (Han et al. 2011; Han, Wang et al. 2013). Herders were paid an allowance for participating in the program as compensate in case the results did not prove as positive as predicted. However, results were consistently positive. While specific changes were implemented on the demonstration farms, the design meant that herders could adapt the changes being trialled to suit seasonal, farm and market conditions. Ethically, it was important that herders could change their practices if needed. Similarly, the control farms were not constrained to rigidly maintain their practices. It was anticipated that over time both demonstration and control farms would evolve, and that some might change states. For example, a demonstration herder may wish to return to a control state, and vice versa. This requires careful consideration of the methods used to analyse the data collected.

The selection of demonstration and control farms was based upon self-selection within a village and advice from local village leaders and officials. The farms were selected on the basis of size, animal numbers and farm enterprise incomes in previous years and their willingness to participate in data collection. The initial Siziwang studies only involved a few farms. This meant herders who would be committed to the program could be selected. In later phases, the number of herders involved increased greatly and there was more variability in commitments and abilities. The monitoring of farms was backed by extension programs to provide advice to herders about what they could do. This meant the herders became better at managing the changes implemented over time.

In the national and expanded studies, stratified random sampling was used to select the households surveyed. The semi-structured survey tool collected data on land resources (area of grassland owned and rented; seasonal utilisation practices; the area, crop types and yields; and irrigation practices), livestock (number and type of animals; body weight in different periods; number of births) and economic variables (prices and volumes of animals and fibre products sold; price and number of animals purchased; prices and volumes of concentrate, maize, hay, stubble and silage purchased; and labour, veterinary, mineral supplement, grassland rental and machinery use costs). Each household was also asked for information on production practices such as the timing of joining, lambing and weaning, and sales, age of animals at off-take and supplementary feeding practices. Data was collected on the livestock/farm system calendar, animals, grassland, economic, policy and weather (Table 4.1).

Table 4.1 Categories and subjects in household/farm surveys

Category	Content
Calendar	Date of joining, lambing, weaning, shearing and sales
Animals	Species, breed, number, age, bodyweight, fat score, health, supplements fed
Grassland	Cropland and natural grassland; area, yield and quality, utilisation mode
Economic	Price and amount of animal production, supplements, health, fuel, salt, machinery, labour, other
Policy	Subsidy from government and project
Climate	Current and historical weather data

Animals were regularly monitored to track their weights and body condition, fat scores, ewe udder scores, lambing times, lamb birth weights, stocking rates, forage and feed supplies and livestock enterprise financial data (Han et al. 2011). The key monitoring times were the start and end of summer (i.e. the period of grass growth) and mid winter, though for various logistical reasons it was not always possible to maintain this schedule. Winter temperatures can be below –20 °C and access to farms is difficult. Some monitoring of grassland condition also occurred. Other animal management practices were added to the program over time.

The design allowed for herders to vary what they did over time. As a result, methods of analysis needed to take these effects into account. Early analyses grouped herders into demonstration or control groups to compare results. In later work, the herder group was not always used to analyse the data. Instead, analyses were done using dependent variables, such as net income per sheep equivalent, in various regression analyses, and then the data were examined to identify the behaviour of demonstration or control herders. Invariably there was some overlap between the original groups, reflecting the variable abilities of herders and the fact that there was no rigid constraint on what herders could do.

Simulation modelling

Prior to establishing the farm demonstrations, data from farm surveys were used to define a typical farm for the village, and to calibrate computer models (Chapter 6) that were used to evaluate management options. A typical farm was based on averages, but anomalies were removed. For example, if most farms had sheep but a few also had some cattle, the SE for cattle was estimated so that stocking rates and other calculations were valid, and the typical farm was considered to be only a sheep enterprise. The models did not aim to exactly replicate any existing farm, which was not possible given the limited data collected, but to provide a workable framework that would allow an analysis of the contrasting effects from changing practices. Four models have been developed and these are now being integrated into a common framework of 'optimised management models for household pasture livestock farm production' so they can share a common dataset.

The four models are:

- feed balance analyser (FBA, also referred to as *StageONE*)
- linear program optimiser (LPO, *StageTWO*)
- dynamic sustainability (DS, *StageTHREE*)
- precision livestock management (PLM, *PhaseONE*).

Further details are given in Chapters 6 and 7.

These models are best used to evaluate contrasting options, rather than management changes that may only produce small effects. The models have been successful at identifying management changes that herders then need to evaluate. The farm demonstration research is vital for resolving exactly how to best implement the better management changes.

Siziwang studies

Farm household surveys commenced in 2006 in Siziwang, IMAR (Figure 4.2) to understand how the grassland–livestock system functioned and model options for improving grassland and household incomes. Similar studies were also commenced at the same time in Taipusi Qi, Xiwu and Abaga in IMAR, and Sunan and Huanxian in Gansu. Some of the results from those additional studies are included in other chapters; earlier work is in Kemp & Michalk (eds 2011).

In Siziwang, three demonstration and three control farms were established in 2007 to evaluate model predictions that reducing stocking rates by 50%, culling the least productive animals and extra feeding of supplements in winter would improve incomes and provide the opportunity for grasslands to start and recover. Monitoring continued through 2009. This phase of the work also aimed to resolve how best to do on-farm demonstration research. The initial results have been published (Han et al. 2011).

Siziwang is located in IMAR. The landscape is gently undulating grassland with some limited cropping land. Grassland degradation due to overgrazing and drought is widespread and severe (Han et al. 2011). Elevation averages 1400 m. The climate is characterised as continental, windy in spring, low precipitation in summer when most rainfall occurs, and dry and cold throughout winter. Mean annual temperature, precipitation and evaporation are 4.1 °C, 305 mm and 2,213 mm respectively. The frost-free period is 17 days. The vegetation type is desert steppe. The dominant plant species are short flower needle grass (*Stipa breviflora* Griseb.) fringed sagebrush (*Artemisia frigida* Willd.) and awnless Cleistogenes (*Cleistogenes songorica* (Roshev.) Ohwi.) (Li 2015). The soil is Kastanozem (FAO 2006) with a sandy loam texture.

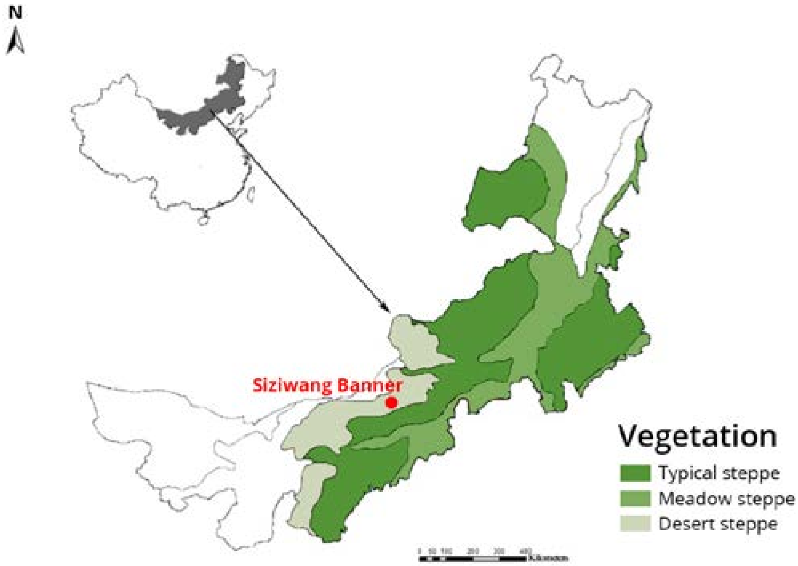

Figure 4.2 Vegetation regions and location of the Siziwang demonstration site, IMAR
Source: Inner Mongolia Grassland Resource (1990)

Mr Buhuchalou, village leader (left), and Professor Han Guodong outlining plans for the farm demonstrations at Siziwang, IMAR. Photo: D.R. Kemp

Sheep and goats are the main domestic animals and are herded together. In the typical production system in Siziwang, lambing occurred around February, mating in September and sales in October. Livestock rely on grassland grazing through summer (May–September) with limited dry frosted forage through the rest of the year and limited feed supplements in winter (October–April). A severe energy deficit occurs during every winter and spring, when animals typically lose 20–30% of their bodyweight. Although low-input extensive livestock production continues to be common, in recent decades many herders have faced pressures to change production practices. These pressures include population, limits on herd mobility and grazing areas imposed by tenure reform and fencing, and environmental deterioration. New production practices and technologies have been introduced, in part by this program. These include changes in herd structure, the use of more supplementary feed in winter, seasonal rotational grazing, and construction of infrastructure, such as warmer animal shelters and hay shelters, often with government support. One innovation in Siziwang has been the introduction of Dorper and other sheep breeds, made available to herders through a nucleus herd managed by a herder association and artificial insemination services provided by local government. Dorper x Mongolian fat-tail lambs have a faster potential growth rate and a higher yield of lean meat.

National farm demonstration program

From 2010 to 2014, the successful studies in Siziwang were expanded across the main grassland provinces of northern China (Figure 4.3). A national program (see Acknowledgments for list of projects) used nine villages in the six main grassland provinces in northern and western China. The national survey was designed in 2010–11, with farms selected and initial datasets obtained in 2011. At each site, 2–6 households were surveyed, half to test new management practices and the other half as controls. At each site, discussions were held with local herders and officials to identify the changes in management practices they thought would be most appropriate for testing in the farm demonstration research program (Table 4.2). Before implementing the demonstrations, farm survey data was collected to calibrate the FBA (*StageONE*) and LPO (*StageTWO*) models (Chapter 6). These were then used to identify the changes most likely to result in larger improvements in productivity of livestock and grassland. The treatments were then implemented and regular surveys were done in 2012 and 2013 to assess the initial effects of the changes being tested. Basic biophysical and financial data were collected on the components that influence animal production (Table 4.1). For financial analyses, depreciation was set at 20% for fixed assets (e.g. sheds, fences) and 10% for machinery. Remote sensing was used to evaluate the state of the grassland and soils on each farm surveyed. The changes reported here reflect what can be implemented in the short-term. Changes to the grassland condition would take longer to become apparent.

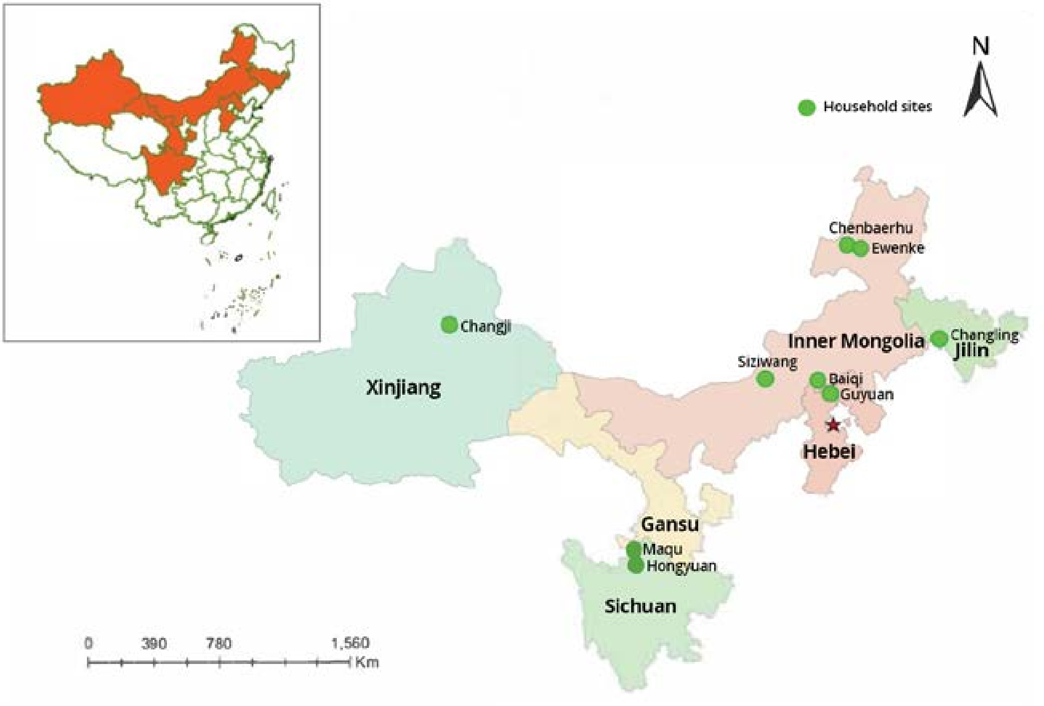

Figure 4.3 The nine demonstration sites across six provinces that were involved in the national farm household demonstration research project

The diversity of sites chosen meant that, while a majority of sites tested reduced stocking rates, other components of the livestock–grassland system varied. For instance, in IMAR, there were four test sites covering the three main grassland types (meadow, typical and desert steppe). Grazing was initially common at all four sites, but other practices varied. Data is not listed for three villages surveyed as they did not have comparable systems with other villages. Hay making became more profitable for local herders in Chenbaerhu and Ewenke, which meant a longer feeding period in sheds through winter and almost no grazing. Zhangxiangbai was a typical steppe site, but with small farms (less than 50 ha grazing pasture and 5 ha artificial pasture) there were limited options. In Siziwang and Xisu, all the grassland was used for grazing but supplements were bought from markets, rather than harvested on the farm.

Table 4.2 Basic financial data for the livestock grazing farms in 2011 (prior to implementing practice changes)

Province	Site	Grassland type	Total income (10^3 ¥)	Total cost (10^3 ¥)	Net income/ SE (¥)	Stocking rate (SE/ha)	Number of demon-stration farms	Practice changes for demonstration farms
Jilin	Songyuan	Meadow steppe	337	47	474	2.6	1	Reduce animal numbers by 60%, income based on hay production
IMAR	Hulunbeier	Meadow steppe	1,999	510	753	2.0	2	Reduce stocking rate by 25%, increase corn fed 35% in winter
	Bai	Typical steppe	90	19	327	1.2	2	Increase supplement 10% in winter; increase lambing rate by 14% (using local sheep)
	Xisu	Desert steppe	139	29	333	0.6	3	Reduce animal numbers by 20%, increase supplements by 50% for ewes in winter
Hebei (2012)	Guyuan	Semi-pastoral	80	1	990	0.1	3	Grazing ban, use hay, increase supplements by 20%
Gansu (2013)	Maqu	High-cold steppe	0.1	185	179	2.7	1	Reduce animal numbers (>15%)
Xinjiang	Changji	Upland meadow	76	4	299	1.5	4	Increase concentrate by 30% and plant alfalfa
Sichuan	Hongyuan	High-cold meadow	0	14	36	3.3	1	More alfalfa, more training, reduce animal numbers

Main achievements from demonstration farm research

Siziwang

The monitoring of farms aimed to understand more about why some herders were more efficient than others. In Siziwang, a particular focus was assessing how membership of the local herder association influenced the efficiencies of production. The association provided training in various aspects of improved livestock production and also developed improved marketing arrangements for the sale of meat lambs, which are often now sold direct to restaurants through a feedlot and abattoir. Important practice changes included the culling of goats, improved lamb feeding systems and the use of Dorper rams to achieve the benefits of hybrid vigour. Dorper rams were only available to association members. The expanded farm demonstration research in Siziwang commenced survey work in 2012 after the new practices fostered by the herder association had been implemented.

Both association and non-association farms were surveyed in 2012 and 2013. A simple comparison of association members against the control group did not indicate any clear trends. As a general aim of this work was to evaluate the efficiencies of livestock production, it was decided to use a common, normalised variable (net income/SE) as the dependent variable in a decision tree analysis (using least squares) to identify how the farms were grouped, which ones included association members and what the differences were between the statistically defined groups.

The analyses were done using Systat (V13) with the constraints that variables had to explain at least 5% of the variation and nodes had to contain at least five farms. The model produced explained 59% of the variability (attempts to use normal multiple regressions only achieved an R^2 of 30%). However, as some group sizes were at or close to the minimum of five farms, it was decided to form two larger groups, based on net income/SE, after ranking the groups from the least to the most profitable.

The fundamental relationship, with three closely related terms, was:

income/ha = income/SE x SE/ha

This relationship can dominate these analyses, hence only one of these three terms was used in any analysis. Income/SE is considered the most relevant to herders as they focus on animal performance and are not as familiar with productivity per unit of land. Land areas are also often less accurate than animal numbers. As income/SE is a financial term, that meant other financial terms (total income, total costs, costs/SE and lamb price/head) were most significant in forming the decision tree groups (Table 4.3). To identify the important biophysical terms, the four significant financial terms were excluded. The resulting decision tree explained 41% of the variation with total lambs sold, SE/labour unit, proportion of rented land, total grassland area, total SE and energy fed/lamb as the most significant terms. The main distinguishing characteristics of these two larger groups, formed using the more significant analysis, are listed in Table 4.3. The variables in bold were significant in forming the decision trees. Other relevant additional variables are listed to show how these varied between the income groups.

Table 4.3 Characteristics of 92 Siziwang households, 2012

	Low-income group (mean ± SD)	High-income group (mean ± SD)	High-income group as % of low-income
Net income (¥/SE)	195 ± 25.42(b)	371 ± 22.5(a)	190
Number of households	39	53	136
Association members (%)	18	60	333
Total costs (¥)	67,376 ± 6,571(b)	92,587 ± 6,029(a)	137
• supplement cost (¥)	39,159 ± 4,668(a)	49,439 ± 3,432(a)	126
• forage crop produced (t)	5.8 ± 1.7(a)	10.1 ± 2.6(a)	174
• labour cost (¥)	6,349 ± 1,558(b)	13,251 ± 1,327(a)	209
• cost/SE (¥)	186 ± 16(a)	214 ± 13(a)	115
Total income (¥)	132,865 ± 9,024(b)	257,915 ± 14,643(a)	194
• lamb income/head	554 ± 9.2(b)	807 ± 15.7(a)	146
Total net income (¥)	65,489 ± 7,880(b)	165,328 ± 13,454(a)	252
• net income (¥/ha)	156 ± 20.8(b)	313 ± 31.68(a)	201
Grassland area (ha)	497 ± 28.7(b)	632 ± 40.8(a)	127
• rented land (% of total)	34 ± 5.1(a)	38 ± 3.8(a)	112
Total sheep equivalent	355 ± 14.7(b)	442 ± 16.3(a)	125
• stocking rate (SE/ha)	0.80 ±.006(a)	0.81 ± 0.04(a)	101
• SE/labour unit	169 ± 10.8(b)	219 ± 9.7(a)	130
• new breed lambs (%)	0.05 ± 0.02(b)	0.42 ± 0.05(a)	840
• lambs/ewe	0.89 ± 0.03(a)	0.99 ± 0.05(a)	111
• total lambs sold	146 ± 13.29(b)	222 ± 11.4(a)	152
• energy fed (MJ/lamb)	4.9 ± 0.44(a)	5.6 ± 0.33(a)	114
Number of animal sheds	1.9 ± 0.13(b)	2.4 ± 0.16(a)	126

Note: Different letters in the same row indicate significant differences.

The analysis showed that 60% of herders in the high-income group were in the farmer association, compared to only 18% in the low-income group. Association members received more training in managing and marketing their livestock as well as access to better sheep genetics. More improved management strategies were adopted in the high-income group. It was evident that non-association members in the high-income group also adopted improved practices, arguably from observing their neighbours. The design of this study did not preclude any herder from changing practices.

The low-income group had an average net income of ¥195/SE compared to ¥371/SE for the high-income group. There were association members in the low-income group, but it was evident they did not participate very much in the association's programs, as shown by the low proportion of new breed lambs as a total of all lambs. The more active association members were in the high-income group. There is strong evidence here that association membership, and committed participation in the association's programs, results in improved household incomes. The poorer performing association members in the low-income group may have joined the association for social reasons, rather than a desire to improve their financial performance.

Average stocking rates in both groups were the same (0.8 SE/ha, range 0.35–2.11). Five years earlier, when this research program started in this village, stocking rates were around 1 SE/ha (Han et al. 2011). Some individuals are now closer to 0.5 SE/ha, in part from renting extra land without a similar increase in livestock numbers, and have commented that the grassland condition is getting better. These results show that herders can achieve lower stocking rates, but that does not simply result in higher incomes. Other aspects of management need to change. The high-income group had 25–27% more SE and land than the low-income group. They produced 10% more lambs per ewe, sold 52% more lambs, spent more on supplementary feed and labour, managed more SE per labour unit, grew more forage, had more sheds to protect animals in winter and achieved nearly 50% more in prices per lamb, reflecting their larger size and quality.

The data obtained from all the Siziwang farms enabled some additional analyses on the basic relationships between net financial returns/SE (the dependent variable in the decision tree analyses), net financial returns/ha, SE/ha and the total SE and grassland area per farm. This provided additional insight into herder goals and limits in the livestock system on the desert steppe (Figure 4.4).

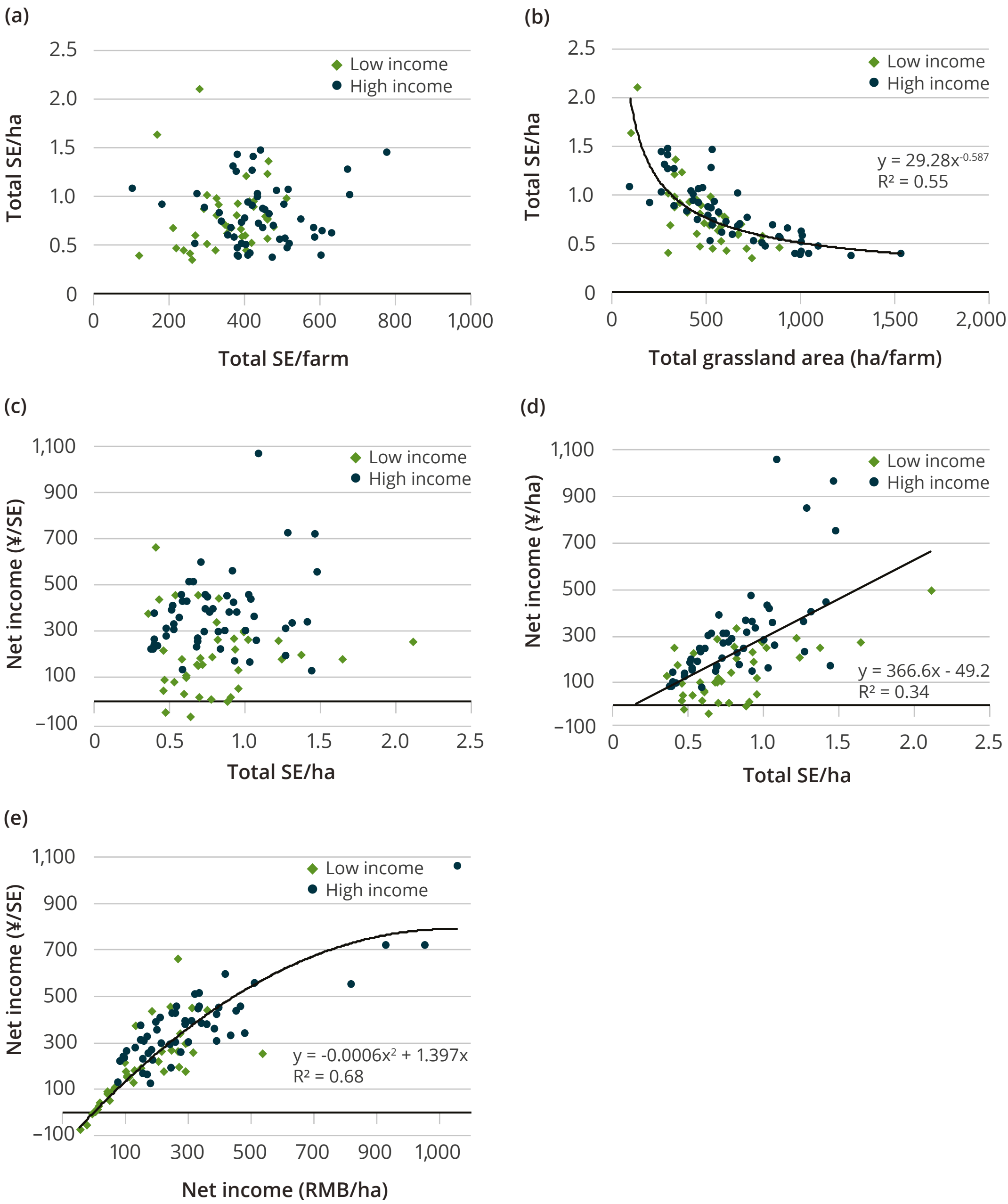

Figure 4.4 Relationships between main production and financial variables for 92 farms in the expanded Siziwang farm studies

Note: Green diamonds = farms that had lower net incomes per SE; blue circles = farms with higher incomes, as per Table 4.3.

There was no relationship between stocking rate and total SE/farm (Figure 4.4a), but there was a significant decline in stocking rate as total farm area increased (Figure 4.4b). This shows that as the land area available to a herder increases, they do not increase animal numbers at the same rate. The constraints arguably change from land limitations to a limit in the number of animals a herder can manage using traditional practices. While there is an overlap between low- and high-income herders, some of the high-income herders had the largest farms and lowest stocking rates, while the few high stocking rate farms were in the smaller and lower income groups.

The key dependent variable used to identify the farm groups (net income/SE) was not related to stocking rates (Figure 4.4c), but was significantly related to net income/ha (Figure 4.4e). Net income/SE reached an average limit of about ¥700/SE for the high-income farms, in those farms that also had higher stocking rates. Net income/ha showed a marginal positive relationship to stocking rate (Figure 4.4d). Some of the low-income farms had almost zero or negative incomes/ha and per SE. These analyses show that larger farms could manage more animals, but used lower stocking rates and still achieved high net incomes/SE.

National farm demonstration research

Grassland types

Across China, grassland types vary continuously, with different dominating plant species, soils, productivity and forage quality. In each of the villages involved in the national program, the grassland types were surveyed using traditional vegetation and soil surveys, combined with higher resolution remote sensing to identify the grassland types that applied across each farm (Wulan 2014) (Table 4.4).

Model analyses of household farms

The initial surveys of farms in each village in the national project were used to construct typical farms in the FBA and LPO models (Table 4.4) using grassland parameters at each site (growth rate, percentage of desirable and undesirable species, digestibility) plus financial, livestock, supplements and climate data. Both models estimated the optimum feed energy balance and the associated optimal stocking rates, determined by manually changing values in FBA or by solution within LPO. The LPO model was used to assess the effect of factors (e.g. changing lambing time, better supplementary feeding and when to graze grasslands) on net income, stocking rates and the animals' energy balance. In most cases, the optimum stocking rate found in the model simulations with the FBA and LPO models were lower than initial surveys had identified. The differences in net income/SE between the two models reflect the simple gross margin used in the FBA model and the more detailed analysis in the LPO model, which also has the constraint that animals are fed to at least maintain body weight throughout the whole year. This constraint has often shown that profits mostly increase as a result, though not in all cases, and the income deficit is small. In general, better feeding of livestock through winter is an important improvement that herders can use. When fixed costs were included in additional analyses, the Jilin farms had negative net incomes in 2011, due to machinery and labour costs, but other sites remained positive.

Table 4.4 Sites in national farm demonstration research, main grassland types, initial stocking rates and simulation results using the FBA and LPO models

Province	Site	Grassland type	Grassland yield (kg DM/ha)	2011 stocking rate (SE/ha)	FBA model simulation	LPO model simulation
Jilin	Songyuan	Meadow steppe	610	2.6	SR: 0.7 SE/ha NI/SE: ¥487	SR: 0.8 SE/ha NI/SE: ¥514 Lambing time: November
IMAR	Hulunbeier	Meadow steppe	770	2.0	SR: 0.8 SE/ha NI/SE: ¥286	SR: 0.5 SE/ha NI/SE: ¥182 Lambing time: April Feed supplements: November to April
	Bai	Typical steppe	670	1.2	SR: 1.0 SE/ha NI/SE: ¥146	SR: 1.0 SE/ha NI/SE: ¥148 Lambing time: April Feed supplements: December to April
	Xisu	Desert steppe	110	0.6	SR: 0.8 SE/ha NI/SE: ¥715	SR: 0.5 SE/ha NI/SE: ¥1,238 Lambing time: April Feed supplements: December to March
Hebei	Guyuan	Semi-pastoral	1,110	0.1	SR: 0.5 SE/ha NI/SE: ¥128	SR: 0.7 SE/ha NI/SE: ¥101 Lambing time: June
Gansu	Maqu	High-cold steppe	440	2.7	SR: 0.6 SE/ha NI/SE: ¥238	SR: 0.5 SE/ha NI/SE: ¥276 Lambing time: April Feed supplements: November to February
Xinjiang	Changji	Upland meadow	1,370	1.5	not analysed	not analysed
Sichuan	Hongyuan	High-cold meadow	950	3.3	not analysed	not analysed

Notes:
- DM = dry matter.
- Net incomes/SE (NI/SE) (gross margins) are for the optimal stocking rate identified.
- In Changji, the condition of the grassland was inadequate for profitable livestock production. It was concluded that herders needed to reduce animal numbers and replant pastures.
- In Hongyuan, the farms had yaks and estimates of area grazed were confounded by common grazing, which limited what could be simulated in the versions of the models used. Yak submodels were being developed (Chapter 7).
- In Guyuan, a total grazing ban had been imposed, hence the low SR, and herders reduced livestock numbers.

Benefits of management changes

The implementation of the changed practices on the demonstration farms varied with local circumstances and markets. In 2012 and 2013, stocking rates tended to be lower than in 2011, except in Xisu and Hongyuan, where stocking rates increased (Table 4.5). Apart from those exceptions, even on control farms the stocking rates declined relative to 2011, suggesting that those herders were recognising some benefits from reducing animal numbers. The high incomes on the Songyuan demonstration farm in 2012 reflected a change to hay production, then a swing back to livestock in 2013. Herders in Guyuan received payments for not grazing that meant their income/SE was high in 2012. This indicates how the level of payments is designed to replace income from grazing. The two yak sites were excluded from other analyses because it was not possible to estimate the area used for grazing and hence stocking rates.

To further investigate the impact of reduced stocking rates on net farm incomes, the stocking rate ratio between demonstration and control farms was plotted against the net income ratio for demonstration and control farms in 2012 and 2013 (Figure 4.5). In 2012, the first year of changes on farms, the income of demonstration farms declined relative to the control farms as the relative stocking rate declined. However, the net income on demonstration farms only declined below that of the control farms when the stocking rate was <85% that of the control. Only small marginal gains in net income were recorded on demonstration farms in that first year. In the second year, 2013, the net incomes of demonstration farms were equal to or up to 4x greater than for the control farms. An extrapolation of the fitted line (Figure 4.5, 2013 data) indicated that the stocking rate again needed to be <85% that of the control for the demonstration farms' income to be less than the control.

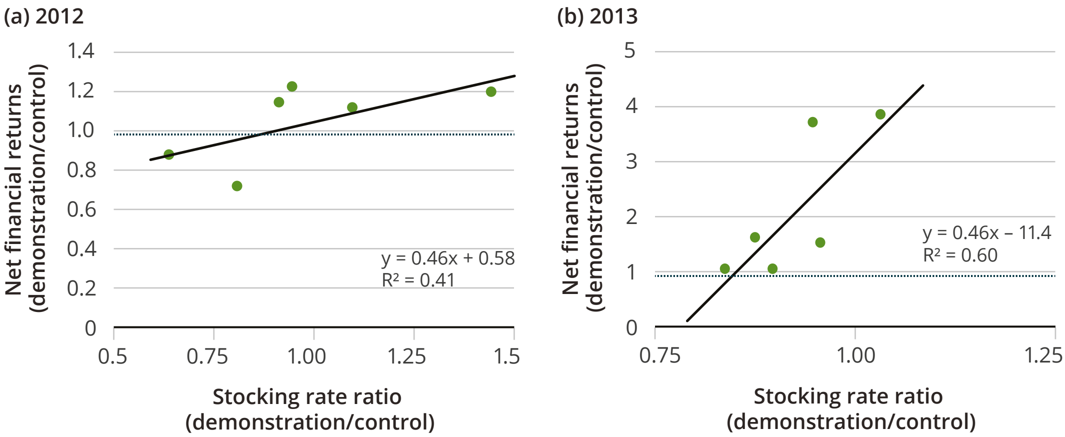

Figure 4.5 Net income vs stocking rates for demonstration and control farms in (a) 2012 and (b) 2013

Note: The horizontal dotted line shows where the net income of demonstration and control farms were equal.

These data need to be viewed against the earlier data (Table 4.5) where the stocking rates on control farms were sometimes less than they had been in 2011. In general, these results support the view that stocking rates can be reduced without harming household incomes. However, these results will be influenced by other changed practices, including the control farms observing and implementing what the demonstration farms did. Other modelling has indicated that a 50% reduction in stocking rates would not reduce incomes below previous practice (eds Kemp & Michalk 2011). A 50% reduction in stocking rates was required to improve grassland management (Chapters 8 & 9).

Table 4.5 Farm income, costs and stocking rates for demonstration and control farms in eight villages, 2012 and 2013

	Demonstration farms 2012				Control farms 2012			
Site	Total income (¥'000)	Total costs (¥'000)	Net income per SE (¥/SE)	Stocking rate (SE/ha)	Total income (¥'000)	Total costs (¥'000)	Net income per SE (RMB/SE)	Stocking rate (SE/ha)
Songyuan	2,400	629	461	1.7	295	673	649	2.0
Hulunbeier	1,470	507	566	1.5	370	109	514	1.4
Bai	66	17	398	1.3	63	20	329	1.4
Xisu	163	49	310	0.8	84	18	275	0.9
Guyuan	44	1	688	0.1	82	1	787	0.1
Maqu	–	–	–	–	–	–	–	–
Changji	–	–	–	–	–	–	–	–
Hongyuan	14	0	35	3.3	19	4	30	7.3

	Demonstration farms 2013				Control farms 2013			
Site	Total income (¥'000)	Total costs (¥'000)	Net income per SE (¥/SE)	Stocking rate (SE/ha)	Total income (¥'000)	Total costs (¥'000)	Net income per SE (¥/SE)	Stocking rate (SE/ha)
Songyuan	331	38	604	2.1	116	53	164	2.2
Hulunbeier	1,340	525	583	1.6	418	134	575	1.8
Bai	124	19	512	1.6	61	9	327	1.8
Xisu	211	46	382	0.8	94	27	261	0.9
Guyuan	–	–	–	–	–	–	–	–
Maqu	185	0.5	179	2.7	185	0.2	175	3.2
Changji	–	–	–	–	–	–	–	–
Hongyuan	43	0.5	68	7.7	19	9.5	18	7.5

Discussion

The techniques developed in this program provide a useful method for rapidly demonstrating the benefits of improved technologies. Surveys of how current farms function, and the use of that data in models based on the main limiting factors (in this case livestock energy budgets), enabled a series of practices to be identified that could significantly improve herder incomes and help grasslands recover from degradation. The outcomes from modelling were discussed with local herders and officials to resolve what practices were possible within the local livestock/farm system. The selected practices were then trialled on demonstration farms. In general, the demonstration farms had higher incomes and lower stocking rates than the control farms, achieving the program's goals. This occurred even though the control farms started to change their practices during the course of this research, after observing what was being done on the demonstration farms. The difference between demonstration and control farms was therefore less than might have otherwise applied.

To make practice changes and be part of this program, herders received a participation payment. This payment was to compensate them if their income declined, although that did not occur. This payment probably achieved a quicker response to practice changes among herders than would have been the case if they had to fund the changes themselves. Initially, it was thought that culling unproductive animals would provide extra cash to buy better rams for breeding, extra supplements for winter or other farm changes. However, herders are unfamiliar with such business models and it was realised they may not readily use this self-financing strategy. In China, there is a clear need for business training among herders and farmers. When this program started, most herders thought the best way to improve incomes was to have more animals (eds Kemp & Michalk 2011). They were not aware that increasing animal product (meat, wool, milk) could be achieved with less animals (Kemp et al. 2011).

When the project started, herders expressed a desire to continue their traditional management practices. They thought that declining rainfall and the high cost of purchasing animals were the main factors restricting their ability to improve incomes. In Sichuan, Gansu and Xinxiang provinces, the herders wanted to keep their higher stocking rates and reduce their costs, especially for supplementary feed in winter. These data showed that reductions in stocking rates, when combined with better feeding of animals and other changes, does not reduce incomes. As shown in Chapter 3, improving the livestock system on several fronts, while reducing stocking rates, does lead to major gains for households and provides the circumstances where degraded grasslands can recover. When stocking rates are reduced, herders can focus more on improving per animal performance, with the aim of achieving a higher income per SE. This was clearly evident in the Siziwang data (Table 4.3).

The program was backed with training so that herders could understand the logic behind practice changes and be better able to manage them. In Siziwang, where the various techniques were first developed, it was evident that the leading herders understood these changes. The training programs and practice changes were formalised through the local herder association. Some incentives were provided, but herders needed to be involved in the whole program to receive them. Access to Dorper rams required herders to also implement other changes. It was evident that herder groups with a high commitment to the program made the most money, whereas association members who produced few lambs were among those with the lowest net incomes and prices per lamb. Further research is needed to understand why some herders do not adopt practices that can improve their income.

This farm demonstration research showed that reductions in stocking rates, along with better feeding of animals, changing breeding cycles to match grassland feed supply and other reasonable practices, resulted in improved incomes. The reduced grazing pressure is expected to help grassland rehabilitation; however, it will be some years before the impact of reduced grazing pressure on grasslands can be confirmed. The total area of farms involved in the national farm demonstration research was approximately 25,000 ha and the average net financial returns increased by ¥5,000–30,000, resulting in a total benefit of ¥10–20 million across all farms involved. The total area of similar grasslands in the counties studied is about 35 Mha. The general nature of the benefits would apply to 300 Mha across China, as the farms studied cover the different major grassland types found across China. It is a reasonable expectation that when herders appreciate the benefits of changing practices, further changes in the livestock system can be introduced and greater benefits will flow. However, this is a continuing process without any defined end point.

Initial estimates of the effects on grassland productivity suggested it had increased. This view is supported by evidence that litter accumulates and biodiversity increases when stocking rates are reduced on these grasslands (Wang, Zhao et al. 2011; Wang, Jiao et al. 2011). Grazing experiments have shown that the proportion of desirable species increases when stocking rates are reduced (Chapters 8 & 9).

The work presented here is the first phase of an ongoing program to modify livestock and grassland management practices. The practices tested on the demonstration farms are the first steps in reorganising the livestock production system to improve herder household incomes and help rehabilitate the degraded grasslands. These steps include culling unproductive animals that cost more to keep than they return in income. The remaining animals can be better feed, improving weight gains, fertility, fecundity and the value of livestock produced for sale.

As herders cull unproductive animals, the remaining animals need to be better fed. This reduces grazing pressures and increases their rates of growth so these animals can be sold earlier. Early surveys (Han et al. 2011) found that lambs were often not sold until they were 18 months or older, meaning extra animals were being carried over from year to year, adding to the total grazing pressure. Increasing animal growth rates enables herders to sell those destined for market at a younger age. Other animal practices that can be changed are outlined in Chapter 3. Herders are becoming aware of the importance of improving the quality of their livestock rather than increasing livestock numbers to improve both incomes and grasslands (Li et al. 2015).

The next steps required in this program are to commence a regular, objective program of selecting and keeping better animals, based on measurements. At present, traders demand to see all the animals that herders have. Traders selects the best animals, which leads to a progressive decline in the quality of flocks and herds. Herders need to acquire better skills for dealing with traders to allow them to keep the better animals as breeding stock. In the future, this would mean that herders only have good quality animals in their flocks and herds. Herders also need to identify which livestock enterprises are the more profitable (e.g. meat, wool, cashmere, milk, breeding young stock for feedlots). Along with these changes is the need to use and better manage warm sheds (Chapter 3). Warm sheds help compensate for limited supplementary feeding and can reduce the total amount of feed required to maintain livestock. To adequately feed animals, particularly through the cold seasons, more use could be made of managed forages. These include maize and other crops for silage, sown pasture for hay or silage, and the tactical use of nitrogen fertiliser on the better areas of grassland to feed the more profitable animals in summer, or make hay or silage for winter. The optimal combination of natural and managed fodder needs to be resolved in future research. All of these practices can be implemented in a staged sequence to minimise transition costs and enable benefits to continue to increase, providing the incentive for adoption of the more effective practices. Along with research to identify the better practices and testing them on farms, this adaptive research program has shown that it is vital to have a demonstration program that operates in collaboration with local herders and officials, plus private companies where they are closely involved, and is backed by training programs so that practice changes are well understood.

Acknowledgments

The farm demonstration research was funded by the Ministry of Science and Technology of China (2012BAD13B02), the Ministry of Agriculture of China (201003019), the National Nature Science Foundation of China (31260123, 31260124, 31070413), ACIAR, Grassland Resources Innovative Team of the Ministry of Education of China and Inner Mongolia Agricultural University (NDTD2010–5).

References

Department of Animal Husbandry and Veterinary Medicine, Ministry of Agriculture of China 1996, *Rangeland resources of China*, China Science & Technology Press, Beijing.

Ding, Y 2008, 'The study of sustainable development on grazing ecosystem of natural grassland: household perspective', PhD thesis, Inner Mongolia University, Hohhot.

Estell, RE, Havstad, KM, Cibils, AF, Fredrickson, EL, Anderson, DM, Schrader, TS & James, DK 2012, 'Increasing shrub use by livestock in a world with less grass', *Rangeland Ecology & Management*, vol. 65 (6), pp. 553–562.

Food and Agriculture Organization of the United Nations 2006, *World reference base for soil resources: a framework for international classification, correlation and communication*, Rome, Italy.

Han, GD, Li, N, Zhao, ML, Zhang, M, Wang, ZW, Li, ZG, Bai, WJ, Jones, R, Kemp, DR, Takahashi, T & Michalk, DL 2011, 'Changing livestock numbers and farm management to improve the livelihood of farmers and rehabilitate grassland in desert steppe: a case study in Siziwang Banner, Inner Mongolia Autonomous Region', in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 80–95.

Han, GD, Wang, ZW, Li, ZG, Zhao, ML, Kemp, DR, Michalk, DL & Havstad, K 2013, 'Grassland rehabilitation through re-designing livestock management systems', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings 22nd International Grassland Conference, Sydney, Australia, pp. 1637–1642.

Inner Mongolia Grassland Resource 1990, *Inner Mongolia Grassland Resource*, Inner Mongolia People Press, Hohhot.

Kang, L, Han, XG, Zhang, ZB & Sun, OJ 2007, 'Grassland ecosystems in China: review of current knowledge and research advancement', *Philosophical Transactions Royal Society B – Biological Sciences (Series B)*, vol. 362(1482), pp. 997–1008.

Kemp, DR & Michalk, DL (eds) 2011, *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 189.

Kemp, DR & Michalk, DL 2011, 'Livestock production styles and managing grassland ecosystems', in Lemaire, G, Hodgson, J & Abad Chabbi (eds), *Grassland Ecosystems: Productivity and Environmental Issues*, Chapter 1.6 , CABI. Pp. 53–62.

Kemp, DR, Han, GD, Michalk, DL, Nan, ZB, Wu, JP & Xu, Z 2011, 'China's grassland livestock farming systems – tactics and strategies for improvement', in Kemp, DR & Michalk DL (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 177–189.

Li, ZG 2015, 'Simulation study of the resources optimizing allocation and adaptive management in household farm, Inner Mongolia: a case in Siziwang Banner', PhD thesis, Inner Mongolia Agricultural University, Hohhot.

Li, ZG, Han, GD, Zhao, ML, Wang, J, Wang, ZW & Kemp, DR 2015, 'Identifying management strategies to improve sustainability and household income for herders on the desert steppe in Inner Mongolia, China', *Agricultural Systems,* vol. 132, pp. 62–72, doi: 10.1016/j.agsy.2014.08.011.

Mou, XD 1998, 'Management decision of 30 household farm in grassland area', *Pratacultural Science*, vol. 8(5), pp. 4–7.

Ning, BY & He, YQ 2006, 'Causes analyses about farmers overgrazing – an investigation of farmers coming from Sunan county lying in Heihe river basin', *Economic Geology*, vol. 26(1), pp. 128–132.

Pope III, CA & McBryde, GL 1984, 'Optimal stocking of rangeland for livestock production within a dynamic framework', *Western Journal Agricultural Economics*, pp. 160–169.

Ren, JZ 2013, 'China's traditional agricultural structure must be changed: the worries of food nine increased', *Acta Pratacultural Sinica*, vol. 22(3), pp. 1–5.

Wang, CM, Yang, LJ, Chang, SH & Hou, FJ 2014, 'Price analysis of domestic and international major livestock and forage products', *Acta Pratacultural Sinica*, vol. 23(1), pp. 300–311.

Wang, JJ 2006, 'Dynamic changes of grassland vegetation in Inner Mongolia during the 10th Five–Year Plan period. *Inner Mongolia Prataculture*, vol. 18(3), pp. 47–50.

Wang, J, Zhao, ML, Willms, WD, Han, GD, Wang, ZW & Bai, YF 2011, 'Can plant litter affect net primary production of a typical steppe in Inner Mongolia?', *Journal Vegetation Science*, vol. 22, pp. 367–376.

Wang, ZW, Jiao, S, Han, GD, Zhao, ML, Willms, WD, Hao, X, Wang J, Din, H & Havstad, KM 2011, 'Impact of stocking rate and rainfall on sheep performance in a desert steppe', *Rangeland Ecology and Management*, vol. 64, pp. 249–256.

Wu, SQ, Wu, RQ, Jin, WX & Guo, SJ 2003, 'Development direction of grassland resource and pratacultural in Sunjia Tan, Ningxia', *Grassland and Turf,* vol. 1, pp. 23–24.

Yang, YH 2007, 'Views on the establishment of a new type of household farm in "return grazing land to grassland project"', *Grassland and Turf*, vol. 3, pp. 64–66, 68.

Wulan 2014, 'Division of ecological site and construction of state-and-transition model based on high resolution remote sensing image in family ranch scale', PhD thesis, Inner Mongolia Agricultural University, Hohhot.

5 Herders' attitudes on stocking rates and implications for grassland management in northern China

Hou Xiangyang, Yin Yanting, David Kemp, Li Ping

Chinese grasslands are extensive, comprising approximately 40% (400 Mha) of the national land area (Ren et al. 2008). The grasslands have been seriously degraded because of overgrazing, exacerbated by reduced rainfall in large areas and the continuation of high stocking rates, resulting in a decline in grassland productivity (Li 1999; Liu et al. 2002; Li et al. 2008; Yang 2010; Kemp et al. 2011; eds Kemp & Michalk 2011). Grazing is arguably (Li 1999) the dominant factor affecting vegetation community characteristics, more so than climate change. It has been recognised that stocking rates need to be reduced to aid grassland rehabilitation (Kemp et al. 2013).

To rehabilitate degraded grassland, the Chinese Government initiated grazing bans and forage–livestock balance policies from 2002, designed to encourage herders to reduce their livestock numbers. However, there is a high degree of non-compliance by herders with these programs (Li & Zhang 2009; Hou et al. 2013). Herders may appear to behave in accord with policy requirements, but it is well known that while there is no grazing during the day, there is often a lot of night-time grazing in areas where grazing bans have been imposed. Outcomes have been described as a 'partial improvement amidst overall deterioration' (Yang 2010). Reasons for the non-compliance with these policies have been the subject of much discussions (Li & Liu 2005; Yang & Hou 2005; Waldron, Brown & Longworth 2010; Wang et al. 2010; Li & Hao 2011; Qi, Chen & Wan 2012). Ultimately, herders make pastoral decisions, yet there has been a lack of research on the important role of herder attitudes on grazing decision-making and how that aligns with policy objectives. Such knowledge is vital for improving the application of current policies and ensuring a higher level of compliance.

Chinese grasslands are collectively part of the largest natural ecosystem in the country. For millennia, people have been dependent on the grasslands for their livelihoods and for cultural reasons. Good policies need to consider the whole socioeconomic and natural systems. Although this was argued some years ago (Ma & Wang 1984), this approach has not been thoroughly implemented to date. The program considered in this monograph is the first to apply this approach to grassland–livestock–herder systems in China. The need to adequately understand the ecological, economic and social needs of natural systems like the permanent grasslands of China has been stressed in studies done elsewhere (Grumbine 1994; Folke et al. 2005; Norton 2005; Folke 2006; Xu, Liang & Gao 2008; Meffe et al. 2010). In Chinese grassland systems, the herder is the key stakeholder.

Herder households have been directly and progressively responsible for grassland management under the Pasture Household Contract Responsibility System since 1985 (further details in Chapter 1). Under this system, herders are responsible for a specified area of land. Previously, under common grazing systems, herders could move their animals to wherever they thought there was more grassland available. Today the level of grassland productivity and animal performance directly depends upon the stocking rates on a herder's allocated land.

Stocking rates can be defined from various perspectives. This can range from the maximum number of animals that can survive on the land through the year to the number that will produce the optimum (economic) output of animal products (meat, fibre, milk). This range depends upon whether the herders are primarily interested in keeping animals for survival or producing the most saleable product (Neidhardt et al. 1996). Exactly where current Chinese herders fit within this range is unclear, although experience suggests most are thinking about maximising the number of animals they have. Herders have been progressively engaged with the modern market systems in China and an increasing proportion of their livestock and livestock products are being sold. The concept of a desirable stocking rate (DSR) (Hou et al. 2014) has been developed to help understand the decisions herders make. Knowledge of the herders' DSR is needed to compare with stocking rates that are considered sustainable on ecological grounds. These are sometimes called theoretical or ecological stocking rates, and are promoted by government organisations. Understanding how herders select a can then better inform policies for managing China's grasslands (Wei & Hou 2015). It is also important to know if the herders' DSR is different to their actual stocking rates, and the reasons for that.

In this chapter, we report on a survey of herder styles, attitudes and intentions for stocking rates, the DSRs they choose, and how that relates to actual and recommended stocking rates and the implications for policies designed to rehabilitate degraded grasslands.

Study areas

This research was done in the five most important grassland regions across IMAR in northern China: meadow steppe, typical steppe, desert steppe, sandy steppe and desert regions (Figure 5.1). These regions are on or near the Mongolian Plateau, which also extends through Mongolia. Grassland productivity declines from east to west, associated with the gradually decreasing rainfall. The growing season is from May to September in summer, when 60–70% of the annual precipitation occurs, then there is a long drier and colder period through autumn, winter and spring. Three neighbouring banners (counties) were chosen in each region surveyed. The Pasture

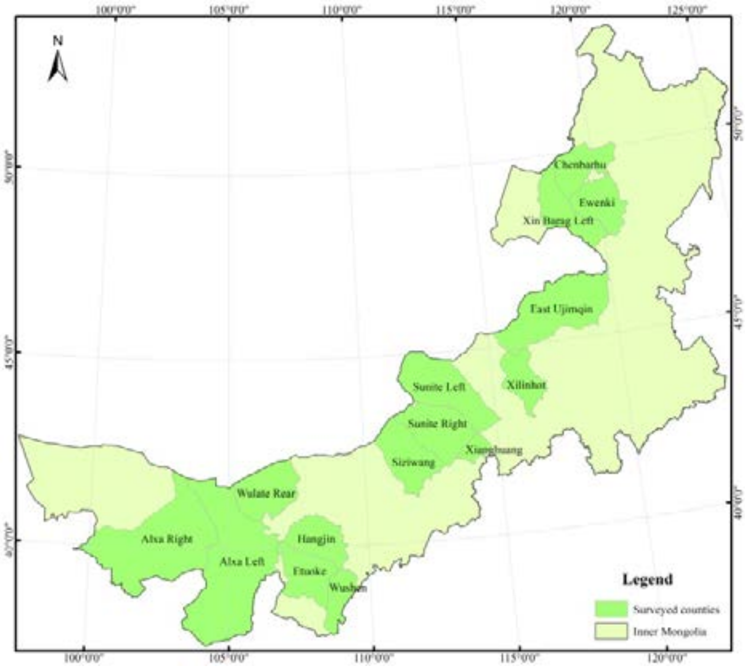

Figure 5.1 Study regions in IMAR

Household Contract Responsibility System has been implemented since the 1980s in these regions. Households have responsibility for the grassland under the contract, and they own and are directly responsible for the livestock.

Survey design

The first household survey was done in 2010 in the 15 counties studied (Figure 5.1). At least 60 households in each county were randomly selected, giving a total of approximately 180 households within each of the five grassland regions. The second survey was done in 2012 to explore herder perception about DSR in the meadow steppe (Xinbaerhu Left), typical steppe (Xilinhot City) and desert steppe (Sunite Right) regions. Both surveys included structured questions in five topic areas:

1. the socioeconomic characteristics of the herders and their households
2. opinions about overstocking, carrying capacity, and the degradation of their rangelands (responses were coded on a 5-point Likert scale: 1 = absolutely not, 2 = not, 3 = unsure, 3 = yes, 5 = absolutely yes)
3. information about the herders' current management practices (including their actual stocking rates on their grasslands and their desired stocking rate)
4. attitudes towards new agriculture practices
5. attitudes towards the policy of balancing animals and grass.

Most questions were semi-structured rather than open-ended. An initial version of the survey was tested with 20 herders in their homes to ensure that the questions were understandable and unambiguous.

Household characteristics

Across the five grassland types, the average family size (4) and household labour (2) were similar, but the number of animals managed varied considerably, as did the area of grassland per household (Table 5.1). The households from the meadow steppe region had the largest number of livestock (661 SE), the highest stocking rates (3.2 SE/ha) and the lowest net livestock income/SE (¥118/SE). In contrast, the households in the desert steppe region had the largest areas of grasslands (963 ha), the lowest stocking rates (0.6 SE/ha) and a higher net livestock income/SE (¥198/SE). The total livestock income was greatest (¥126,796) for households from the typical steppe region, and they also had a high net livestock income/SE (¥245/SE). Households in the sandy steppe region had the fewest animals, the lowest total livestock income (¥57,745) but the lowest livestock cost/SE (¥33/SE), which resulted in a similar high net livestock income/SE (¥246/SE) as in the typical steppe. In the sandy steppe, herders had some irrigation to grow forage, more so than in other regions, which resulted in a higher stocking rate than in the desert steppe where precipitation is similar. The considerable variation in total livestock income/SE reflects the current state of markets across grassland areas and the variability in amount of animal product per SE.

Table 5.1 Mean socioeconomic characteristics of households across five grassland regions, IMAR, 2010

	Meadow steppe	Typical steppe	Desert steppe	Sandy steppe	Desert
Number of surveyed households	179	180	191	179	180
Family size	4	4	4	4	4
Household labour	2	2	2	2	2
Herd size (SE)	661	548	419	220	415
Grassland area (ha)	328	601	963	196	994
Stocking rate (SE/ha)	3.17	1.23	0.60	1.41	0.99
Total livestock income (¥)	87,789	126,796	75,160	57,745	57,881
Total livestock income/SE (¥)	133	231	179	262	139
Total livestock cost/SE (¥)	34	104	123	33	49
Net livestock income/SE (¥)	118	245	198	246	151

Herder household styles

A conceptual framework was used to help understand herder styles and their attitudes. These styles can in part be characterised by how the animals are managed and fed through the year. The transitional framework for herders in East Africa, developed by Neidhardt et al. (1996), of 'user/keeper/producer/breeder' is similar for herders in China. A 'user' is similar to the gatherer/hunter mode, where management is minimal and herders harvest from a wild population of animals. Users are primarily exploitative and animals are left to their own devices for feeding, water, shelter and reproduction. Some elements of users still remain in China. Traditional herders in China, though, have more in common with 'keepers', who routinely constrain their animals, herding them and keeping them in yards or shelters at night for protection from predators. Keepers do manage their animals for water and (maybe) reproduction, but feeding is minimal—typically only when animals are in poor condition in winter. Keepers are often more focused on maximising the survival of the most animals, as their livestock are their main asset. As herders increase the amount of animal products sold to markets, there is the incentive to become 'producers', where more effort is made to feed animals and look after their welfare in order to increase incomes by better satisfying consumer demands. The final stage, 'breeder', is where herders employ more intense management to improve the efficiencies of production, typical of developed economies (Kemp et al. 2011). The step to livestock breeder will only succeed once the herder has experience as a producer (Sölkner, Nakimbugwe & Valle Zarate 1998). This transitional framework suggests that the stage a herder is at can be indicated by the amount of feed provided per animal, in this case feed cost/SE (Table 5.2).

The main cost for livestock is feed. The median cost for the five regions was around 50% of income/SE (Table 5.2). Income figures are based on total income received and total livestock numbers (SE). Income/SE depends in part on the proportion of animals being sold. As incomes increase with increasing costs, this indicates an increasing proportion of livestock being sold. When these probability data are compared (Figure 5.2), it is evident that the patterns were very similar across grassland types, even though the absolute amounts for costs and income per SE differed. Below the median costs per SE, the rate of increase in costs was less than for income, but the reverse applied above the median cost. In the typical and sandy steppes, the highest costs were almost equal to the income received. The more money herders spent on their livestock, the more income they obtained, though net income/SE may have declined. Where feed costs/SE and income/SE were low, the herders were probably in keeper mode. As costs/SE and income/SE increased, the herders were transitioning to producers (Figure 5.2).

Table 5.2 Cost and income per SE for households across five grassland regions, IMAR, 2010

	Meadow steppe		Typical steppe		Desert steppe		Sandy steppe		Desert	
Percentile of farms	Cost (¥/SE)	Income (¥/SE)	Cost (¥/SE)	Income (¥/SE)	Cost (¥/SE)	Income (¥/SE)	Cost (¥/SE)	Income (¥/SE)	Cost (¥/SE)	Income (¥/SE)
1	3.0	5.1	20.8	80.5	18.4	4.6	16.0	79.0	7.9	17.3
10	18.0	41.7	55.6	125.8	41.1	77.0	51.8	135.7	28.2	76.3
20	26.2	67.7	80.5	162.5	56.2	107.4	76.6	174.3	34.6	98.3
30	35.2	79.9	93.2	185.8	66.6	142.6	102.0	194.3	44.0	113.7
40	43.7	93.6	118.0	202.8	78.0	169.9	125.6	213.6	55.5	131.8
50	51.8	104.5	131.7	242.3	91.3	194.2	141.8	243.1	67.5	152.0
60	62.7	122.5	161.1	261.2	115.6	229.7	173.8	261.9	78.6	168.6
70	84.9	143.8	188.9	295.4	141.0	261.1	203.8	286.7	86.1	183.6
80	108.1	174.7	249.5	334.5	165.7	288.2	231.3	327.0	102.2	204.6
90	163.0	211.7	302.4	406.9	222.6	335.2	278.6	388.0	117.9	238.4
99	260.2	422.4	485.6	545.4	330.4	405.8	597.4	613.5	173.3	312.4

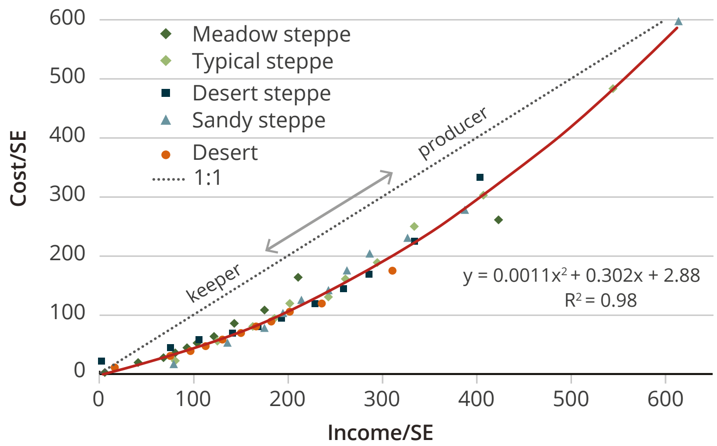

Figure 5.2 Relationship between income and costs per SE for five grassland regions, IMAR, 2010

Note: Data are the limits for probability classes presented in Table 5.2.

The data on feed costs do not include estimates of hay made by herders. It is reasonable to assume, based on anecdotal evidence, that the amount of hay fed could be in proportion to the amount of purchased feed. The price received per SE was in proportion to the feed cost/SE, suggesting that any hay fed was not having any significant effect on that relationship.

This general analysis suggests that a significant number of herders are still behaving as keepers. They provide minimal inputs for their animals, wish to increase the size of their flocks and herds and only sell a small proportion of animals each year (Kemp & Michalk 2011). These are traditional practices of older herders, who still function that way.

One issue that constrains the way that herders manage their livestock is the lines of credit available to them. Bank loans are typically for a maximum of one year, based on crop loan practices. However, it is difficult to earn enough from livestock within a year to repay loans, especially loans to purchase better-quality animals to build a productive herd or flock, or extra feed supplies. Existing livestock are the main asset that herders use to support a loan application. These factors mean that herders adopt a risk-adverse strategy and tend to only take out minimal loans to provide minimal support for their livestock enterprise and/or for household use. This constrains them to a keeper mode. Maximising animal numbers provides a bank to help survive adverse seasons, though this typically leads to reduced productivity per animal and overgrazing. Policies need to provide incentives to enable these herders to transition to a producer mode, while reducing overgrazing. However, only those who are strongly motivated are likely to change (West 1979).

The conceptual model for desirable stocking rate

The actual stocking rate (ASR) used by a herder is influenced by many components, including:

- ecological/biophysical factors (state of the grassland, grassland area, forage quality, ecological condition, rainfall)
- financial factors (market prices for livestock, forage, fodder, bank charges, total household income)
- social factors (labour available, herder age, education and medical needs of family, status).

Interacting with each of these components are government policies. The relative importance of each factor will change with time and household circumstances. From this range of qualitative and quantitative factors, herders develop their own idea of their DSR. This may be greater or less than the current ASR, and the scale and direction of that difference provides useful information on what management decisions a herder is likely to make and how they might comply with policies on recommended stocking rates. It is difficult to quantify all the possible factors that might influence a herder's decision about stocking rates. However, experience suggests that there are three factors that commonly emerge in discussions with herders about stocking rates. These components are arguably known to influence the ASR decisions of herders:

$$\mathbf{ASR = f(DSR, SR_e, SR_f)} \qquad \mathbf{(1)}$$

DSR is defined by the herder as their ideal stocking rate under current circumstances and is usually related to a defined period (Hou et al. 2013). SR_e is defined as the stocking rate recommended by local officials. Unfortunately, SR_e is often quoted uniformly across a county, rather than adjusted for each farm. Ideally, SR_e would be modelled for each farm, based on the condition of the grassland. SR_f is the stocking rate that optimises financial returns for the herder. This could be modelled to find the optimal stocking rate, based on the individual financial situation of each herder. However, as herders are often focused primarily on the gross sale price of their animals, using average livestock prices could be a reasonable approximation of the main driver for this term. This model is difficult to analyse in practice, as SR_e tends to be a constant within districts and data for understanding SR_f is difficult to obtain. It is possible, however, to evaluate ASR in relation to a herder's perception of DSR.

Herder perceptions of DSR

The 2015 survey found that in Xinbaerhu Left (XZ, meadow steppe), Xilinhot City (XL, typical steppe) and Sunite Right (SY, desert steppe) counties, 65%, 61% and 49% of respondents respectively stated that they carried more livestock now than 10 years earlier, when the balancing animals and grass policy was implemented in those counties (Table 5.3). While most herders (74%, 79% and 68% respectively) said there was no overstocking on their rangelands, a lower proportion (51%, 57% and 63% respectively) believed that their rangelands could still graze more livestock, suggesting that only a small proportion (23%, 22% and 5% respectively) thought levels were at their DSR. In addition, 80%, 88% and 76% of respondents insisted that they always took into consideration the carrying capacity of the rangeland when deciding whether to increase livestock numbers or not, indicating that 20%, 12% and 24% gave carrying capacity a low priority in their decision-making. This could be an underestimate. Carrying capacity in this case could mean either the herder's DSR or the SRe. In these three counties, herders considered that the average DSRs were 1.20 SE/ha, 1.15 SE/ha and 0.59 SE/ha respectively, which was 25–50% higher than the ASRs (0.96 SE/ha, 0.76 SE/ha and

0.39 SE/ha respectively) at the time. The proportions of herders in Xinbaerhu, Xilinhot and Sunite counties with individual DSRs greater than the ASR were 61%, 61% and 77% respectively. This is 10%, 4% and 14% larger than the 51%, 57% and 63% who believed the rangelands could carry more livestock. This discrepancy may indicate that herders have some uncertainty about their DSR estimates. The ASRs were, on average, higher than the ecological standard imposed by the policies (SRe) but lower than the herders' DSRs, supporting the view that that the ASR was affected by both the policy standard and the herder's DSR.

Table 5.3 Herders' responses to statements about stocking rates, 2012

Question/SR levels	Region		
	Xinbaerhu	Xilinhot	Sunite
Had more livestock than 10 years ago (%)	65	61	49
Believed that there was no overstocking on rangeland (%)	74	79	68
Believed that the rangeland could still carry more livestock (%)	51	57	63
Always considered the carrying capacity of rangeland when deciding whether to breed more livestock (%)	80	88	76
Herder DSR (SE/ha)	1.20	1.15	0.59
Household ASR (SE/ha)	0.96	0.76	0.39
Standard ecological stocking rates imposed by policies (SE/ha)	0.75	0.50	0.38

The general results from the survey showed that herder responses were not always consistent. To further investigate herder attitudes, the desire to increase or decrease stocking rates was plotted against the difference between the DSR and ASR (Figure 5.3). This classified herders into five main groups. Where herders were intending to decrease their ASR (groups 1 and 3, 38% of the total), 12% had higher ASRs than desired and 26% had less than desired. Group 1 may have been indicating that, while they desired a higher stocking rate, they acknowledged this might not be rational, given the current state of the grasslands. However, 58% of herders intended to increase their stocking rates (groups 2 and 4)—40% considered their ASR was below their DSR, but 18% were above their DSR. Group 4 was possibly being driven by financial and social motivations more than a consideration of the grassland condition. Only 3% of herders did not intend to change their stocking rates even though the difference between their DSR and ASR was not zero. Most of the individual herder differences between DSR and ASR were within 0.5SE/ha. That would be equivalent to a 15% change for the meadow steppe (XZ) but 40% for the typical steppe (XL) and 83% for the desert steppe (SY). On the desert steppe, more herders considered their ASRs were below desired, compared to the other counties, yet a moderate proportion still intended to decrease stocking rates. It was evident that, overall, only about half the herders (52%) intended to change their stocking rates in a way that aligned with the difference between DSR and ASR.

Figure 5.3 Classification of herders into five groups based on the relationship between their intention to increase or decrease stocking rates and the difference between DSR and ASR for Sunite (SY), Xilinhot (XL) and Xinbaerhu (XZ), 2012

This classification of herders supports the view that, while herders may be aware of the recommended stocking rates, in practice a majority give more consideration to their DSR and any changes they make are more likely to move towards their DSR than towards the SR_e. But, even where the DSR was less than the ASR, 18% of herders (group 4) intended to increase stocking rates. What might be their primary motivation?

While this chapter focuses on stocking rates, it is important to consider if herders think about stocking rates in the ways applied in the literature, such as animals per unit area, or differently, such as the number of animals per household. Discussions with herders on stocking rates often reveal that they talk more about the number of animals they wish to have than the density of animals on the ground. This arguably reflects their views about their status as a herder and that, prior to recent decades, they were not limited by land area but only by the number of animals they could manage. They consider their DSR on the basis of total number of animals per household.

The mean responses for groups 1–4 were examined in relation to total household animal numbers and the difference between DSR and ASR (Figure 5.4). There was a consistent negative relationship between the difference in stocking rates and the total animal numbers per household across three groups in all counties. Group 2 wanted to increase animals, while group 3 wanted to decrease them. This may align along a common relationship, as group 2 had fewer animals than group 3. These groups for Sunite and Xilinhot were not significantly different and the fitted regression was not significantly different for group 1, who said their intent was to decrease animals, even though their DSR was greater than the ASR. The hypothesis presented here suggests they may in effect choose the county trend and increase their animal numbers. The fitted regression for Sunite and Xilinhot suggests that herders aim for a flock size of about 450 SE, at which their DSR and ASR would be the same. Similarly, the Xinbaerhu groups 1, 2 and 3 aligned on a common relationship, suggesting that they would settle on 600 SE, where their DSR and ASR would be the same.

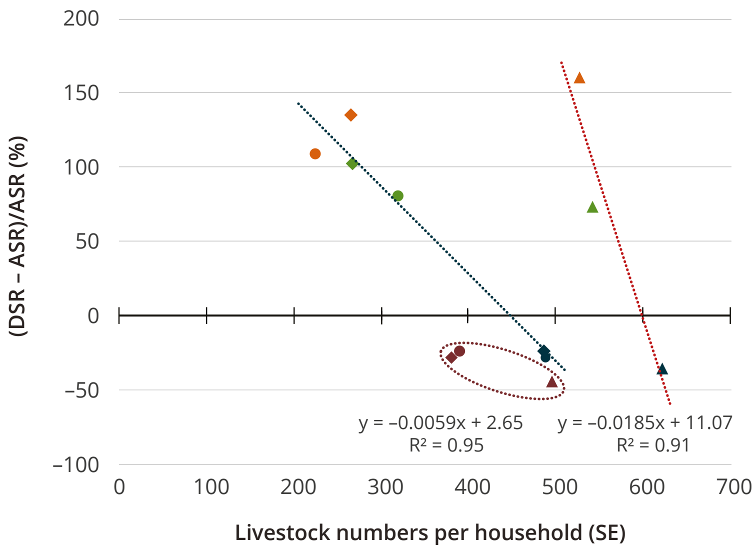

Figure 5.4 Herder DSR as percentage of ASR, in relation to livestock numbers per household, Sunite, Xilinhot and Xinbaerhu, 2012

Note: Data are means for the four main groups in each county, identified by same colours as Figure 5.3 (green = group 1, orange = group 2, blue = group 3, maroon = group 4). Data points in ellipse (group 4) were excluded from fitted regressions.

The group in each county that did not conform to the same pattern as the others was group 4, especially in Xinbaerhu. These were herders whose DSR was less than the ASR, yet they still intended to increase their animals. The Xinbaerhu group 4 herders had an average SE of 500, 100 SE less than where the other herders would consider DSR and ASR agree. Their intention to increase stocking rates could reflect a desire to have a similar flock size to the other herders in Xinbaerhu, even though this would result in a 20% increase in stocking rates to 1.8 SE/ha, more than twice that of the other farms. The DSR for this outlying group was 0.8 SE/ha, close to the SR_e of 0.75 SE/ha for the county, yet their intent was to increase animal numbers. Similarly, in Sunite and Xilinhot the group 4 herders had <400 SE and wanted to increase their number, possibly to the target of 450 SE.

The discrepancies between SR_e, ASR and DSR were considerable (Figure 5.5). Across the three counties, ASRs for groups 1 and 2 were closest to the SR_e, but groups 3 and 4 were often 50% higher. The DSR data showed a contrasting pattern. The DSRs for groups 3 and 4 were generally closest to the SR_e, but groups 1 and 2 had DSRs of up to twice that of the SR_e. The herders on the desert steppe at Sunite had the narrowest range of DSRs and the smallest average difference to the SR_e.

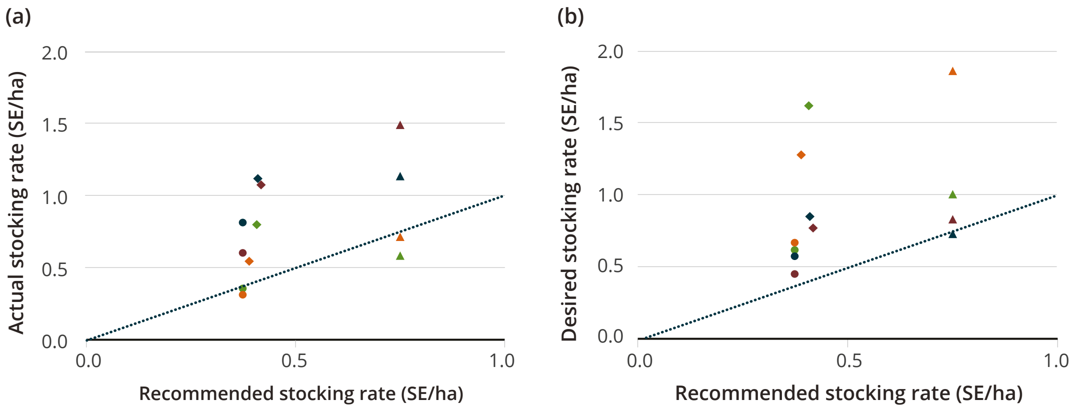

Figure 5.5 (a) ASR and (b) DSR in relation to SR_e, Sunite, Xilinhot and Xinbaerhu, 2012

Note: Data are means for the four main groups in each county, identified by same colours as Figure 5.3 (green = group 1, orange = group 2, blue = group 3, maroon = group 4). Mean values are shown in Figure 5.3. The dotted line shows the line of equality.

The motivations of the four main groups of herders are clearly different, and they also are on different parts of the line relating costs/SE with income/SE (Figure 5.6). The main differences are that in Xinbaerhu (meadow steppe) average incomes and feed costs were the lowest, while Sunite (desert steppe) had the highest costs and incomes. Xilinhot (typical steppe) prices were closer to the desert steppe. It was not possible to get consistent data on the prices paid per SE, only total livestock income, but if market prices for animals were reasonably consistent, this suggests a higher proportion of animals were sold at Sunite, less at Xilinhot and least at Xinbaerhu. That could be true, as feed costs across grassland types show the same trend. The size and quality of animal products would bear some relationship to how the animals were fed. The amount of hay made and fed to animals by herders could not be estimated. This could change these results, though given the ranking in income/SE, it is reasonable to assume that any hay made and fed by herders was of the same order as purchased feed costs/SE. Sunite is the driest region of these sites, which may mean that herders prefer to sell more animals each year rather than maximising the number of animals they keep, especially through winter. These considerations suggest that the herders at Xinbaerhu were behaving more in a keeper mode (Figure 5.2) while those at Xilinhot and Sunite were more focused on being producers.

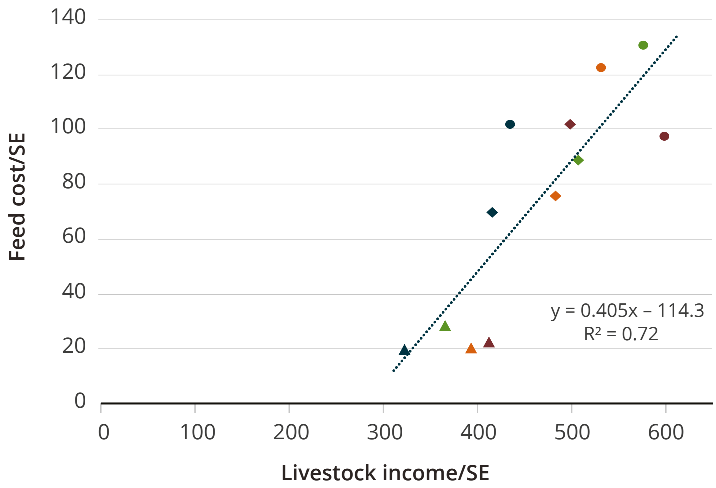

Figure 5.6 Feed cost/SE in relation to livestock income/SE, Sunite, Xilinhot and Xinbaerhu, 2012

Note: Data are means for the four main groups in each county, identified by same colours as Figure 5.3 (green = group 1, orange = group 2, blue = group 3, maroon = group 4).

Herder opinions of the policy

Herders were asked for their perception of current government policies. In Xinbaerhu, Xilinhot and Sunite, 22%, 53% and 34% respectively considered the forage–animal balance policy was unreasonable. These herders stated that the local standard set by the policy was too restrictive, compared to the stocking rates that they believed could ensure their livelihoods remained unchanged or improved. They believed their livelihoods would be adversely affected if they complied with the policy and reduced livestock numbers. Additionally, 38%, 83% and 78% respectively thought there was no need to implement the forage–animal balance policy, as they had their own DSRs and would adjust their livestock numbers and other relevant production practices (e.g. renting grasslands and buying more forage and fodder) based on their own understanding of the interaction between animals and grasslands.

Notably, this survey was conducted in 2012, after one year of the implementation of the Grassland Ecological Protection Award Policy (GEPAP). Households could receive subsidies from the GEPAP (¥90/ha/year if they complied with the grazing ban policy and ¥22.5/ha/year if they complied with the grass–animal balance policy). However, many herders expressed their concern about the policy. They were not sure about the details of the implementation, including if they had to reduce livestock numbers, and whether there would be any punishment if they did not reduce livestock. In effect, many herders adopted a wait-and-see attitude towards the policy and did not change their livestock numbers. There was almost no monitoring of herder activities or punishment in the study regions, and all households got the same subsidy whether they reduced livestock numbers or there was a total ban on livestock grazing in a specific region. Herders still depended on themselves to make decisions about animal numbers and no officials seem to have been involved in those decisions.

Policy implications

The results reported here show that the attitudes of herders to stocking rates are variable and often in conflict with policy objectives. Herder definitions of their DSR were often significantly different to the recommended sustainable stocking rates. Part of the reason for this difference is that herders may be behaving more as animal keepers than producers of animal products. Their definition of sustainable stocking rates may be more about how many animals can survive on the resources (land, sheds, feed) available, rather than how much animal product they could sell. Many herders are arguably in the transition between keeper and producer. A keeper often aims to have animals eat every plant they see, whereas producers acknowledge that animal production requires a lower rate of utilisation, with implications for rehabilitating grasslands. An additional factor identified in these analyses is that many herders may think about stocking rates in terms of the total number of animals that would ensure their household needs into the near-future. The data suggests that, within any district, there is an animal number where DSRs and ASRs are equal. Desired animal numbers take priority over stocking rates per hectare. Traditionally, herders were not constrained by land area, so the idea of stocking rates per hectare would be new to them. Herder status may also depend upon the number of animals they have. Other work presented in this monograph shows that, as farm size increases, stocking rate decreases. Herders do not maintain stocking rates as a priority if they have more land.

DSRs are based on herders' consideration of a diversity of factors (Hou et al. 2014). Where the DSR was less than the ASR, the DSR was similar to the SR_e, suggesting those herders had recognised the merit of the recommended SR_e, but their primary motivation could be to first achieve a desired number of animals by decreasing or increasing their herd/flock size. To achieve lower stocking rates in group 4 (herders who intend to increase animal numbers) would require land reform that allows them to increase their farm size. Group 3 herders were intent on reducing their flock/herd size in line with policy.

Where DSR was greater than ASR (groups 1 and 2), the ASR was closer to the SR_e but herders intended to change their stocking rate and flock/herd size. Group 1 herders intended to decrease their animal numbers, but given their DSRs were considerably greater than SR_e, they may still not comply with the policy objectives if they perceive the difference between DSR and SR_e to be too great. Some further research is needed to determine what these herders have done since the surveys and what their motivations are. They may not conform to the relationship found in Figure 5.4. These group 1 herders could be older and more interested in reducing their workload and therefore willing to reduce animal numbers. Group 2 herders intended to increase their animal numbers, even though they were starting close to the SR_e. Both these groups could be primarily motivated to have the number of animals (450 SE for Sunite and Xilinhot, 600 SE for Xinbaerhu) that they considered viable in their county.

There were 58% of the herders who intended to increase their stocking rates. These herders do not appear to accept current recommendations as their priority. This could be driven primarily by the desire to increase their flock/herd size to a number they consider is needed to adequately support their household. This desire seems to take priority over current recommendations. To achieve their goal, and reduce stocking rates, individual herder households need access to more land. At present, they are renting land from their neighbours on short-term arrangements. They need to pay rent and have no incentive to avoid overgrazing on rented land. In some villages, it is evident that up to half the herders have rented land to their neighbours, which has enabled the remaining herders to increase their farm size. The net effect has been a reduction in stocking rates (Chapter 4). However, these arrangements are not permanent. Herders have to pay rent and they do not guarantee that stocking rates are sustainable on all land areas. In fact, in order to pay rent, these herders may want to have more animals than they would otherwise desire. Government payments to cover rents may be a useful way to limit animal numbers and aid household incomes (de Janvry, Sadoulet & Zhu 2005).

The evidence presented here showing that herders often behave as keepers rather than producers has implications for policy changes. What limits herders from transitioning to being producers? The financial problems that herders have when they wish to upgrade their animals, feeding and facilities need to be addressed. Bank loans need to be longer-term for livestock producers and have lower interest rates. Government payments for infrastructure would further assist herders, but these need to be combined with training programs, so that herders make better use of new or upgraded facilities (Wu et al. 2011). Herders have great skills in managing their animals through difficult seasons, but many do not have the skills required to become efficient producers.

The experience of the program reported in this monograph is that herders do respond to farm demonstrations as a mechanism to improve animal production techniques. This monograph outlines the techniques that were found to be useful. As part of these programs, training is needed on how herders should use information on DSRs. The results presented here show that herder DSRs were typically above SR_e and often the ASR. The results support the view that herders think about the maximum number of animals that they consider will survive on the grasslands, rather than the maximum amount of animal production and saleable products they could achieve. The transition from keeper to producer cannot always be done in a single step. A more gradual series of steps is recommended so that herders can adjust and learn to optimise production more effectively.

Acknowledgments

This paper was funded by ACIAR (ADP/2012/107), National Natural Science Foundation of China (NSFC) (71774162; 71403272), Science and Technology Innovation Project of Chinese Academy of Agricultural Science (CAAS-ASTIP-IGR2015–05) and National Key Basic Research Program of China (2014CB138806). We thank all other participants for their efforts in the survey work. We are very grateful to the herders for giving us much time and allowing us to ask them so many questions.

References

De Janvry, A, Sadoulet, E & Zhu, N 2005, 'The role of non-farm incomes in reducing rural poverty and inequality in China', UC Berkeley: Department of Agricultural and Resource Economics.

Folke, C 2006, 'Resilience: the emergence of a perspective for social–ecological systems analyses', *Global Environmental Change*, vol. 16(3), pp. 253–267.

Folke, C, Hahn, T, Olsson, P & Norberg, J 2005, 'Adaptive governance of social-ecological systems', *Annual Review of Environment and Resources*, vol. 30, pp. 441–473.

Grumbine, RE 1994, 'What is ecosystem management?', *Conservation Biology*, vol. 8(1), pp. 27–38.

Hou, X, Yin, Y, Michalk, DL, Yun, X, Ding, Y, Li, X & Ren, J 2014, 'Herders' opinions about desirable stocking rates and overstocking in the rangelands of northern China', *The Rangeland Journal*, vol. 36(6), pp. 601–610.

Hou, XY, Yin, YT, Yun, XJ, Li, XL & Ding, Y 2013, 'Herders' stocking rates and shift of grass-animal balance model in northern grassland of China', *Chinese Journal of Grassland*, vol. 35(1), pp. 1–11.

Kemp, DR, Brown, C, Han, GD, Michalk, DL, Nan, ZB, Wu, JP & Xu Z 2011, 'Chinese grasslands: problems, dilemmas, and finding solutions', in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, 12–24.

Kemp, DR, Han, GD, Hou, XY, Michalk, DL, Hou, FJ, Wu, JP & Zhang YJ 2013, 'Innovative grassland management systems for environmental and livelihood benefits', *Proceedings of the National Academy of Sciences*, vol. 110 (21), pp. 8369–8374.

Kemp, DR & Michalk, DL (eds) 2011, *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 189.

—— 'Livestock production styles and managing grassland ecosystems' in G Lemaire, J Hodgson, A Chabbi (eds), *Grassland ecosystems: productivity and environmental issues*, CABI Publishing, Wallingford, Ch. 1.6, p. 53–62.

Li, B 1999, 'Steppe degradation in northern China and preventing measures', in RG Xu (ed.), *Collected Papers of Li Bo*, Science Press, Beijing.

Li, QF & Liu, TM 2005, 'Feed-animal balance control: approach based on feed availability in critical period', *Grassland of China*, vol. 27(1), pp. 72–74.

Li, WJ & Zhang, Q 2009, *Unscrambling the grassland dilemma: understanding problems of grassland utilization and management in arid and semiarid areas*, Economic Science Press, Beijing.

Li, XL, Yuan, QH, Wan, LQ & He, F 2008, 'Perspectives on livestock production systems in China', *The Rangeland Journal*, vol. 30(2), pp. 211–220.

Li, Y & Hao, RM 2011, 'Grazing resource management and grassland degradation in northern China', *Journal of Resources and Ecology*, vol. 2(3), pp. 286–288.

Liu, ZL, Wang, W, Hao, DY & Liang, CZ 2002, 'Probes on the degeneration and recovery succession mechanisms of Inner Mongolia steppe', *Journal of Arid Land Resources and Environment*, vol. 16(1), pp. 84–91.

Ma, S & Wang, R 1984, ' The social-economic-natural complex ecosystem', *Acta Ecologica Sinica*, vol. 27(1), pp. 1–9.

Meffe, G, Nielsen, L, Knight, RL & Schenborn, D 2010, *Ecosystem management: adaptive, community-based conservation*, Island Press, Washington, DC.

Neidhardt, R, Grell, H, Schrecke, W & Jakob H 1996, 'Sustainable livestock farming in east Africa', *Animal Research and Development*, vol. 43/44, pp. 45–53.

Norton, BG 2005, *Sustainability: a philosophy of adaptive ecosystem management*, University of Chicago Press.

Qi, J, Chen, J, Wan, S & Ai, L 2012, 'Understanding the coupled natural and human systems in Dryland East Asia', *Environmental Research Letters*, vol. 7(1), doi: 10.1088/1748-9326/7/1/015202

Ren, JZ, Hu, ZZ, Zhao, J, Zhang, DG, Hou, FJ, Lin, HL & Mu, XD 2008, 'A grassland classification system and its application in China', *The Rangeland Journal*, vol. 30(2), pp. 199–209.

Sölkner, J, Nakimbugwe, H & Valle Zarate, A 1998, 'Analysis of determinants for success and failure of village breeding programmes', *Proceedings of the 6th World Congress on Genetics Applied to Livestock Production*, vol. 25, pp. 273–281.

Waldron, S, Brown, C & Longworth, J 2010, 'Grassland degradation and livelihoods in China's western pastoral region: a framework for understanding and refining China's recent policy responses', *China Agricultural Economic Review*, vol. 2(3), pp. 298–320.

Wang, MP, Zhao, CZ, Long, RJ & Yang, YH 2010, 'Rangeland governance in China: overview, impacts on Sunan County in Gansu Province and future options', *The Rangeland Journal*, vol. 32(2), pp. 155–163.

Wei, Q & Hou X 2015, 'Reflections on establishing a long-term mechanism of grassland ecological compensation in China', *Scientia Agricultura Sinica*, vol. 48(18), pp. 3719–3720.

West, JG 1979, 'Agricultural economics research and extension needs of small-scale, limited-resource farmers', *Southern Journal of Agricultural Economics*, vol. 11(1), pp. 49–56.

Wu, JP, Michalk, DL, Kemp, DR, Yang, L & Gong, X 2011, 'Talking with China's livestock herders – what was learnt about their attitudes to new practices?' in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 162–176.

Xu, L, Liang, N & Gao, Q 2008, 'An integrated approach for agricultural ecosystem management', *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews),* vol. 38(4), pp. 590–599, doi: 10.1109/TSMCC.2007.913894.

Yang, L & Hou, XY 2005, 'Reflection of the forage-livestock balance modes', *Chinese Rural Economy*, vol. 9, pp. 62–66.

Yang, ZH 2010, 'Speeding up grassland protection and construction', *China Animal Industry*, vol. 16, p. 9.

6 Sustainability modelling of grassland systems

Karl Behrendt, Haibo Liu, David Kemp, Taro Takahashi

Environmental, financial and political influences affect herders and farmers livelihoods because of the expectation that they maintain biologically and economically resilient systems. Making decisions regarding the management of a grassland resource is an important and complex bioeconomic problem. It involves the consideration of interactions between grassland ecology, the use of technology to improve and manage the resource, environmental externalities, utilisation of the resource by grazing animals and the profitability of the farming system.

Within any grazing system, decisions need to be made by managers and herders on how to best manage the mosaic of grassland resources available to them. This involves making decisions about how to utilise the existing resource through the adjustment of stocking rates and grazing management, or making decisions about the use of inputs and existing technologies, such as fencing or labour, to aid in the control of grazing, the application of fertiliser or manure and the sowing of introduced species. The ultimate aims of these decisions are to improve farm profitability, household cash flows, animal production and grassland productivity, quality and persistence (Scott et al. 2000; eds Kemp & Michalk 2011; Behrendt, Cacho et al. 2013). A series of tactical and strategic decisions[4] need to be made in a climate of uncertainty about their degree of success in achieving desired levels of production, profitability and environmental outcomes.

A grassland resource is dynamic in its response to utilisation and climate, and the impacts of decisions made at different points in time significantly influence profitability over the long term. Climate risk influences the future profitability and productivity of the grazing system and the future state of the soil and grassland resource. The more recent approach to managing grassland resources is the continuation of a paradigm shift that occurred during the late 1980s and 1990s, to one where grasslands need to be managed as continually changing ecological systems. Kemp and Michalk (1994) defined grassland management as the process of actively intervening in the production of plants and their utilisation by grazing animals to maintain or improve production while sustaining the resource. The options and technologies available to herders allows them to modify their management and utilisation of grasslands under stochastic climatic conditions. Hence grassland management includes the need to find a balance between grassland productivity and persistence, environmental outcomes, livestock production and whole-farm profit.

The use of conventional production economics to support decision-making regarding shorter-term production and profit objectives of livestock grazing systems is unlikely to be acceptable to modern community values, where the focus is increasingly on improving environmental outcomes. The challenge lies in identifying profitable and ecologically sustainable livestock production systems from dynamic grassland resources (MacLeod & McIvor 2006).

A greater realisation of environmental responsibilities over the past three decades has led to an increased emphasis on the development of sustainable grazing systems (Gramshaw et al. 1989; Humphreys 1997; Hutchinson 1992; Kemp & Dowling 2000; Wilson & Simpson 1994). A critical component to achieving sustainable grazing systems is one that is capable of sustaining high levels of productivity as well as meeting environmental objectives. Sustaining Chinese grasslands means developing a grassland resource that is dominated by species capable of sustaining positive livestock production.

The complexity of the grazing and grassland system, and the need for it to be integrated within the farming system in a profitable and sustainable way, limits the usefulness of relying solely on field experimentation to obtain answers to the complex questions of sustainability in grassland systems. Modelling and simulation of complex farming systems provides the most efficient method of undertaking systems research to improve decision-making (Bywater & Cacho 1994). The development of bioeconomic models that consider the biophysical system and integrate dynamic grassland and soil resources, with livestock production and economic analysis, provides a useful tool for finding sustainable solutions for grassland systems. However, existing models and decision support tools such as the GrazPlan suite of models (Donnelly, Moore & Freer 1997; Moore et al. 2007) and the Sustainable Grazing Systems (SGS) Pasture Model (Johnson, Lodge & White 2003) are complex and require significant inputs and skills by users to create, calibrate and validate model outputs. In countries with limited modelling capacity and quantities of data in appropriate forms, parameterisation of such complex models is difficult. These models are further constrained in the approaches that can be taken to simulating different innovations and the interactions of a stochastic climate with whole-farm profitability and herder cashflows.

4 Tactical decisions represent decisions made by producers to adjust their farming strategies in response to changes in seasonal and market conditions (Antle 1983). Strategic decisions represent decisions made for the development of the business which involve inter-temporal benefits and costs (Rae 1994).

This chapter introduces a suite of models that have been developed to help understand grazing systems and investigate options for changes in stocking rates and management. Several of these models were developed in the earlier phase of this program (eds Kemp & Michalk 2011). Although they have been modified since, readers are referred to the earlier work for more details. This chapter provides a more detailed introduction to the most recent iteration of the modelling suite, the *StageTHREE* Sustainable Grasslands Model (SGM). This model utilises the core functions and dynamic dimensionality of more mechanistic tools, such as those used in the GrazPlan suite and the SGS Pasture Model, but has been designed to minimise the skill and data required for parameterisation. Additionally, the *StageTHREE* SGM has been designed to provide a range of commonly assessed measures of production, economic and environmental outcomes in response to pertinent questions (or decision variables) that are being considered critical for sustainable Chinese grasslands systems. To support the parameterisation of the *StageTHREE* SGM, a Grassland Growth Calibration (GGC) tool has also been developed to enable researchers, advisers and analysts to calibrate the grassland growth models to different agro-ecological zones. This chapter demonstrates the application of the SGM to a case study in IMAR, and then (Chapter 7) applies the SGM to animal production systems on the Qinghai–Tibetan Plateau.

Modelling suite

The four models developed are:

1. feed balance analyser (*StageONE*)
2. linear program optimiser (*StageTWO*)
3. dynamic sustainability (*StageTHREE* SGM)
4. precision livestock management (*PhaseONE*).

Each of these models contains a different set of modules and features (Table 6.1), and is designed to address separate research questions identified in Chapter 1 (Table 6.2). The *StageONE*, *StageTWO* and *PhaseONE* models were originally developed in Excel to enable wider use, but have recently been incorporated into a standalone common platform, optimised management models for household pasture livestock farm production (OMMLP) (Figure 6.1), so they can share a common dataset. The *StageTWO* model requires the Excel add-in 'What's Best' to manage optimisation routines, which is not needed in the OMMLP framework. The *StageTHREE* SGM model has been written in Matlab and a runtime version is used in OMMLP or as a standalone tool. The models require a combination of basic in-field experimental data and data from literature and other sources.

Table 6.1 Modules and features of each model in the modelling suite

Model feature	*StageONE*	*StageTWO*	*StageTHREE*	*PhaseONE*
Pasture module	✓	✓	✓	
Animal module	✓		✓	✓
Soil module			✓	
Economic module		✓	✓	
Multiple enterprises	✓			
Heterogeneous animals				✓
Light data requirement	✓	✓		
Already validated	✓	✓	✓	✓
Fine temporal resolution			✓	
Dynamic			✓	
Optimisation		✓		✓

Table 6.2 Research questions suitable for each model in the modelling suite

Research question	*StageONE*	*StageTWO*	*StageTHREE*	*PhaseONE*
1. Livestock enterprise	✓	✓	✓	
2. Animal management		✓	✓	✓
3. Animal nutrition	✓	✓	✓	
4. Grassland management	✓		✓	
5. Infrastructure changes	✓		✓	
6. Government policies			✓	✓
7. Capacity building	Not suitable for modelling			

Figure 6.1 Initial windows of the OMMLP modelling platform for China

StageONE

The *StageONE* model (Takahashi, Jones & Kemp 2011) estimates the energy balance between feed supply and demand, using standard functions for sheep, goat and cattle nutrition (eds Freer, Dove & Nolan 2007; Freer, Moore & Donnelly 1997). This is a manual, steady-state model that needs monthly data on numbers and liveweights of livestock, and of grassland growth and digestibility for the desirable and less-desirable, but edible, species. The model is commonly used to check data collected on farms to see if it is consistent and sensible. Once the control condition is established, the model is used to investigate changing livestock practices and other components of feed supply and demand. The objective is often to minimise energy deficits through the year.

The *StageONE* model also calculates a gross margin for the livestock enterprise and greenhouse gas production using standard functions. The functions used in the model are those from the literature for sheep, which are also applied to goats. Cattle are converted to SE for analyses. This poses a few issues with calves, which can be managed provided the user remembers they are using sheep equivalents. However, as the main use is often to simply evaluate contrasting options and get a general idea of effects, rather than to get exact predictions, this strategy has been found to be satisfactory. Much of the data required can be obtained from interviews with herders and additional information local experts that have acquired. This model was developed using Excel and can be used without any specialised software. It is very useful for introducing people to modelling and regular users do not need much ongoing guidance. It has been widely used in the program reported in this monograph.

Professor Kemp (standing at the whiteboard), Dr Xu, Dr Yuan and Dr Wang (right) at the first workshop at Inner Mongolia Agricultural University to plan the *StageONE* model.
Photo: D.R. Kemp

StageTWO

This model is designed to evaluate farm enterprise options, including the financial responses to changes in stocking rates (Takahashi, Jones & Kemp 2011). *StageTWO* is a linear programming model that optimises the livestock, grassland, feed, crops, labour and other resources to maximise net farm financial returns. This model uses the same basic farm data as *StageONE* with some additional items. It is also a steady-state model for a typical farm in a typical year. A constraint in the model, arising from the linear programming tools used, is that animals are not allowed to lose weight. The interesting result is that, with this constraint, farm profitability generally exceeds the actual net income from traditional practices. This model was developed in Excel, but as the linear programming structure is large, it needs the Excel add-on 'What's Best' to function, or can be operated in the OMMLP platform.

StageTHREE

The *StageTHREE* SGM is a dynamic bioeconomic model that is designed to assess the long-run sustainability of grassland systems under climate uncertainty. It is discussed in more detail throughout this chapter. The current version of this model has been developed to incorporate cattle and a yak submodel for the evaluation of grassland management options on the Qinghai–Tibetan Plateau (Chapter 7; Liu 2017). The cattle and yak submodels are too complex to be used in the *StageONE* and *StageTWO* models. In those models, cattle and yaks are simulated by being converted to SEs, based on liveweights.

Dr Badgery (left) and Professor Behrendt (front row) at a workshop at Gansu Agricultural University to develop the models.
Photo: D.R. Kemp

PhaseONE

The *PhaseONE* model was developed from a different perspective. This model aims to identify the animals in a flock or herd that should be kept or culled (Takahashi et al. 2015). It requires measurements of the liveweight and condition of each animal in a flock or herd, plus financial information and estimates of how age and condition influence fecundity. The animals are ranked from highest net (financial) income/head to lowest net income/head. Graphical tools are provided to show the animals to keep and cull and there is an intermediary group for discussion that may be kept or culled. The principles in this model have proved to be a great educational tool for researchers. They have strongly supported the other models and experiments that showed a significant reduction in stocking rates was needed to achieve financial viability. Examples of its use are in Chapter 3.

Model usage

The first three models are regarded as an integrated set (Figure 6.2). *StageONE* is the easiest model to use and requires the minimal dataset. It is used to develop a 'typical' farm based on the averages, but removing anomalies. For example, if most farms had sheep but a few had some cattle, the SE for the cattle is estimated (so that stocking rates and other calculations remain valid) and the typical farm is considered to be only a sheep enterprise. It can then be used to quickly evaluate various livestock management options, especially their energy balance and nutrition. This was done when designing the farm demonstrations (Chapter 4). Once the options of interest have been narrowed down, the *StageTWO* model can evaluate the options in a more complex framework, with various constraints (e.g. land, labour, capital), to assess strategies for improving grasslands and herder household incomes. The better options can then be evaluated dynamically over time with the *StageTHREE* model, along with other complexities in grassland management, to assess their impact on the sustainability of the grassland system. These models have all been built as standalone units, but they share data and functions to address different questions.

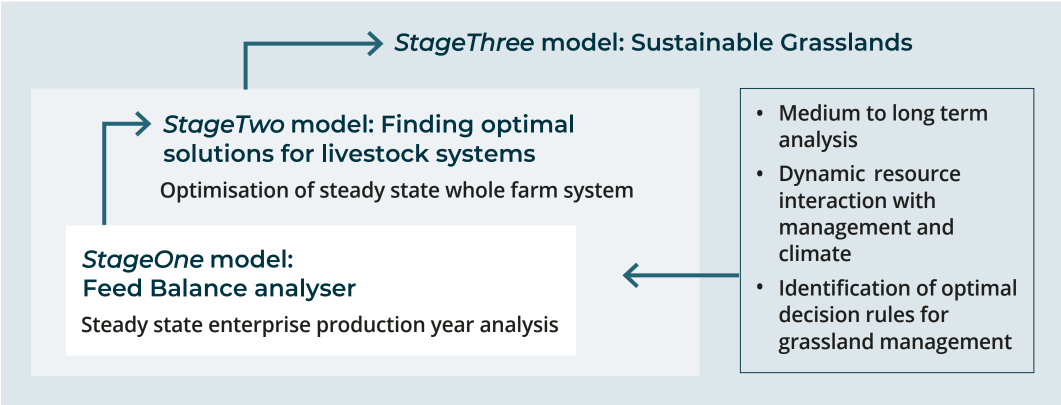

Figure 6.2 Integrated set of models for analysing the livestock–grassland system

StageTHREE sustainability modelling approach

The objective of the SGM was to develop a bioeconomic method that adequately models the dynamic nature of grassland resources and integrates climatic uncertainty. The methods developed needed to be capable of identifying the inter-temporal trade-offs between the management of the grassland resource for herder household welfare and the resulting productivity and environmental outcomes from the grazing system.

The specific objectives of the model are to:

- assess the impacts of different grassland management strategies on grassland condition, soil erosion, ecosystem services and herder household income
- analyse grassland management strategies over the medium to long term (10–50 years)
- account for the dynamic interaction of resource condition (grassland and soils) with management (livestock production system, stocking rate and supplementary feeding) and climate.

The bioeconomic framework that has been developed is unique in that it considers the impact of embedded climate risk, technology application and management on the botanical composition of the grassland resource over time, which in turn impacts on the economics and environmental outcomes of different strategies (Figure 6.3). It is a dynamic model of the interaction of resource condition (grassland and soils) with management (livestock production system, including sheep, goats, cattle and yaks, stocking rate and supplementary feeding) and climate risk. The *StageTHREE* SGM operates as a simulation model that is executed for each nominated grazing area (field or paddock) level on a daily time step and contains 11 submodels accounting for grassland dry matter digestibility (DMD); herd/flock structure, size and culling; supplementary feeding policies; growth, production and state variables for each age cohort of females, male progeny and breeding males; growth indexes and grassland growth; deep soil water drainage and rainfall run-off; and soil erosion from wind and water run-off. Grassland composition and soil depth/fertility submodels predict changes at an annual time step. Livestock production and system externalities are aggregated to determine the environmental, economic and financial performance of the system at the enterprise and whole-farm level.

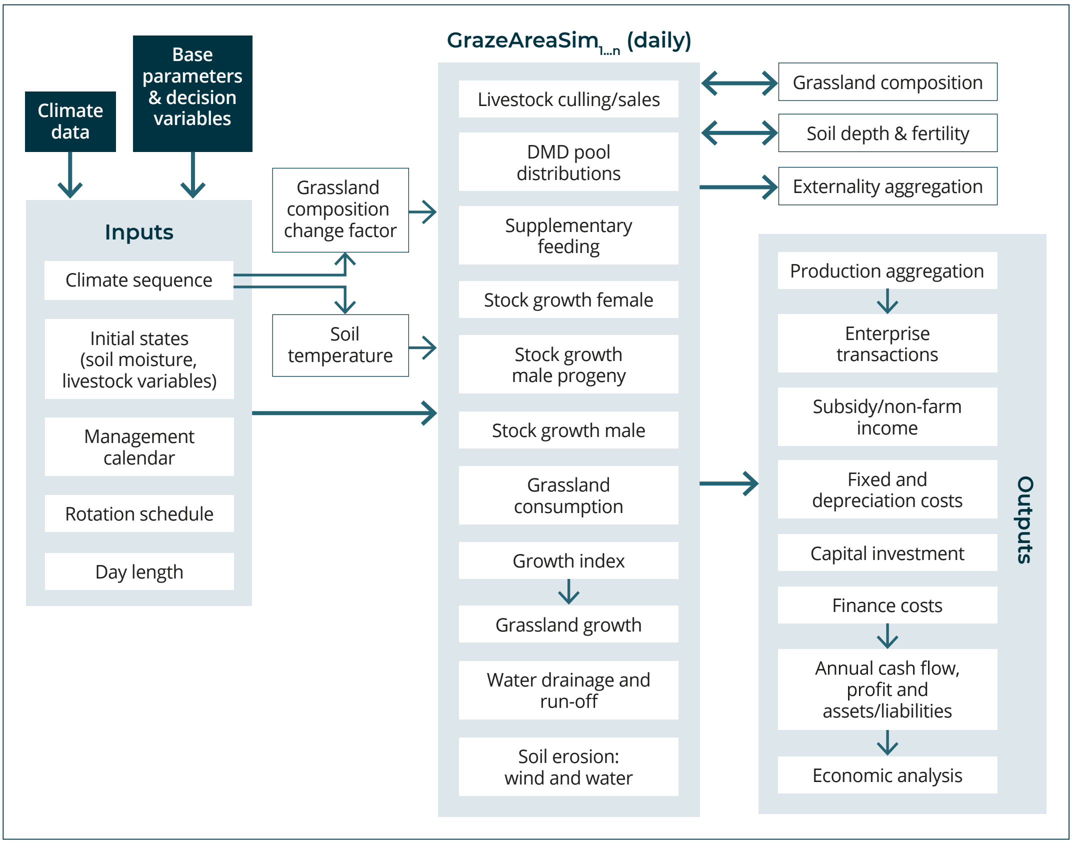

Figure 6.3 *StageTHREE* SGM simulation framework

The additional data required for the customisation and running of the model include soil fertility change over time and its interaction with soil erosion from wind and water; grassland growth and digestibility parameters; long-term daily climate data (temperature, wind speed, precipitation and relative humidity); dynamics of changes in grassland botanical composition under different management practices, soil conditions and climate; and livestock production in relation to grassland quantity and quality. The model is capable of running in a deterministic mode (a single year type being repeated) and a stochastic mode (either a single run of randomly selected climate years or a selected number of iterations of randomly selected climate year sequences) to test the impacts of a range of decision variables (such as flock/herd size, supplementary feeding rules, output price variability, management systems, etc.) on system performance.

The *StageTHREE* SGM has been developed using Matlab (Mathworks 2017) and some specialised additional tools. A runtime version is available (Figure 6.4) that can be used independently of the specialised software and full model specifications and functionality are available from K. Behrendt. Monte Carlo simulation procedures, which draw upon randomised annual sequences of daily climate data, are used to evaluate a range of policies for managing Chinese and Australian grasslands. This descriptive simulation framework is used to investigate the expected production and environmental outcomes, and economic performance and risks associated with different technologies and grassland management policies over 10–50-year planning horizons.

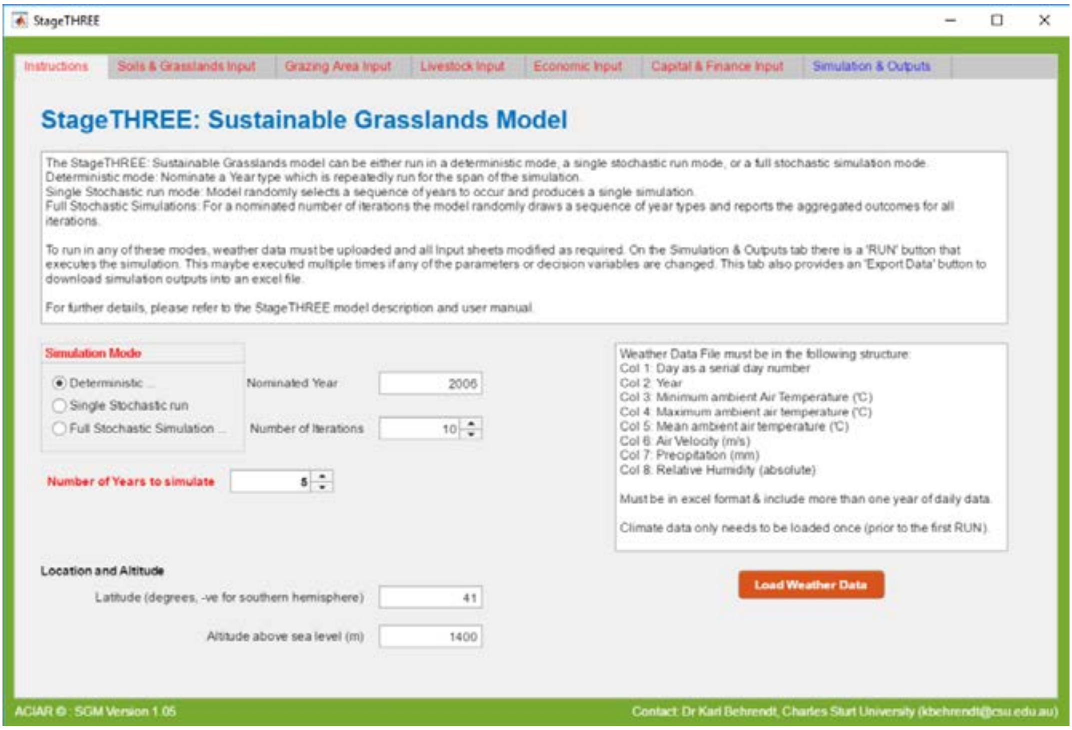

Figure 6.4 Runtime version of *StageTHREE* SGM

Modelling botanical composition of the grassland resource

Changes in plant composition are often the first signs of degradation (Chapter 8). In mechanistic grassland or crop models, plant composition is generally modelled on the assumption of competitive interference for resources such as water, light and nutrients. The limitation of applying this method to grassland resource management is that it does not cope well with simulating more than two competing species. Few models have ever been developed that do this with some success, and where they do it is for very specific circumstances. There is also the underlying assumption in some models that species persist indefinitely and homogenously occupy space within the sward. Rather than modelling explicitly how plants interact, the response of plants to changes in their environment can be represented by the net ability of a group of plants to capture resources and compete (Kemp & King 2001). For decision-making, the modelled changes in botanical composition need to respond over the long term and represent the changes in the basal area of competing species, especially in response to sporadic events such as droughts (Jones, Jones & McDonald 1995).

The empirical grassland composition submodel within the *StageTHREE* SGM adapts the method proposed by Loewer (1998) on the use of partial paddocks. In Loewer's GRAZE model, it is assumed that each species is uniformly distributed throughout a paddock and that the initial area they occupy remains fixed. However, the dry matter availability of each species is varied through selective grazing (driven by differences in forage quality) and independent species growth, with the regrowth of these species then dependent upon the residual biomass at any one time. In the *StageTHREE* SGM, the space occupied by species is assumed to be variable and to respond to climate, management, inputs and the state of soil resources. This enables the cycle of grassland degradation to very low populations of desirable species to be modelled adequately. This then enables the potentially positive response of the grassland resource condition to tactical grazing management, production system modification, supplementary feeding and/or fertiliser inputs to be modelled.

This empirical modelling approach is analogous with in-field measures of basal areas of grassland species and is similar to the methods of basal area adjustments applied in some rangeland models (Stafford Smith et al. 1995). Separation of grassland yield and basal area of different species groups is justified, as basal area provides a more meaningful and stable indicator of ecological or botanical composition change than grassland yield (Cook, Lazenby & Blair 1978).

The population of desirable species in the sward is modelled by using differential equations describing population growth and the impact of harvesting (determined by the consumption rate of the desirable component of the grassland). The value of the livestock impact parameter reflects the sensitivity of botanical composition change to consumption rate and species phenology. These represent the grassland resource as an exploitable renewable resource as described by Clark (1990). In the grassland composition submodel, a logistic growth model is used for regeneration of desirable species with the rate of change influenced by both a soil fertility factor (which is influenced by inputs such as fertiliser and soil erosion) and an annual rainfall factor using stochastic multipliers (Cacho, Bywater & Dillon 1999). This empirical method adapts the concepts of state and transition models of rangelands (Westoby, Walker & Noy-Meir 1989) with the benefit of an indefinite number of grassland states and responses to climate, management and input factors. The modified partial paddock approach developed allows the desirable components within the sward to increase their basal area over time. The spatial measure of grassland composition in the model is similar to basal measurements common in agronomic experiments (Whalley & Hardy 2000).

In the model, two grassland populations are defined. They represent desirable and less-desirable species groups, which are the key groups of interest to herders, farmers and officials. The two groups may have different growth parameters, different responses to soil fertility and different dry matter digestibilities. All these factors combine to influence the potential carrying capacity and livestock production from the system. This process allows the expression of changes in the quality of the grassland resource in response to changes in grassland composition and the total amount of herbage available to grazing livestock.

Modelling grassland growth

There are several mechanistic grassland growth models available (Thornley & France 2007) as well as single function models that account for net grassland production (Woodward 1998). Previous studies and reviews have shown that simple models of grassland growth may adequately represent the changes in net grassland production (Behrendt, Cacho et al. 2013; Behrendt, Scott et al. 2013; Cacho 1993). These simpler models may be adequate for making management decisions when they provide dynamic descriptions of the key variables used in predicting changes in production (Woodward 1998). An equation that relates grassland growth to grassland mass, LAI or height, coupled with descriptions of monthly changes in grassland quality (DMD), is all that is required in the SGM model, as the animal–plant–resource interactions are the main concern in the simulation model.

Using a modification of the growth index method, originally proposed by Fitzpatrick and Nix (1970), the effects of daily temperature (air and soil), solar radiation and soil moisture on plant growth controls and interacts with a sigmoidal grassland growth function (Cacho 1993) in the SGM (Behrendt et al. 2018; Liu 2017). In these submodels, the growth of desirable and less-desirable species is modelled independently of the area being occupied, as the grazing area is assumed to be homogenous in microclimate, soil type and fertility. At a grazing area (field) level, soil water balance and dynamics are modelled using the capacitance approach described by Johnson (2013), which also links to rate of soil formation through deep drainage and soil erosion through run-off. The proportional distribution of biomass to each of the digestibility pools is based on a modification of the equations described by Freer et al. (1997) and the *StageTHREE* SGM models the DMD pool distribution for desirable and less-desirable species at monthly intervals, although the aggregated biomass within these pools are available to grazing livestock for consumption through selective grazing. In combination, this allows the effective representation of differences in both the productive capacity and quality of desirable and less-desirable species to be more rigorously expressed in its influence on livestock production, especially as the state of the grassland resource changes in response to climate and management over the long term. The grassland growth submodel is parameterised using the developed GGC tool that utilises biomass and daily climate data throughout a growing season and across multiple years.

Modelling livestock performance

To adequately represent the production of wool and meat, the livestock submodels need to be capable of responding to changes in the available grassland mass and changes in botanical composition with its inherent effect on feed quality. A more mechanistic approach was taken in developing the livestock submodels. The livestock submodels are based on many of the equations described by Freer, Dove and Nolan (eds 2007) and Freer et al. (1997). These publications represent a revised version of the original report by SCA (1990) and fundamentally describe the functions used in the GrazPlan suite of decision support tools (Donnelly, Moore & Freer 1997; Moore, Donnelly & Freer 1997), which have been broadly applied and shown to adequately predict ruminant livestock performance under diverse environments. This was required to ensure there were adequate feedback mechanisms between the selective grazing by livestock and changes in botanical composition, grassland quantity and growth. The framework has been developed for the modelling of sheep, goat, cattle and yak production systems.

For each livestock species, three types of animals are modelled: females, males for breeding, and castrated or non-castrated males not used for breeding that are the progeny of the females. For breeding females and non-breeding males, an unlimited number of age cohorts can be modelled with differing selling and supplementary feeding policies applicable across different age cohorts. In these submodels, grazing livestock are capable of selectively grazing between the digestibility pools of total combined dry matter available to them from each partial paddock. This selective grazing assumes that grazing ruminants will aim to maximise their intake based on the DMD of plants. To estimate the actual dry matter intake of grazing livestock and the digestibility of their diets from the dry matter available in each digestibility pool, the model assumes that the animal attempts to consume its potential intake from each pool from the highest to lowest digestibility in succession. The ability of animals to select from each pool is related to the quantity of dry matter in each pool and its digestibility. The more an animal satisfies its potential intake from a higher digestibility pool, the less will be consumed from the lower digestibility pools,, resulting in an increase in less-desirable species. The substitutional effect of feeding supplements on grassland dry matter intake, as well as its impact on diet digestibility and energy consumption for livestock maintenance and production, is accounted for. The grassland consumption from the desirable and less-desirable components are assumed to be evenly distributed throughout the grazing area, depending on the weighted consumption from the digestibility pools and the proportion of the grazing area occupied by desirable and less-desirable species groups. Such models, which base diet selection between species or species groups on the digestibility of the dry matter, have been validated by research into the influence of grassland degradation on diet selection and livestock production (Chen et al. 2002).

Flock structure has been accounted for through the modelling of flock and herd structures and dynamics using a daily state flow model with up to 15 age cohorts available. It allows for all daily state variables relating to age (in days), bodyweights, fleece/hair weights, reproductive rates and foetus weights to be carried between age cohorts and across multiple years. The number of individuals in each age cohort is determined by reproductive and mortality rates, purchasing and selling policies.

One of the most significant direct externalities from grazing ruminant livestock is the production of greenhouse gases, particularly methane from rumination. To determine the capacity of system management and the use of grassland resources to reduce the intensity of methane outputs from ruminant livestock production (i.e. the units of methane per unit of animal product), Intergovernmental Panel on Climate Change (IPCC) Tier 2 functions (Dong et al. 2006) have been embedded into the *StageTHREE* SGM. These functions predict the amount of methane produced from the whole farming system and the emission intensity for meat production.

Modelling soil erosion

The combined loss of soil through wind and water erosion processes have been determined through a combination of empirical and process base models that utilise daily weather data. The estimation of wind erosion is based on a combination of a process-based model to determine saltation, and an empirical model to determine the vertical flux of dust emissions into the atmosphere. These are calculated using the process-based models of Shao, Raupach and Leys (1996), Lu and Shao (2001) and applied as adapted by Kang et al. (2011). The estimation of soil erosion due to rainfall run-off is modelled using the Revised Universal Soil Loss Equation as defined by Littleboy et al. (1999). The combined total loss of soil is expressed through changes in soil mass, which is offset by the rate of soil formation. The rate of soil formation relates to the amount of deep soil water drainage and is estimated using the method described by Wakatsuki and Rasyidin (1992) and utilises an approach of chemical weathering and mass balance accounting (Minasny, McBratney & Salvador-Blanes 2008). The ratio of soil mass to initial soil mass defines the soil fertility index, which allows for soils to either increase or decrease in depth and fertility depending on the rate of soil mass change.

Modelling household economics

To understand the expected economic and financial performance of herder households, a whole-farm system approach is required. Typically, the economic analysis of farming systems in this type of research has only considered the analysis to a gross margin level, usually on a unit area basis. Although this provides useful information on the variability of enterprise returns, it provides little information on the impact of such variability on whole-farm system performance and resource use from a community perspective. A whole-farm system approach considers the cumulative effect of enterprise and system performance on a herder's cash flow, profitability and wealth over the long term.

The approach applied in the *StageTHREE* SGM follows the standard method of analysing whole-farm financial and economic performance described in Behrendt, Malcolm and Jackson (2014) and Malcolm, Makeham and Wright (2005). The whole-farm financial and economic submodel operates at daily, annual and planning horizon intervals. It uses the biophysical outputs to calculate enterprise income, cash costs and gross margins. The cumulative net flows of cash from enterprises (i.e. net of variable costs) and assets interact with whole-farm fixed and financial costs to determine a range of financial key performance indicators that measure profitability, efficiency and viability. Daily cash inflows and outflows are extracted (including the value of initial capital invested by herders and its salvage value, which predominantly represents livestock assets and small plant and equipment) to undertake the economic analysis of the farming systems through commonly used investment analysis techniques, such as net present value (NPV).

To provide insights into both household financial and economic measures that may be of interest to herders and policymakers alike, the *StageTHREE* SGM reports and aggregates economic data at multiple levels. At the herder household level, the operating cash margin (OCM) represents the cash flow of a herder household before the costs of any financing are considered (i.e. they are assumed to be at full equity) and may be aggregated at different intervals (e.g. annual) to indicate operating cash flow variability. Any volatility in the OCM represents business risk and accounts for any variability in the production of outputs, the use of inputs and their respective values. Key assumptions in the derivation of the OCM is that it allows for both the cost of the herder's family labour (e.g. education, medical and other household expenses) and the cost of owning machinery.

Whole-farm financial and economic performance is analysed on both an annual and multi-year basis. Each simulation is initiated using a common opening balance sheet (i.e. consistent opening assets and long-term liabilities between all simulations of a specified farming system) into which the OCM is integrated to produce long-term net cash flows, profit and loss statements and balance sheets. Any potential costs of financing the herder household through the cash account, as well as existing liabilities, is calculated sequentially at a daily intervals. Additionally, any subsidy payments or other income received adds to the cash flow of the whole system. From this data, further measures of both herder household financial performance and system economic performance can be examined at annual (e.g. returns on assets or equity) or planning horizon intervals (e.g. NPV as an annuity). At this whole-farm system level of analysis, the variability in outcome accounts for both business and financial risk, and can provide insights into whole-system economic performance for policy planning.

Managing the desert steppe for sustainable livestock production

The *StageTHREE* SGM was used to evaluate current and alternative stocking rates on the desert steppe in Siziwang, IMAR (Figure 6.5). Further details on this region can be found in Chapters 2, 4, 5 and 8. This area is north of the Yellow River and shares the Mongolian Plateau with Mongolia. Altitude is around 1,400 m and annual precipitation is around 250–300 mm. Rainfall is predominantly distributed during the summer months. Average daily maximum and minimum temperatures range from 29 °C to –20 °C (Figure 6.6). Research has shown that IMAR is a primary source of dust storms for the populated areas of eastern China, including Beijing (Liu et al. 2004), with dust at times extending to Korea and Japan. Overgrazing has been a primary factor in driving grassland degradation (Chapter 2). Grassland degradation and gradual desertification is contributing to the increased incidence of dust storms and reduced air quality both locally and in populated urban areas.

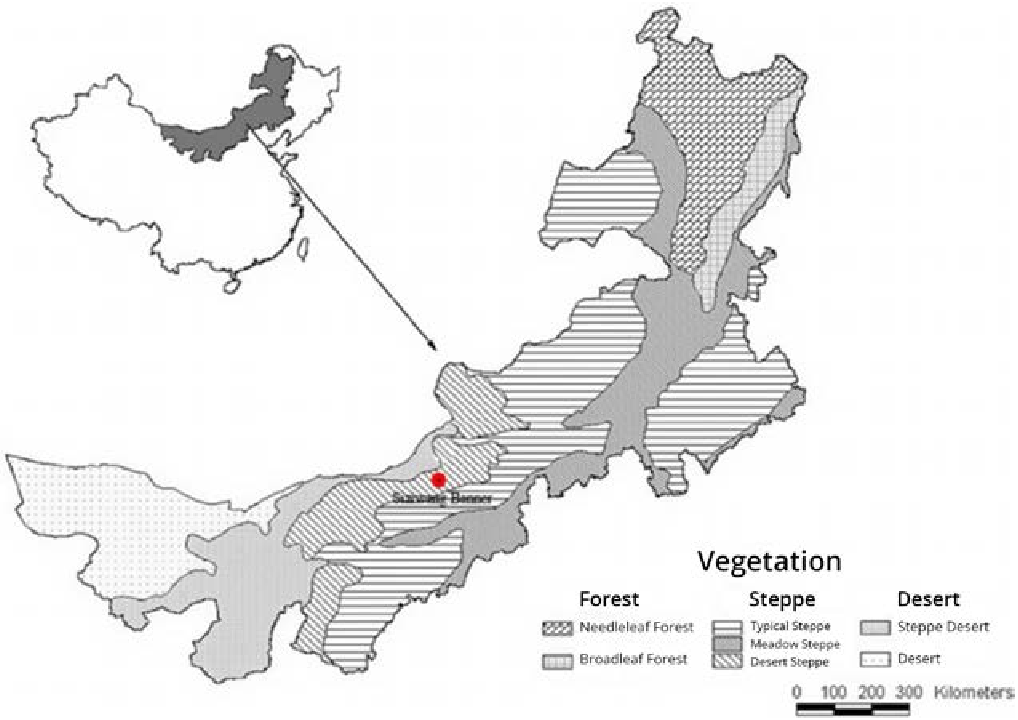

Figure 6.5 Vegetation and location of the IMAR case study

Source: Li et al. (2015)

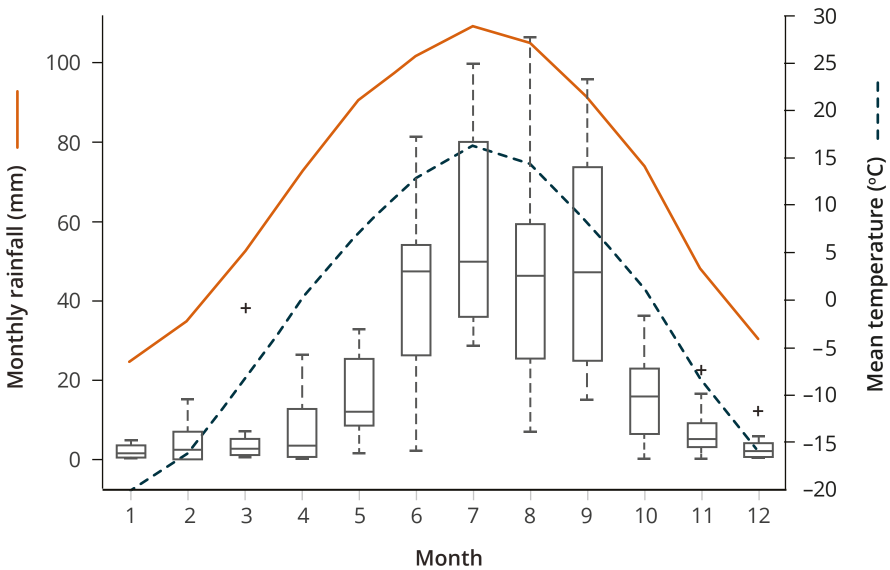

Figure 6.6 Climate of Siziwang, IMAR

Note: Rainfall distribution = boxplot, average maximum temperature = solid red line, minimum temperature = dashed blue line

Sheep, goats, cattle and camels are grazed on summer and winter grasslands. The summer grazing areas are often leased areas with an aggregation of livestock from several households, while the winter areas are allocated to individual households. In this application of the *StageTHREE* SGM, long-run stochastic simulations based on a variable climate (over 10 years) were used to analyse the effects of currently observed stocking rates on herder economics, grasslands and livestock. The stocking rate was varied between 50 and 750 ewes, with the flock having access to 320 ha of winter grazing (starting 28 October for 185 days), and 200 ha of summer grazing (starting 1 May for 180 days). These areas are based on survey data. As animal numbers were automatically varied within the model to maintain a specified level of target females, in part depending upon seasonal conditions and predicted animal performance, this resulted in a range of median stocking rates from approximately 0.1 SE/ha to 1.1 SE/ha. Using the *StageTHREE* SGM model, various new flock sizes were tested, with a typical herder (starting with around 370 animals/320 females) adjusting their flock size to a new level that was maintained over the simulated 10-year period. There is survey evidence to suggest that many herders aim to maintain in excess of 450 adult sheep (400 females or a stocking rate of > 0.7 SE/ha assuming a grazing area of 520 ha) in an attempt to satisfy personal and family requirements (see Chapter 5 for an analysis of this issue). As shown in Chapter 2, the current stocking rates in this region have been reduced from 2 SE to 0.8 SE in response to the program outlined in this monograph.

The model was calibrated using local farm surveys and measurements of grassland and animal productivity. The grassland data, including grassland composition change, was based on experimental data from the Siziwang experimental farm (Inner Mongolia Agricultural University) that has continuously run a grazing experiment since 2004 (Chapter 8). The emphasis is on sheep production, as that is the more profitable and prominent enterprise for the region. A key issue in many parts of China in identifying a more sustainable stocking rate is the risk associated with climate variability, which has been embedded into the model through importing regional climate time-series data.

To define a sustainably optimal stocking rate, the analysis considers the impact of different stocking rates on production, long-term economics and the environment within which the grazing system operates. The *StageTHREE* SGM predicts changes in grassland resource condition (defined as both the amount of grassland biomass and plant composition), soil erosion (caused by both wind and water), livestock production, greenhouse gas emissions (methane emissions) and economics (short- and long-term).

Grassland condition and environmental impacts

The condition of a grassland resource and its management is evident in the mean biomass over each year for each simulated stocking rate for both winter and summer grazing areas (Figure 6.7). The data highlights the difference between the two grazing areas, and indicates that summer grazing maintained the lowest biomass/ground cover. Additionally, with increasing stocking rates, the summer grazing area had decreasing amounts of biomass/ground cover. The winter grazing area also had a declining biomass, but to a lesser extent than the summer grazing area. This has both impacts on long-term grassland composition and the amount of soil erosion.

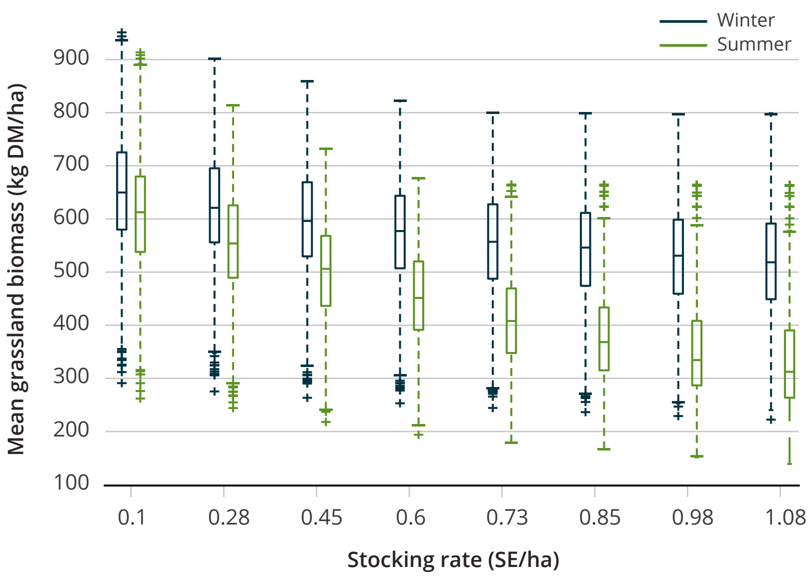

Figure 6.7 Mean annual grassland biomass for winter and summer grazing areas across the tested stocking rates, Siziwang

The predicted ratio of desirable species to less-desirable species at the end of the 10-year simulation period remained around 1:1 (Figure 6.8), the starting ratio for these simulations, when the stocking rate averaged 0.6 SE/ha. At lower stocking rates, the desirables increased, while at higher stocking rates the desirable species became the minor component. These effects are what would be expected, as shown by the experimental results for the desert steppe and typical steppe (Chapters 8 and 9). In the desert steppe grazing experiment, where there were two main species (neither of which was ideal), the best result was with a ratio of approximately 1:1. Over a longer period, it could be possible to achieve a result similar to this simulation. In the desert steppe experiment, the lowest stocking rate was still approximately 1 SE/ha. Another *Stipa* species of higher nutritive value has been invading the light and nil grazing treatments. Over time, this species could become important. Where the desirable species was of better quality than *Artemisia*, as shown with the typical steppe grazing experiment (Chapter 9), higher ratios would be possible (e.g. 10:1 or better). The outcome depends upon the basic relationships set in the model. Indicatively, in most grasslands, a ratio in the vicinity of 2–3:1 is arguably optimal and balances the energy provided by desirable and less-desirable components, the need for resource use (i.e. the harvesting of the desirable components for livestock production and working with a grassland that is not pristine) and the persistence of the desirable component within the grasslands. This is only maintained at stocking rates of less than 0.45 SE/ha.

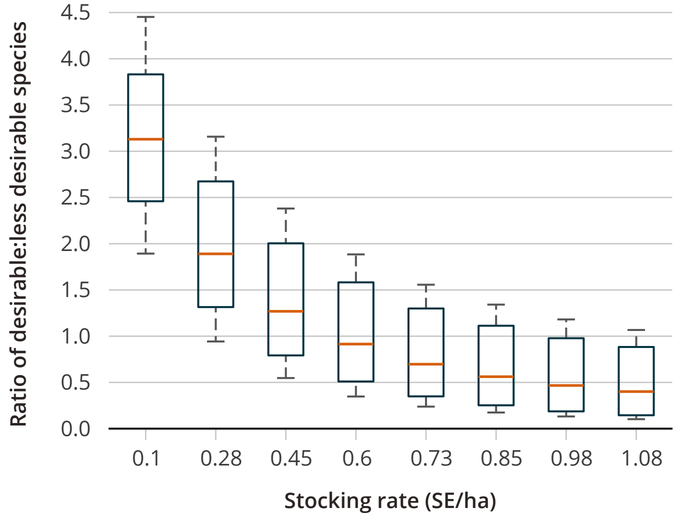

Figure 6.8 Ratio of desirable to less-desirable species at the end of the simulation period across the tested stocking rates, Siziwang

The resulting ratio of desirable to less-desirable species and its range of potential outcomes is largely driven by the interaction between the stocking rate and the effect of climate variability on grassland growth. In the modelled scenarios, stocking rates are strategically set. The number of animals only vary seasonally in accordance with local breeding and selling policies. Figure 6.9 indicates the relationship between mean consumption rate (the proportion of total grassland biomass consumed by livestock) and the final proportion of desirables in the grassland at the end of the 10-year simulation period. When the consumption rate was < 20%, the proportion of desirables was > 50%. Experience in Australia (Dowling et al. 2006) suggests that the desirable species need to be > 60% of the total biomass to effectively exert competitive pressures on the less desirable components and optimise animal productivity. This level was achieved when the mean consumption rate was < 12%. The Siziwang grazing experiment showed that a 10% consumption rate was optimal for sustaining the grassland and livestock production (Chapter 8). At that rate, these simulations predict that the desirables would be about two-thirds the total biomass. A 2:1 ratio occurred at a stocking rate of 0.28 SE/ha (Figure 6.8). This was lower than the light stocking rate testing in the desert steppe grazing experiment (Chapter 8), but could be reasonable as local herders have now been aiming for stocking rates of that order (Chapter 2).

Figure 6.9 highlights the difference in consumption rates between winter and summer grazing pastures. For the same flock size, the higher cluster of data towards the top left corner of the figure indicates the consumption rate and resulting proportion of desirables in the winter grazing areas. For example, at a flock size of 250 females, the winter grazing area is centred on a proportion of 65% desirables (often required to create a competitive environment where these species can remain the dominant component, Dowling et al. 2006) under a consumption rate of 10%, whereas the summer grazing area is centred on a proportion of 40% desirables and a consumption rate of 23%. This highlights the importance of both grazing duration and timing on resulting grassland condition.

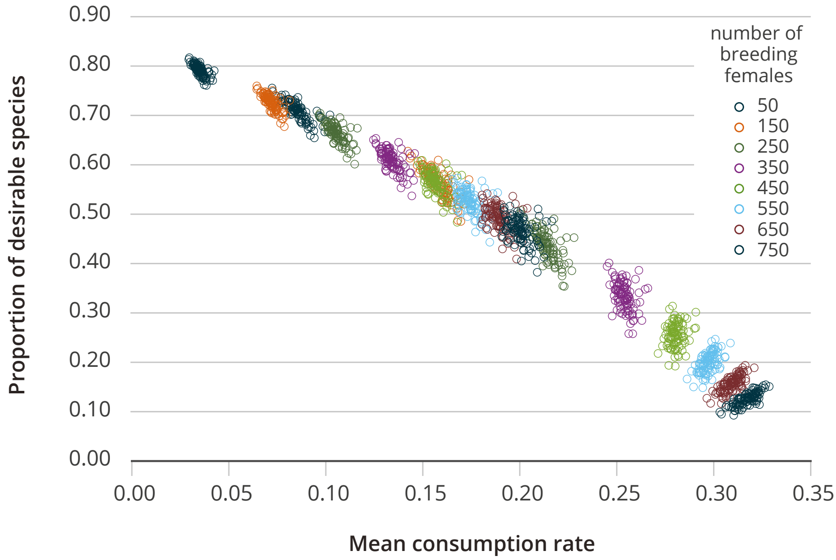

Figure 6.9 Mean consumption rate vs final proportion of desirable species in the grassland across the tested stocking rates, Siziwang

With decreasing biomass/ground cover under increasing grazing pressure (Figure 6.7) there is also a clear impact on total soil erosion. Figure 6.10 indicates the predicted amount of cumulative soil erosion over each 10-year simulation period for both summer and winter grazing areas in relation to the tested stocking rates. The modelling results indicate that both winter and summer grazing areas have increased rates of soil erosion with increasing stocking rates, and that summer grazing areas will be impacted more than winter grazing areas. The earlier consideration of the stocking rate to maintain consumption at 10% and the ratio of desirables to less-desirables at 2:1 indicated the optimum to be around 0.28 SE/ha. At that stocking rate, the average grassland biomass was approximately 0.6 t of dry matter per ha, similar to the sustainable values estimated in the Siziwang grazing experiment (Chapter 8). The annual soil loss was averaging approximately 6–7 t/ha for winter and summer grazing areas respectively. In the desert steppe, the grassland biomass never gets close to complete ground cover and some soil erosion is inevitable. At the lowest stocking rate tested (0.1 SE/ha), the estimated average soil erosion rate was still 5–6 t/ha each year. When stocking rates are greater than 0.45 SE/ha, soil erosion becomes significantly greater than the base rate—approximately 7–8 t/ha each year over 10 years for winter areas (33–40% increase) and 10–17 t/ha each year for summer grazing areas (100–280% increase).

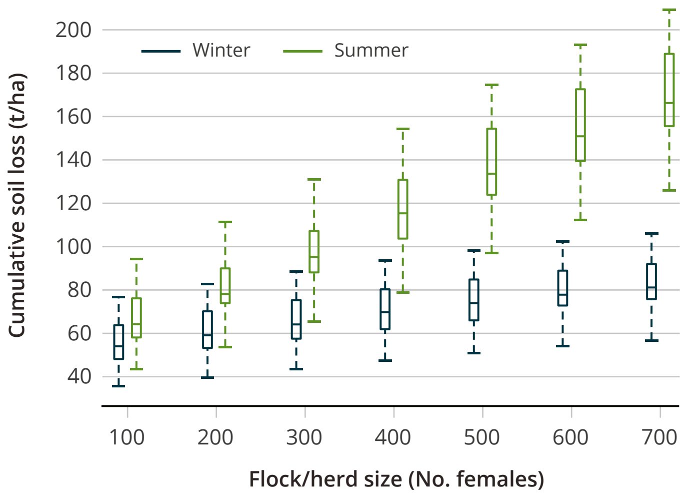

Figure 6.10 Cumulative soil loss per hectare over the 10-year simulation period for winter and summer grazing areas across the tested stocking rates, Siziwang

Any increases in flock size by herders leads to an expected increased incidence of dust storms, as stocking rates would need to be at least halved to manage the plant species composition and achieve a significant reduction in the erosion risk. Additionally, the typically leased summer grazing areas will degrade at a much faster rate than the herder-managed (entitled) winter grazing areas. Various strategies could be adopted to improve grassland management and change the consumption rates on grazing areas, such as increasing the area of summer grazing that herders can use, delaying the onset of summer grazing until adequate ground cover is reached (as most dust storms are in spring), increased supplementary feeding in winter to reduce demand on the grassland, or adjusting the area, ratio and duration of grazing between summer to winter grazing areas.

The intensity of greenhouse gas emissions, such as methane produced per kg of sheep meat produced, reflects the efficiency of production from grasslands in regard to minimising such externalities. At lower stocking rates, not only are total emissions about one-third lower than at the higher stocking rates, the externalities from meat production are also reduced. As would be expected, it is not possible to eliminate the externalities related to greenhouse gas emissions, but it is possible to minimise them.

Livestock production and economics

Meat production per hectare shows a diminishing gain at increasing risk with increasing stocking rate (Figure 6.11a), while production per head showed a linear decline with increasing stocking rate (Figure 6.11b) as found in the grazing experiment (Chapter 8). At low stocking rates, the median production per head was 50% greater than at high stocking rates. There was more variability at low stocking rates, reflecting the response to good seasons, which did not occur at high stocking rates. Additionally, as would be expected, production per hectare showed a curvilinear response—as flock size (i.e. stocking rate) increases, the marginal gain in production per extra animal decreases.

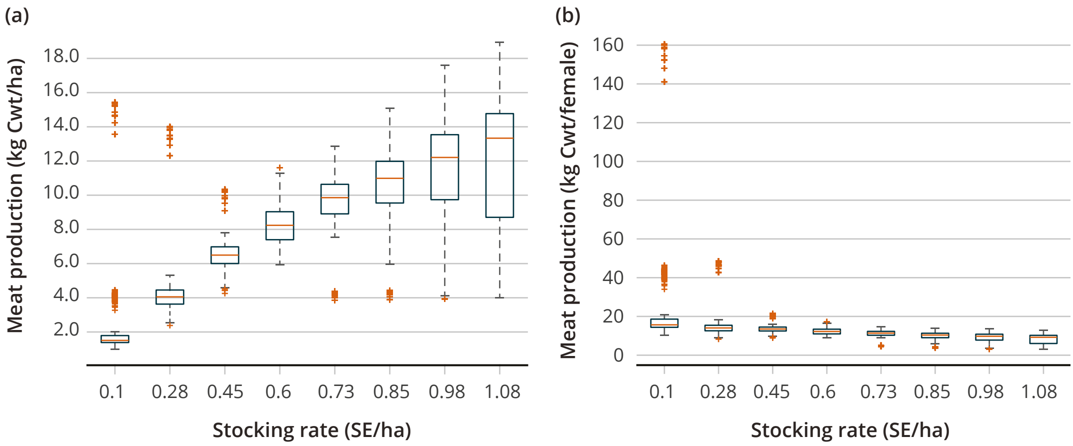

Figure 6.11 Meat production per (a) hectare and (b) head across the tested stocking rates, Siziwang

When the economics at an expected gross margin level are considered (i.e. risk-neutral), the optimal stocking rate (or flock size) would be in the vicinity of 0.6 SE/ha on a per hectare basis (Figure 6.12a) and 0.1 SE/ha on a per head basis (Figure 6.12b). Variability in gross margins per hectare clearly increased with stocking rates, emphasising the increased farm risk. At all stocking rates, the gross margins were negative in some years, although the proportion of negative gross margin years declined with lower stocking rates. From a risk-efficiency perspective, it would be illogical for herders to increase their flock size beyond 0.6 SE/ha (350 females), as median gross margin per hectare declines and the associated risks increase.

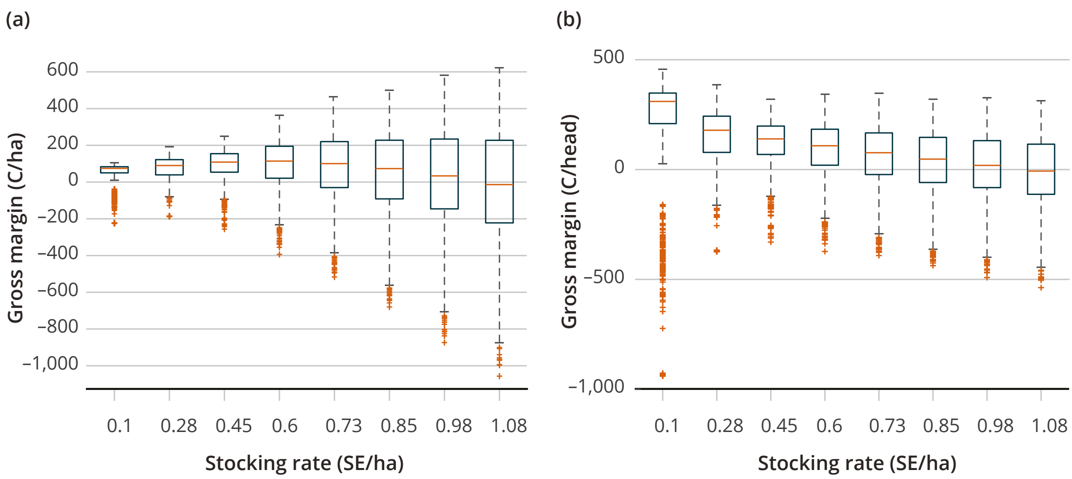

Figure 6.12 Gross margins per (a) hectare and (b) head across the tested stocking rates, Siziwang

Gross margins reflect the short-term income levels that herders would perceive and that would probably be the basis for many of their decisions. However, NPV and household cash flows are better measures, as they give a medium–long term view of the herders' economic performance. To represent the long-term economic returns of herders over the 10-year simulation period, NPV as annuity (NPVa) expresses the annual equivalent of all future cash flows and asset values in today's currency terms. The highest NPVa values with the lowest amount of risk are achieved at the lower stocking rates (< 0.3 SE/ha) (Figure 6.13). This is partly a function of capital gain from the sale of surplus livestock under the lower flock size scenarios, and more stable incomes under lower stocking rates (as depicted by gross margins in Figure 6.12). If herders chose to move to smaller flocks, with more accurate selection of productive animals, it would be possible to further increase future gross margins (Takahashi et al. 2015). The fact that the NPVa is negative at all flock sizes indicates the overall series of net cash flows are lower than the applied conservative discount rate (2%).

Cumulative herder household cash flows indicate that herders achieve the highest median cumulative cash flows at a stocking rate of 0.45 SE/ha (250 breeding females). Given the lower NPVa values and lower cumulative cash flows with more risk at higher stocking rates, it should be illogical for herders to seek larger flock sizes, unless they had more land available and could reduce stocking rates (Chapter 4). The net cash position indicates that the typical herder may not be sustainable without seeking other forms of income or changing the scale of operations. In Figure 6.13b all median cash flows were negative, which may not be a true reflection of the herder households' position in practice, as it was not possible to determine which assets and other costs (e.g. fodder, livestock, sheds, housing, fencing etc.) had been subsidised. The values estimated reflect the combined economic position of herders, excluding government financial support. However, the pattern shown is likely to be reasonably true, with the lower stocking rates generating the higher returns. The modelled negative cash flows align with the anecdotal evidence in the farm surveys that most herders borrow money each year in order to survive, not just in bad years (Chapter 5).

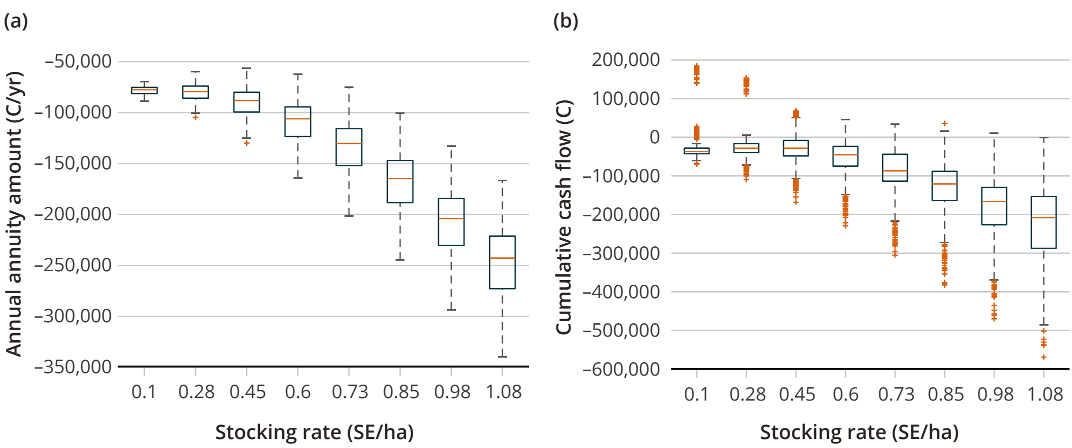

Figure 6.13 (a) NPV as an annuity and (b) cumulative herder household cash flow across the tested stocking rates, Siziwang

Following on from earlier theoretical work in this ACIAR program (Kemp et al. 2011), Figure 6.14 indicates the expected responses and variability in outcomes for both production per head and per hectare, and gross margin and NPVa per hectare across the range of stocking rates tested. The results indicate that, with an increasing stocking rate, both measures of production per head and economics decline, although production per hectare initially shows a small increase. However, the rate of increase in production per hectare does not lead to higher profitability or economic outcomes for households. Herders in the desert steppe would be better off reducing their number of animals and overall stocking rate by around 20–25% (from current reduced rates, Chapter 2) to achieve higher long-term economic returns with less risk (volatility of production and returns). Based on risk-efficiency concepts, this data again confirms that it would be illogical for herders to maintain current or higher numbers of animals, as they are more likely to have lower economic returns and higher risk, unless they had more land and stocking rates could be reduced.

These analyses support the outcomes of farm surveys. They show that, while the gross margins were positive, herders can survive but in general they do not consider herding to be a longer-term viable option. That position becomes clearer when considering the NPVa and cash flow results. However, these simulations do show that higher financial gains would probably be achieved through lower stocking rates, which would help reduce environmental impacts and rehabilitate the grasslands.

A crucial issue is the development of more suitable ways for herders who remain in the industry to increase their farm size and have at least medium-term control over the land they use to encourage better management. Larger flock sizes are a useful way to improve incomes, but without increasing stocking rates. Herder households would also benefit from aiming to have better livestock genetics, feeding animals more effectively, having better marketing systems in place to enable them to receive higher prices, seeking to increase scale by acquiring access to more grassland and seeking more off-farm income.

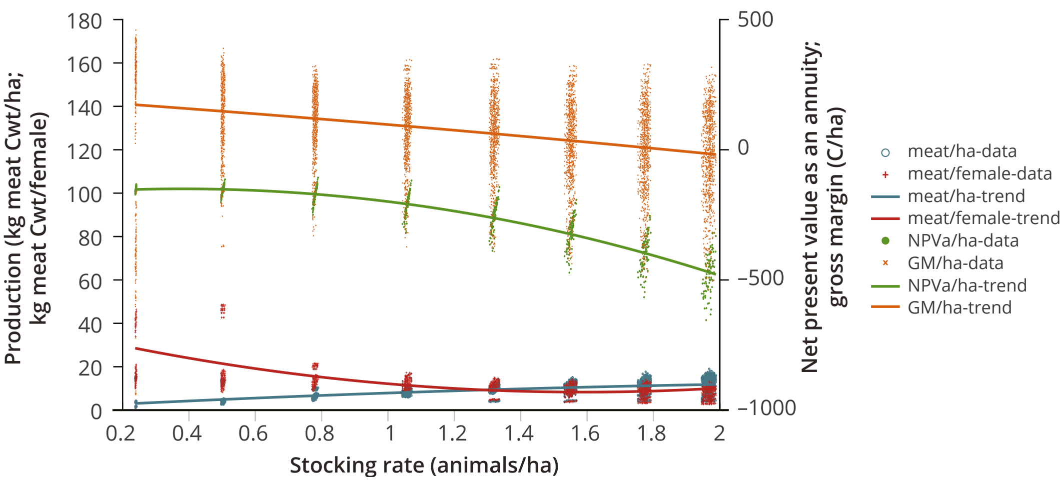

Figure 6.14 Individual iterations and trends for meat production per hectare, meat production per female, gross margin per hectare, and NPVa per hectare across the tested stocking rates, Siziwang

Conclusion

Components of the *StageTHREE* SGM have been developed to meet the need for modelling a dynamic grassland resource under stochastic climatic conditions over the long term. The model captures the predominant interactions between the production and persistence of the desirable components of grasslands, and that of grazing livestock harvesting the grassland resource. The modelling of interactions between botanical composition in grasslands, their productivity and the expected livestock production, externalities and subsequent economic returns, is unique. This model has the capacity to adequately test a range of tactical and strategic decisions available to herders. The *StageTHREE* SGM can develop insights into the expected range of outcomes from changes in how herders manage and interact with grasslands. With consideration of outcomes relating to production, grassland and soil resource condition, household finances and economics, and the externalities of ruminant livestock production from grasslands, herders and policymakers can identify more sustainable management strategies. The embedding of climate variability in the simulation model also presents the risk and probabilities of certain outcomes, which can then be considered by decision-makers. The robust nature of the functions in the model also ensures the model has broad applicability, especially in agro-ecological zones and systems with minimal experimental data.

Herders in IMAR attending a program training session on assessing the quantity and quality of fodder for feeding in winter.
Photo: D.R. Kemp

Siziwang herders, local officials and program members at a training session on winter feeding. Dr Li and Prof Han (bottom left) Mr Langford & Ms Junk (Australian livestock extension specialists) (centre) and Professor Kemp (middle rear).
Photo: D.R. Kemp

Professor Wu, President, Gansu Academy of Agricultural Science (right), discussing farm demonstrations with the village leader and herders at Sunan in western Gansu. Photo: D.R. Kemp

International visitors at the China–Korea–Japan biennial Grassland Congress visiting a field site on the Qinghai–Tibetan Plateau. At the International Grassland Congress in China in 2008, visitors went to the Siziwang research site.
Photo: D.R. Kemp

References

Antle, JM 1983, 'Incorporating risk in production analysis', *American Journal of Agricultural Economics*, vol. 65, pp. 1099–1106.

Behrendt, K, Cacho, O, Scott, JM & Jones, R 2013, 'Optimising pasture and grazing management decisions on the Cicerone Project farmlets over variable time horizons', *Animal Production Science*, vol. 53, pp. 796–805.

Behrendt, K, Liu, HB, Kemp, DR & Takahashi, T 2018, 'StageTHREE Sustainable Grasslands Model: model description and technical manual', *Australian Centre for International Agricultural Research*, Canberra, Australia (in press).

Behrendt, K, Malcolm, B, Jackson, T 2014, 'Beef business management', in L Kahn & D Cottle (eds), *Beef Cattle Production and Trade*, CSIRO Publishing, Collingwood, pp. 493–513.

Behrendt, K, Scott, JM, Cacho, O & Jones, RE 2013, 'Simulating the impact of fertiliser strategies and prices on the economics of developing and managing the Cicerone Project farmlets under climatic uncertainty', *Animal Production Science*, vol. 53, pp. 806–816.

Bywater, AC & Cacho, O 1994, 'Use of simulation models in research', *Proceedings of the New Zealand Society of Animal Production*, pp. 403–412.

Cacho, OJ 1993, 'A practical equation for pasture growth under grazing', *Grass and Forage Science*, vol. 48, pp. 387–394.

Cacho, OJ, Bywater, AC & Dillon, JL 1999, 'Assessment of production risk in grazing models', *Agricultural Systems*, vol. 60, pp. 87–98.

Chen, W, Scott, JM, Blair, GJ, Lefroy, RDB, Hutchinson, KJ, King, KL & Harris C 2002, 'Diet selection and sheep productivity of sheep grazing contrasting pastures', *Australian Journal of Agricultural Research*, vol. 53, pp. 529–539.

Clark, CW 1990, *Mathematical bioeconomics: the optimal management of renewable resources*, 2nd edn, John Wiley and Sons Inc, New York, USA.

Cook, S, Lazenby, A & Blair G 1978, 'Pasture degeneration. I. Effect on total and seasonal pasture production', *Australian Journal of Agricultural Research*, vol. 29, pp. 9–18, doi: 10.1071/AR9780009

Dong, H, Mangino, J, McAllister, TA, Hatfield, JL, Johnson, DE, Lassey, KR, Aparecida de Lima, M & Romanovskaya, A 2006, 'Emissions from Livestock and Manure Management', in HS Eggleston, L Buendia, K Miwa & T Ngara & K Tanabe K (eds), *2006 IPCC guidelines for national greenhouse gas inventories*, Institute for Global Environmental Strategies, Hayama, Japan, vol. 4, p. 87.

Donnelly, JR, Moore, AD & Freer, M 1997, 'GRAZPLAN: decision support systems for Australian grazing enterprises. I. Overview of the GRAZPLAN project, and a description of the MetAccess and LambAlive DSS', *Agricultural Systems*, vol. 54, pp. 57–76.

Dowling, PM, Michalk, DL, Kemp, DR, Millar, GD, Priest, SM, King, WM, Packer, IJ, Holst, PJ & Tarleton, JA 2006, 'Sustainable grazing systems for the Central Tablelands of New South Wales. 2. Effect of pasture type and grazing management on pasture productivity and composition', *Australian Journal of Experimental Agriculture*, vol. 46, pp. 457–469.

Fitzpatrick, EA & Nix, HA 1970, 'The climate factor in Australian grassland ecology', in RM Moore (ed.), *Australian Grasslands*, ANU Press, Canberra, pp. 3–26.

Freer, M, Dove, H & Nolan, JV (eds) 2007, *Nutrient requirements of domesticated ruminants*, CSIRO Publishing, Collingwood, p. 270.

Freer, M, Moore, AD, Donnelly, JR 1997, 'GRAZPLAN: decision support systems for Australian grazing enterprise. II. The Animal Biology Model for feed intake, production and reproduction and the GrazFeed DSS', *Agricultural Systems*, vol. 54, pp. 77–126.

Gramshaw, D, Read, JW, Collins, WJ & Carter, ED 1989, 'Sown pastures and persistence: an Australian overview', in GC Marten, AG Matches, RF Barnes, RW Brougham, RJ Clements & GW Sheath (eds), *Persistence of forage legumes*, American Society of Agronomy, Madison, Wisconsin, USA, pp. 1–21.

Humphreys, LR 1997, *The evolving science of grassland improvement*, Cambridge University Press, Cambridge.

Hutchinson, KJ 1992, 'The grazing resource', in KJ Hutchinson & P Vickery (eds), *Proceedings 6th Australian Society of Agronomy conference*, UNE, Armidale, pp. 54–60.

Johnson, IR 2013, *DairyMod and the SGS Pasture Model: a mathematical description of the biophysical model structure*, IMJ Consultants, Dorrigo, NSW, Australia.

Johnson, IR, Lodge, GM & White, RE 2003, 'The Sustainable Grazing Systems Pasture Model: description, philosophy and application to the SGS National Experiment', *Australian Journal of Experimental Agriculture*, vol. 43, pp. 711–728.

Jones, RM, Jones, RJ & McDonald, CK 1995, 'Some advantages of long-term grazing trials, with particular reference to changes in botanical composition', *Australian Journal of Experimental Agriculture*, vol. 35, pp. 1029–1038.

Kang, JY, Yoon, SC, Shao, Y & Kim, SW 2011, 'Comparison of vertical dust flux by implementing three dust emission schemes in WRF/Chem', *Journal of Geophysical Research: Atmospheres,* (1984–2012)116.

Kemp, DR, Brown, C, Han, G, Michalk, DL, Nan, Z, Wu, J & Xu, Z 2011, 'Chinese grasslands: problems, dilemmas and finding solutions', in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings No. 134*, Australian Centre for International Agricultural Research, Canberra, pp. 12–23.

Kemp, DR & Dowling, PM 2000, 'Towards sustainable temperate perennial pastures', *Australian Journal of Experimental Agriculture*, vol. 40, pp. 125–132.

Kemp, DR & King, WM 2001, 'Plant competition in pastures: implications for management', in PG Tow & A Lazenby (eds), *Competition and succession in pastures*, CABI Publishing, Wallingford, pp. 85–102.

Kemp, DR & Michalk, DL 1994, 'Pasture management: introduction', in DR Kemp & DL Michalk (eds), *Pasture management: technology for the 21st century*, CSIRO Publishing, Melbourne, pp. ix-xi.

Kemp, DR & Michalk, DL 2011, *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra.

Li, ZG, Han, GD, Zhao, ML, Wang, J, Wang, ZW & Kemp, DR 2015, 'Identifying management strategies to improve sustainability and household income for herders on the desert steppe in Inner Mongolia, China', *Agricultural Systems*, vol. 132, pp. 62–72, doi: 10.1016/j.agsy.2014.08.011.

Littleboy, M, Freebairn, D, Silburn, D, Woodruff, D & Hammer G 1999, *A computer simulation model of Productivity Erosion Runoff Functions to Evaluate Conservation Techniques (PERFECT)*, Queensland Department of Natural Resources and Queensland Department of Primary Industries.

Liu, HB 2017, 'Simulation and application of the Sustainable Grasslands Model in the meadow area of Qinghai-Tibetan Plateau', PhD thesis, Gansu Agricultural University, Lanzhou, China.

Liu, X, Yin, ZY, Zhang, X & Yang, X 2004, 'Analyses of the spring dust storm frequency of northern China in relation to antecedent and concurrent wind, precipitation, vegetation, and soil moisture conditions', *Journal of Geophysical Research: Atmospheres*, vol. 109.

Loewer, OJ 1998, 'GRAZE: A Beef-Forage Model of selective grazing', in RM Peart & BR Curry (eds), *Agricultural Systems Modeling and Simulation*, Marcel Dekker, Inc., New York, pp. 301–418.

Lu, H & Shao, Y 2001, 'Toward quantitative prediction of dust storms: an integrated wind erosion modelling system and its applications', *Environmental Modelling & Software*, vol. 16, pp. 233–249.

MacLeod, ND & McIvor, JG 2006, 'Reconciling economic and ecological conflicts for sustained management of grazing lands', *Ecological Economics Think Tank*, Proceedings of the 2003 Ecological Economics Think Tank, Auckland, New Zealand, pp. 56, 386–401.

Malcolm, LR, Makeham, JP & Wright, V 2005, *The farming game: agricultural management and marketing*, 2nd edn, Cambridge University Press, New York.

Mathworks 2017, *Matlab & Simulink (academic version)*, release R2017a, The Mathworks Inc, Massachusetts.

Minasny, B, McBratney, AB & Salvador-Blanes, S 2008, 'Quantitative models for pedogenesis: a review', *Geoderma*, vol. 144, pp. 140–157.

Moore, AD, Donnelly, JR & Freer, M 1997, 'GRAZPLAN: decision support systems for Australian grazing enterprises. III. Pasture growth and soil moisture submodels, and GrassGro DSS', *Agricultural Systems*, vol. 55, pp. 535–582.

Moore, AD, Holzworth, DP, Herrmann, NI, Huth, NI & Robertson, MJ 2007, 'The Common Modelling Protocol: a hierarchical framework for simulation of agricultural and environmental systems', *Agricultural Systems*, vol. 95, pp. 37–48.

Rae, AN 1994, 'Intertemporal activity analysis', *Agricultural management economics: activity analysis and decision making*, CABI Publishing, Wallingford, pp. 223–231.

Standing Committee on Agriculture (SCA) 1990, 'Feeding standards for Australian livestock: ruminants', in CSIRO, *Report for the Standing Committee on Agriculture*, CSIRO, Melbourne.

Scott, JM, Hutchinson, KJ, King, K, Chen, W, McLeod, M, Blair, GJ, White, A, Wilkinson, D, Lefroy, RDB, Cresswell, H, Daniel, H, Harris, C, MacLeod, DA, Blair, N & Chamberlain, G 2000, 'Quantifying the sustainability of grazed pastures on the Northern Tablelands of New South Wales', *Australian Journal of Experimental Agriculture*, vol. 40, pp. 257–265.

Shao, Y, Raupach, M & Leys, J 1996, 'A model for predicting aeolian sand drift and dust entrainment on scales from paddock to region', *Soil Research*, vol. 34, pp. 309–342.

Stafford Smith, DM, Milham, N, Douglas, R, Tapp, N, Breen, J, Buxton, R & McKeon, G 1995, 'Whole farm modelling and ecological sustainability: a practical application in the NSW rangelands', in *Conference papers: Australia & New Zealand Society for Ecological Economics in association with the Centre for Agricultural and Resource Economics*, Ecological Economics Conference, Coffs Harbour, NSW, November 19–23 1995, pp. 243–249.

Takahashi, T, Jones, R & Kemp, DR 2011, 'Steady-state modelling for better understanding of current livestock production systems and for exploration of optimal short-term strategies', in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 26–35.

Takahashi, T, Li, Z, Wang, ZW, Han, GD, Behrendt, K & Kemp, DR 2015, 'Quantifying the economic value of evidence-based animal selection on the Inner Mongolian desert steppe', in AK Roy (ed.), *Proceedings of the 23nd International Grasslands Congress. International Grasslands Congress*, New Delhi.

Thornley, JHM & France, J 2007, *Mathematical models in agriculture: quantitative methods for the plant, animal and ecological sciences*, 2nd edn, CABI Publishing, Wallingford.

Wakatsuki, T & Rasyidin, A 1992, 'Rates of weathering and soil formation', *Geoderma*, vol. 52, pp. 251–263.

Westoby, M, Walker, B & Noy-Meir, I 1989, 'Opportunistic management for rangelands not at equilibrium', *Journal of Range Management*, vol. 42, pp. 266–274.

Whalley, RDB & Hardy, MB 2000, 'Measuring botanical composition of grasslands', *Field and laboratory methods for grassland and animal production research*, CABI Publishing, Wallingford UK, pp. 67–102.

Wilson, AD & Simpson, RJ 1994, 'The Pasture Resource Base: status and issues', in DR Kemp & DL Michalk (eds), *Pasture management: technology for the 21st century*, CSIRO, East Melbourne, pp. 1–25.

Woodward, SJR 1998, 'Dynamical systems models and their application to optimizing grazing management', in RM Peart & BR Curry (eds), *Agricultural systems modeling and simulation*, Marcel Dekker Inc, New York, pp. 419–473.

7 Modelling the sustainability of Qinghai–Tibetan Plateau grasslands

Liu Haibo, Karl Behrendt, Wu Jianping, Du Wenhua, David Kemp

The Qinghai–Tibetan Plateau is the largest, high altitude plateau (4,500 m) in the world, with one of the world largest pastoral ecosystems (Liu & Chen 2000; Miehe et al. 2009; Shang et al. 2014). Its global significance is not simply about its physical parameters. More important is the great influence it has on regulating the intensity of Asian monsoons as well as global climate change and hydrology of major river systems (An et al. 2001; Harris 2006). The ecological functions of the Qinghai–Tibetan Plateau can be summarised as:

- a water source for major Asian rivers
- establishment of submarine fan system of the Bay of Bengal and the Arabian Sea and dissolved matter transmission from rivers into the oceans
- a large carbon sink and an important role in global weather regulation (Harris 2006).

The Qinghai–Tibetan Plateau is a crucial and fragile environment that is highly sensitive to climate change (Li et al. 2013).

The Qinghai–Tibetan Plateau covers an area of 169 Mha, of which 70% is natural grassland used for grazing (Miller 1990), which in turn is 30% of the total grassland area of China (Shang et al. 2014). Seventeen of the 18 main types of grasslands in China have been identified on the Qinghai–Tibetan Plateau (Ni 2002). Alpine meadow and alpine steppe are the main vegetation types and account for 45% and 29% of the grassland area, respectively (Li et al. 2013). Extensive areas of the Qinghai–Tibetan Plateau have become degraded to varying degrees (Harris 2010; Li et al. 2013; Wang et al. 2015), although appropriate definitions and standardised measurements for grassland degradation have some ambiguity (Wang et al. 2015).

Overgrazing is regarded as a major cause of Qinghai–Tibetan Plateau grassland degradation (Liu et al. 2016). This has resulted in reduced above-ground plant biomass productivity, increased topsoil erosion, decreased water-holding capacity associated with permafrost thawing, reduced pools of soil organic carbon and nitrogen, loss of plant diversity, species composition and functional groups change associated with degradation and the invasion of weeds (Lu et al. 2013; Lu et al. 2014; Tang et al. 2015; Wen, Dong, Li, Li et al. 2013; Wu et al. 2015). The loss of vegetation has additional effects on the radiation absorbed by the soil surface, which changes the summer monsoon circulation and decreases precipitation in the south-eastern Qinghai–Tibetan Plateau (Li & Xue 2010). These ecosystem changes are generally adverse and management is needed to reverse them in order to restore the integrity of the Qinghai–Tibetan Plateau (Wen, Dong, Li, Li et al. 2013) and the livelihoods of many herder households who live there.

The role of livestock grazing systems in managing the utilisation of Qinghai–Tibetan Plateau grasslands is complex. The need for management to be integrated within the farming system in a profitable and sustainable way limits the usefulness of relying simply on field experimentation to obtain answers. Modelling and simulation of complex farming systems is a more efficient method of researching management systems to improve decision-making. In order to capture the dynamic interactions between different components and maximise the long-term profitability of the grazing system, the *StageTHREE* SGM (Chapter 6; Behrendt et al. 2018) was used to study the interactions between herder management and environmental outcomes.

In this study, parameterisation and calibration of the *StageTHREE* SGM is outlined for the alpine meadow grasslands and animal production submodels and applied to the Oula Tibetan sheep production systems. The *StageTHREE* SGM is used to predict the potential consequences of increased stocking rates and determine a more sustainable stocking rate for the alpine meadow area of Maqu (Figure 7.1).

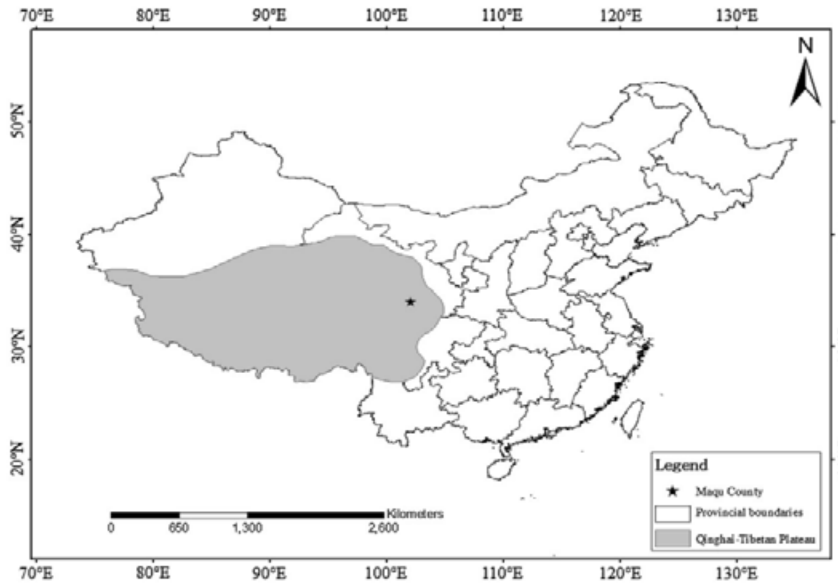

Figure 7.1 The location of Maqu on the Qinghai–Tibetan Plateau
Source: Cao et al. (2013)

Case study site

The large ACIAR sustainable grasslands program and a subproject funded by the Chinese National Department Public Benefit Research Foundation Project (nr 201003019) were implemented from 2010 to 2014 at Maqu in the Gannan Tibetan Autonomous Prefecture of Gansu Province. This program used a study of family herders to investigate resource allocation of the pastoral production systems in the alpine meadow area of Qinghai–Tibetan Plateau, to then investigate ways of reducing overstocking to achieve a sustainable grazing system. Data obtained from those studies were used to calibrate a model of the livestock system on alpine meadows.

A set of experiments were done in the case study area to provide data on grassland production and utilisation, soil texture and nutrient status, Tibetan sheep nutrition, production and household finances. As a precursor to the major study, the ACIAR StageONE steady state model (Chapter 6) was calibrated and the feed balance situation and optimisation solutions were evaluated to refine the likely options that the more complex *StageTHREE* SGM model would then evaluate (Liu et al. 2017). The SGM model was calibrated using climate data (Liu et al. 2016), grassland growth and vegetation composition (Liu et al. 2016), soil nutrients status and soil profile descriptions (Liu 2017), in vitro DMD of mixed grassland samples (Liang et al. 2015), dry matter intake (Wu et al. 2016) and production calendars (Liu 2017; Liu et al. 2017).

Tibetans retain many traditional practices such as this welcoming party to their region. In summer, herders move to higher altitudes with their flocks and herds. Note the absence of a flue to let smoke out of the black tent, which is made from yak hair. Photos: David. Kemp

Model parameterisation and calibration

The SGM model was calibrated against data collected and data available from the literature to minimise the mean bias in model results as much as possible. As part of this process, where there was an initially poor fit between predictions and observations, model parameters were revised to improve the results (Thornley & France 2007). A series of simulations were done with the animal submodels of the *StageTHREE* SGM to determine more sensitive key parameters that significantly influenced the outputs of submodels (Liu 2017). Visual techniques (Mayer & Butler 1993) were used, plotting simulation data against observed data to subjectively assess if the initial parameter values satisfactorily fitted the observed data within the likely range.

Least squares analyses (Thornley & France 2007) were used to identify the optimum values of parameters where applicable, to minimise the total residual sum of squares, *R* using:

$$R = \sum_{i=1}^{i=n} \left(\ln\left(\frac{x_i}{y_i}\right) \right)^2$$

where:

y_i = the observed values from experiments or literature

x_i = the simulated values produced from the model

n = the total number of the observations.

The assumptions and data used for parameterisation and calibration are discussed further in the following section.

Table 7.1 Mean herbage mass in exclusion cages from four grassland sites and day of year

Day	Desirable species (kg DM/ha)	Less-desirable species (kg DM/ha)
198	1,001	158
233	2,797	412
259	3,198	536
199	549	63
231	2,409	412
259	2,814	607
196	1,127	96
232	4,232	386
258	5,224	375
196	152	58
231	2,200	701
257	3,375	1,402

Note: DM = dry matter

Grassland growth submodel

The grassland growth submodel is based on deriving growth indexes for temperature, light and moisture (Fitzpatrick & Nix 1970) then using the minimum of the three indexes, which is then scaled. Calibration of the grassland growth model was done using the GGC tool developed for this purpose (Behrendt et al. 2018). The GGC uses measures of herbage mass in ungrazed fields or quadrats and associated climate data (minimum, average and maximum air temperature, humidity, rainfall and wind speed). The mechanistic SGS (Johnson 2013) grassland submodel (which could be used in this case as experiments were designed to means the range is collect the data required, a problem that limits use of that model for Qinghai–Tibetan Plateau sites) was first used to produce daily growth curves, from which a well-established sigmoidal relationship was derived between daily grassland growth rates and the total green biomass (Cacho 1993). The optimal parameters estimated for the fitted sigmoidal equation (α = asymptote of growth curve; γ = the point at which maximum growth occurs) are given in Table 7.2 along with the maximum yield estimates for desirable and less-desirable plant species. Only a limited dataset on grassland growth was able to be collected, as livestock managed to overturn the cages and eat the available forage at some sites. An amalgamated dataset for the 2011 growing season from three farms was used, describing herbage mass inside the cages for July, August and September (Table 7.1). Measurements of grassland herbage mass over summer were used to estimate the grassland growth rates, using the fitted sigmoid equation and gaps filled in with interpolation to provide daily data. These estimates were further adjusted, based on how climatic conditions (temperature, soil moisture and light) and soil fertility varied. A total of 33 parameters can be modified in the SGM and the supporting GGC tool to improve the accuracy of grassland growth predictions.

The grassland growing season on the Qinghai–Tibetan Plateau is 4–5 months, when average temperatures are above 0 °C. To better predict the onset and cessation of the grassland growing season, a soil temperature threshold was used. By using a soil temperature threshold above 0 °C, grassland growth rate better aligned with herder perceptions of visible growth. For the Qinghai–Tibetan Plateau, the soil temperature threshold was set at 8 °C rather than 5 °C (often used in temperate regions), which represents the typical minimum soil temperature in the top profile that allows for effective plant growth that animals can graze. To our knowledge, there is no data to validate the modelled temperature fluctuation of the topsoil in the case study area, although it is widely acknowledged that when the air temperature exceeds 0 °C, plants would be able to begin growing in the case study area. However, the grassland growth rates are very low between 0–5 °C and can be ignored for practical purposes. The temperature threshold set means that, across the data range, there is an effective linear response in grassland growth to temperature.

Table 7.2 Inputs and outputs of the parameterisation of *α* and *γ* for estimate grassland growth

Species group	Initial proportion	Initial biomass (kg DM/ha)	Optimal *α*	*α* test range	Optimal *γ*	*γ* test range	Y_{max} (kg DM/ha)	*R*
Desirable	0.3	300	0.076	0.001:0.001:0.99	1.01	1.01:0.01:1.99	5,000	2.35
Less-desirable	0.7	300	0.077		1.01		3,000	3.44

Notes:

- DM = dry matter
- Y_{max} = maximum biomass.
- *R* = total residual sum of squares
- The *α* test range of 0.001:0.001:0.99 means the range is 0.001 to 0.99 with an increment of 0.0001.
- The *γ* test range of 1.01:0.01:1.99 means the range is 1.01 to 1.99 with an increment of 0.01.

Grassland biomass measurements (kg DM/ha) inside exclusion cages were used to calculate the daily growth rate, *PGR* (kg DM/ha/d), for direct comparison with predictions, using the following equation:

$$PGR = \frac{B_m - B_{m-1}}{\Delta t}$$

where:

B_m and B_{m-1} = amount of desirable (edible) and less-desirable (inedible) biomass

Δt = number of days between measurements.

Tibetan sheep model

One of the regular aspects of livestock growth in China is the considerable loss in weight (20–30%) (Chapter 3) over autumn, winter and spring due to poor nutrition (eds Kemp & Michalk 2011). In summer there is a considerable component of compensatory gain in animal growth rates, which is simply regaining the weight lost in previous seasons. Compensatory gain can be falsely interpreted as very efficient feed consumption and animal growth rates. These responses suggest that animals have a larger capacity for forage intake than their reduced weights would suggest. In effect, their potential intake capacity for forage is more related to how large they previously were (Freer, Moore & Donnelly 1997; eds Freer, Dove & Nolan 2007). This requires estimates of a standard reference weight (SRW) to adjust forage intake capacity. SRW is defined as the liveweight of an animal (excluding fleece and conceptus) when skeletal development is complete and the condition score is in the middle of the range (eds Freer, Dove & Nolan 2007). For modelling purposes, this number is often treated as the maximum liveweight previously attained. The maximum liveweight of Tibetan sheep found in our studies was up to 75 kg, and that value was used as the SRW. The predicted weight and observed lamb liveweight showed a good fit (Figure 7.2) using this SRW and a birth weight of 4 kg for Tibetan sheep. The discrepancy between observed and predicted liveweights after about 200 days reflects the generally poor nutrition of animals in this environment and the opportunities for improvement.

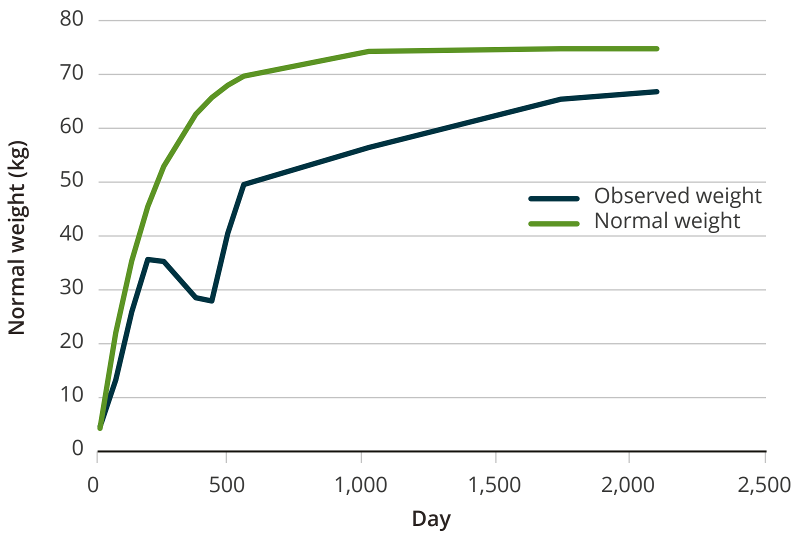

Figure 7.2 Predicted normal weight and observed liveweight of Oula Tibetan sheep from different age cohorts in the field experiment, *StageTHREE* SGM

Left: Students from Charles Sturt University visiting the Sunan demonstration farm winter camp, where overgrazing and inedible shrubs are evident. Right: Female yaks and their calves tied up at the Gannan site, where the cows are milked every 1–2 hours through the day. Photos: D.R. Kemp

Tibetan wool, while coarse, is important for the traditional manufacture of carpets, which are sold at a price premium. Photos: D.R. Kemp

Digestibility measurement

DMD is a key driving variable in the livestock submodel (Behrendt et al. 2018). Monthly estimates of mean DMD of the main plant functional groups are required. For this study, the digestibility of the mixed grassland grazed by the sheep was determined using in vitro measurements, with samples taken by cutting the grazed grasslands to ground level. Samples were taken four times during the growing season (July–October) on summer grasslands and three times outside the growing season (April–June) on winter grasslands (Table 7.3). A detailed description of the in vitro method used is provided by Liang et al. (2015).

Table 7.3 Nominated monthly DMD values for desirable and less-desirable species

Month	Desirable	Less-desirable
Jan	0.48	0.38
Feb	0.48	0.38
Mar	0.48	0.38
Apr	0.48	0.38
May	0.72	0.63
June	0.67	0.58
July	0.63	0.53
Aug	0.63	0.53
Sept	0.63	0.53
Oct	0.53	0.43
Nov	0.48	0.38
Dec	0.48	0.38

Grassland intake

Dry matter intake (DMI) and the simulation of selective grazing are key functions in modelling the interaction between grasslands and animal production in pastoral systems. In the field, the voluntary intake of Oula Tibetan ewes was determined by using the faecal nitrogen excretion method. Details are reported by Wu et al. (2016). Estimates in the field were then compared with model predictions based on the literature (Table 7.4). The predicted DMI versus measured DMI showed R^2 values of 0.86, 0.99 and 0.70 for March, August and October, respectively. The DMI for Tibetan sheep was similar to the results obtained from using standard equations derived for other breeds of sheep (eds Freer, Dove & Nolan 2007). The differences did not lead to any major effects on predictions for liveweight gain or other measures.

Table 7.4 Average liveweights, simulated DMI and measured DMI of Oula Tibetan sheep in different seasons

Age of sheep (year)	March			August			October		
	W (kg)	DMI_{sim} (kg/day)	DMI (kg/day)	W (kg)	DMI_{sim} (kg/day)	DMI (kg/day)	W (kg)	DMI_{sim} (kg/day)	DMI (kg/day)
1	41.7	0.74	0.79	54.7	1.63	1.17	54.3	1.39	1.66
2	50.6	0.91	1.05	57.1	1.70	1.37	56.6	1.43	1.74
3	59.6	0.93	1.10	65.0	1.71	1.38	65.6	1.44	1.79
4	62.6	0.95	1.29	67.1	1.71	1.40	67.0	1.45	1.96
R			0.15			0.25			0.21

Notes:
- W = measured average liveweight
- DMI_{sim} = simulated daily dry matter intake
- DMI = measured daily dry matter intake, estimated by multiplying the measured average liveweight with the reported intake per kg of metabolic bodyweight
- *R* = total residual sum of squares from comparing DMI estimates

Maintenance energy requirements

There is no literature available to specifically indicate the maintenance energy (ME_m) requirements of grazing Tibetan sheep. A single value of 0.44 MJ/kg $W^{0.75}$ for penned sheep was the only information available to provide an indication of the possible ME_m during the June–September period. The sensitivity of grazing sheep to this term was tested by varying the related C_{M2} (basal metabolism weight scaler, Chapter 6) term by 80%, 100% or 120% (Table 7.5) for 2–3 and 3–4-year-old ewes at three different times in a 10-year simulation. Lambing was assumed to be on day 50 of each year. These results suggest that the standard equations often used (eds Freer, Dove & Nolan 2007) estimated higher ME_m values than that single measurement. After reviewing the details behind these results, it was thought that the standard equations did produce a realistic result that was adequate for the current study. The single measurement from the literature had likely a significant error term. This is an area where research on the nutrition of Tibetan sheep is needed to see if they conform to or differ in important ways from the literature.

Table 7.5 Sensitivity analysis of C_{M2} for Tibetan sheep

Age (years)	Day	80% C_{M2} (ME_m/kg $W^{0.75}$)	100% C_{M2} (ME_m/kg $W^{0.75}$)	120% C_{M2} (ME_m/kg $W^{0.75}$)
2–3	910	0.46	0.53	0.6
	1,217	0.62	0.69	0.77
	1,534	0.33	0.39	0.45
3–4	910	0.45	0.52	0.58
	1,217	0.61	0.68	0.75
	1,534	0.33	0.38	0.43
R		0.39	0.49	0.77

Notes:
- C_{M2} is a variable in the SGM model for ME_m/k $W^{0.75}$
- ME_m values are in MJ
- Day = day number over 10 years

Liveweight change

Liveweight change is sensitive to the base reference parameter for the energy value of liveweight gain (C_{G8}) in the SGM model. In the literature (eds Freer, Dove & Nolan 2007) C_{G8} has the same value for both sheep and cattle, though it may be that yaks have a lower C_{G8} value, as their muscles have less fat. If the C_{G8} values reflect some adaptation to the harsh conditions of the Qinghai–Tibetan Plateau, it is possible that Tibetan sheep may have lower C_{G8} values than European breeds. The SGM model was then tested with three different values for C_{G8} to test the effect on estimated liveweight using a 10-year run (Table 7.6). These results showed the average effects at DOY 121, the day for lowest liveweight recorded in a year and at DOY 300, the day for peak liveweight. As C_{G8} decreased, birthweights and liveweight were significantly underestimated, suggesting that Tibetan sheep are unlikely to have lower C_{G8} values, and the standard value (eds Freer, Dove & Nolan 2007) is the better that is currently available. However, in the absence of specific results on appropriate values of C_{G8} for Tibetan sheep, it would not be sensible to arbitrarily make other changes without evidence. Instead, it is noted that research is needed to check what should be the correct values for Tibetan livestock and that the SGM model may be underestimating liveweight.

Table 7.6 Different levels of C_{G8} and its effect on the liveweight prediction

Age (day)	DOY (day)	Observed liveweight (kg)	W_{-1} (kg)	Bias (%)	W_{-2} (kg)	Bias (%)	W_{-3} (kg)	Bias (%)
0	75	4.2	4.0	–3.2	3.3	–20.1	3.3	–20.1
1,170	121	59.6	18.4	–69.2	16.8	–71.8	11.0	–81.5
1,395	300	65.6	47.3	–27.9	49.4	–24.8	56.3	–14.2

Notes:
- DOY = day of year
- W_{-1} = liveweight predicted when C_{G8} = 27; W_{-2} = liveweight predicted when C_{G8} = 25; W_{-3} = liveweight predicted when C_{G8} = 17.7
- Bias = (predicted W – observed W)/observed W x 100%

Qinghai–Tibetan Plateau typical farm

Based on herder surveys and the literature (Wang, Lang & Liu 2012), a typical farm was constructed to represent the current Oula Tibetan sheep production system in the case study area. Key data inputs regarding grassland, livestock and management assumptions are listed in Table 7.7. Case study simulations used deterministic simulations to assess current production under constant climate conditions and investigate the effect of increasing grazing pressure on the production system and biological and economic outcomes. The grazing pressure threshold for this typical farm in the case study area was assessed based on 10-year simulations that are carried out under the same deterministic weather conditions using different stocking pressures.

Table 7.7 *StageTHREE* SGM inputs for the typical farm simulation on the Qinghai–Tibetan Plateau

Parameters	Units	Values
Latitude	°	34
Altitude above sea level	m	3,800
Average rainfall per annum	mm	600
Grassland grazing areas (winter/summer)	ha	133/213
Opening ewe number	head	440
Opening ram number	head	4
Opening wether (male progeny) number	head	90
Lambing date	DOY	75
Lactation period	d	150
Shearing date	DOY	200
Selling month	1–12	10
Standardised birth weight	kg	5
Maximum height of grassland	m	0.6
Starting day of year on winter/summer grassland	DOY	300/150
Starting biomass of desirable/less-desirable species for winter grassland	kg DM/ha	300/300
Starting biomass of desirable/less-desirable species for summer grassland	kg DM/ha	400/500
Starting area proportion of desirable/less-desirable species for winter grassland	0.05–0.95	0.3/0.7
Starting area proportion of desirable/less-desirable species for summer grassland	0.05–0.95	0.4/0.6

Simulation results and discussion

Local officials and herders have in the past seen more animals as the pathway to higher incomes. However, to date the increase in animal numbers on the Qinghai–Tibetan Plateau has not been as great as in other areas of China (Chapter 2). What might be the sustainable number of animals on the Qinghai–Tibetan Plateau? The *StageTHREE* SGM was used to evaluate current and alternative stocking rates on the alpine meadows of Maqu, Gansu. The model was used to first analyse the effects of current stocking rates on grasslands while allowing increases in the household flock size from 440 to 983 breeding ewes. This was done by retaining a higher proportion of breeding animals and castrated males. The total flock size increased from around 534 to 1,580 animals over 10 years (Figure 7.3).

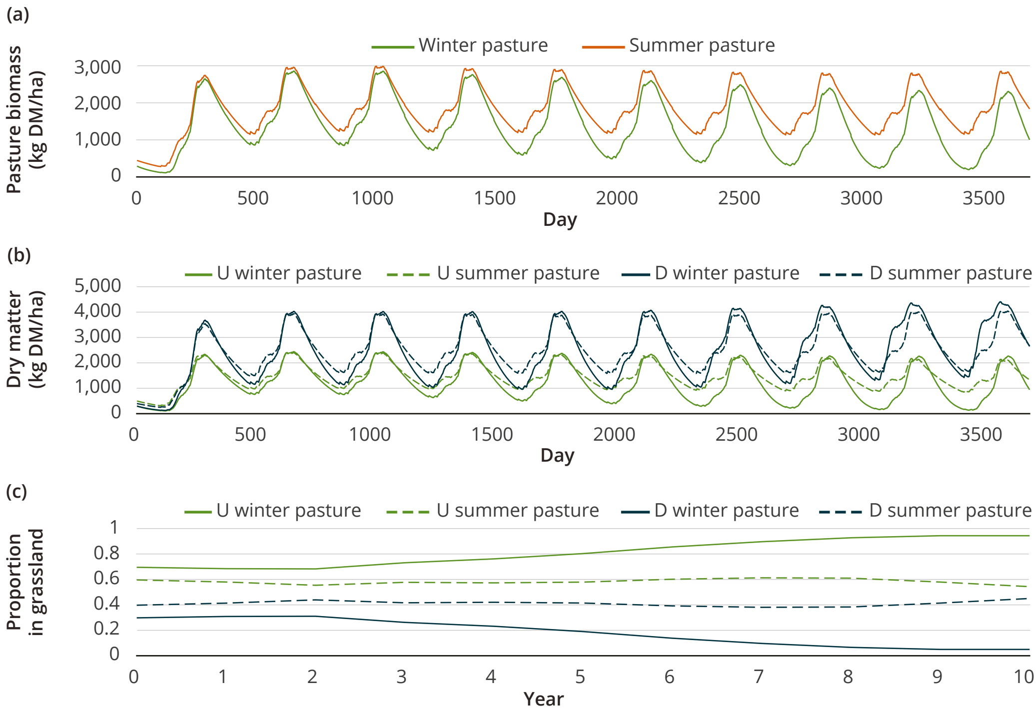

Figure 7.3 10-year simulation of increasing grazing pressure on the production system starting from the 1.4 sheep/ha and allowing a progressive increase to 5.1 SE/ha, showing (a) grassland biomass, (b) grassland biomass of desirable and less-desirable species and (c) grassland composition of desirable and less-desirable species

The simulation, allowing a build-up in flock size, shows that there is a negative effect on winter grazing areas (from an increase in the proportion in the basal cover of less-desirable species) although the summer grasslands remain relatively stable (with differential effects on ground cover, grassland biomass, grassland composition). For the whole flock, there is a decline in energy intake and liveweights (Figure 7.4, Figure 7.5), leading to declining incomes over time (Figure 7.6). Clearly, it would not be a useful policy to encourage herders to increase their stocking rates in this area. The decline in condition of the winter grazing areas shown in this simulation is a real problem, and is clearly evident when visiting the area. This problem is exacerbated by herders asking if they can bring their animals onto their neighbours' properties to be near the road to meet traders when they return from the summer grasslands. This leads to substantial increases in stocking rates that are hard to quantify. The effective stocking rate is then far higher than estimated in these simulations. Winter grazing areas are about two-thirds the size of those used in summer and are grazed for longer than the summer areas. Both those components could be changed.

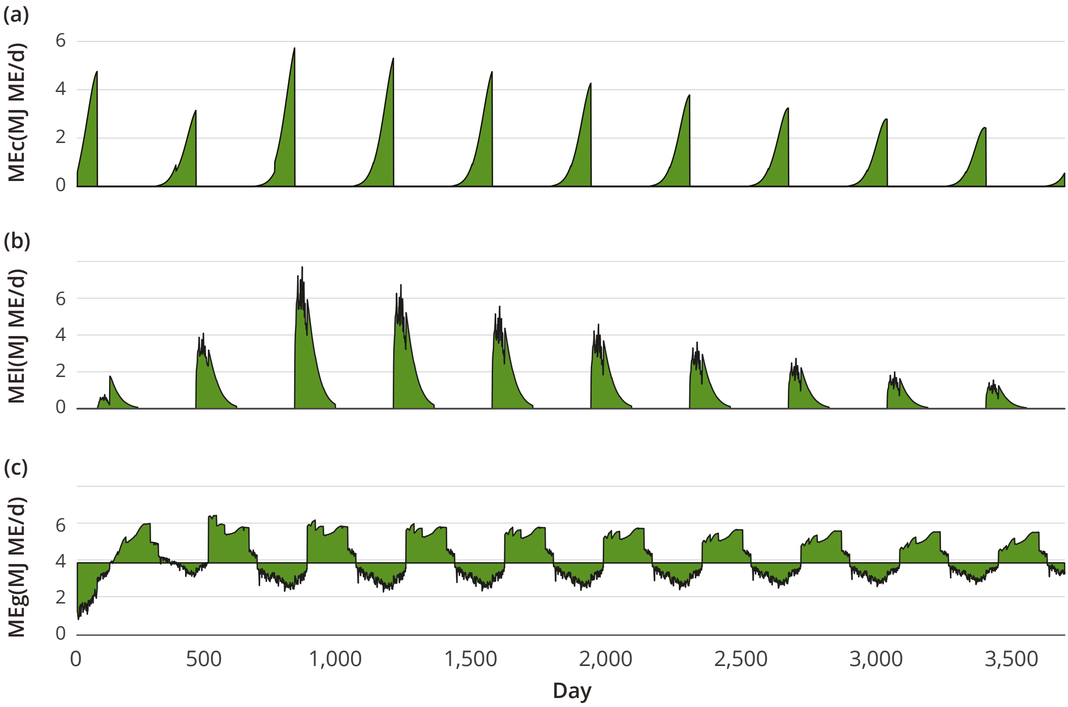

Figure 7.4 10-year simulation of increasing grazing pressure on the production system starting from 1.4 sheep/ha and allowing a progressive increase to 5.1 SE/ha, showing (a) metabolisable energy for conception, (b) metabolisable energy for lactation and (c) metabolisable energy for weight gain in 3-year-old ewes

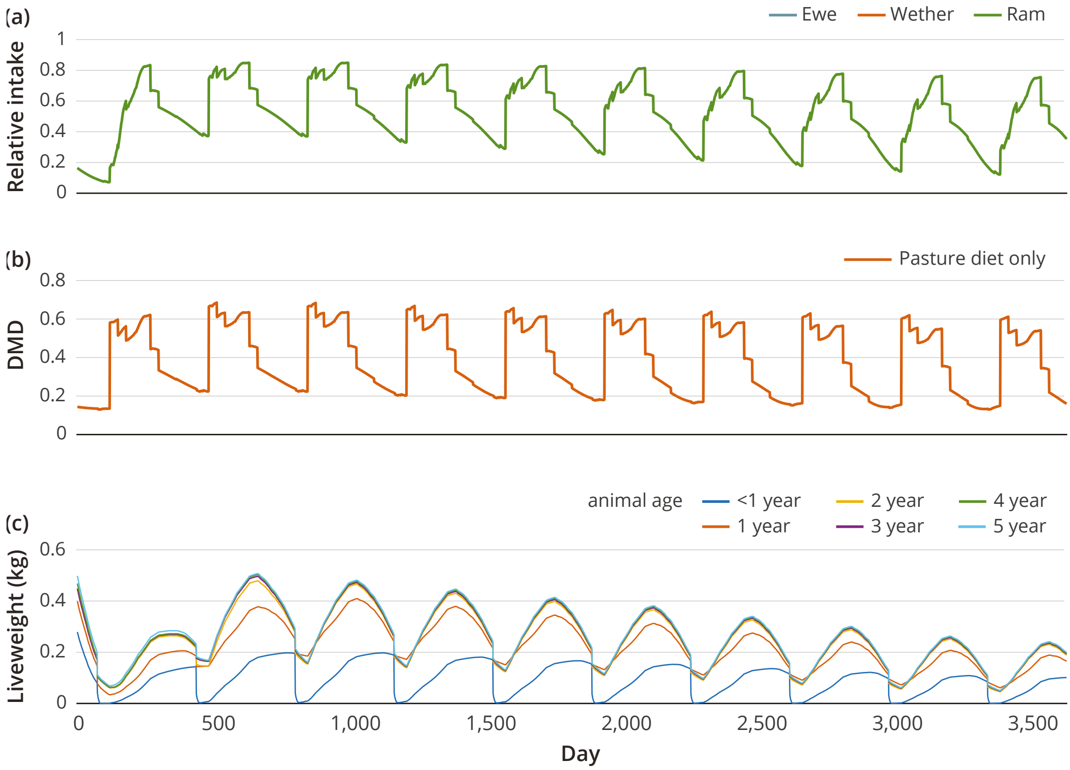

Figure 7.5 **10-year simulation of increasing grazing pressure on the production system starting from 1.4 sheep/ha and allowing a progressive increase to 5.1 SE/ha, showing (a) relative intake, (b) dry matter digestibility and (c) liveweight change in different age cohorts**

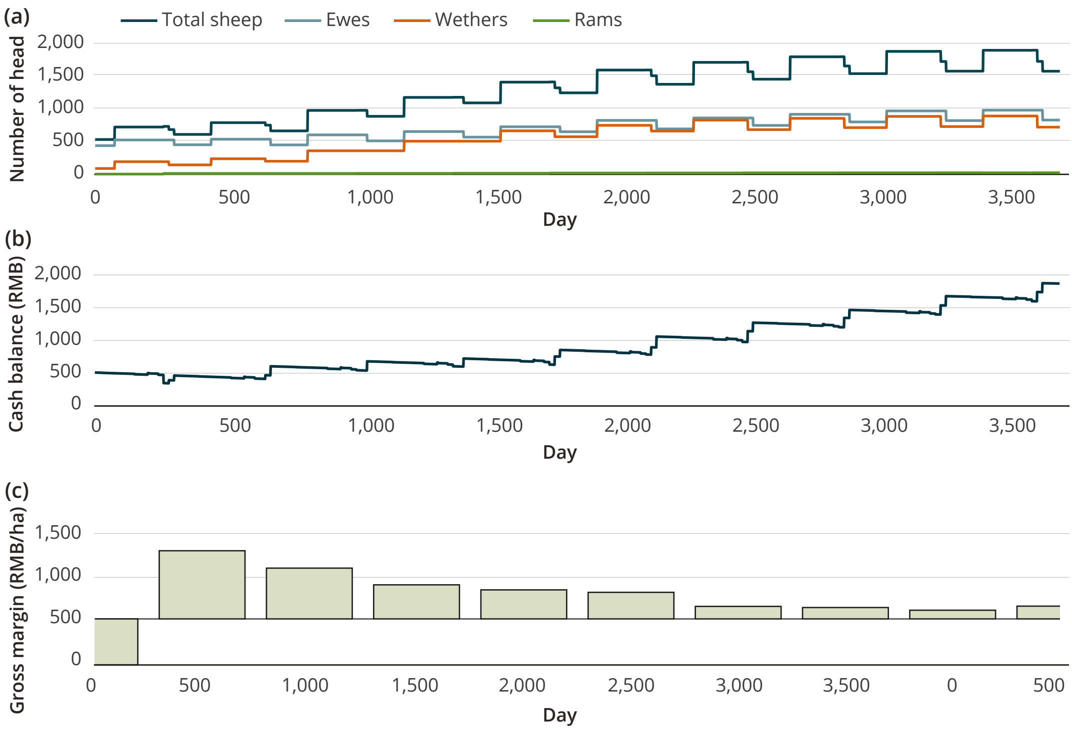

Figure 7.6 10-year simulation of increasing grazing pressure on the production system starting from 1.4 sheep/ha and allowing a progressive increase to 5.1 SE/ha, showing (a) number of animals, (b) daily closing cash balance and (c) annual gross margin of sheep enterprise

A subsequent simulation reduced the stocking rate to 1.2 sheep/ha (1.1 SE/ha) and maintained a minimum of 400 ewes (Figure 7.7). At this lower stocking rate, the grassland biomass and cover remained relatively constant, and the proportion of desirable species was constant in winter grazing areas and increased in summer areas. Energy intake, liveweights and gross margins were constant, with the herder's cash balance increasing over time and greater than for the initial case. In each case, the model captures and reflects the impact of any changes to the system.

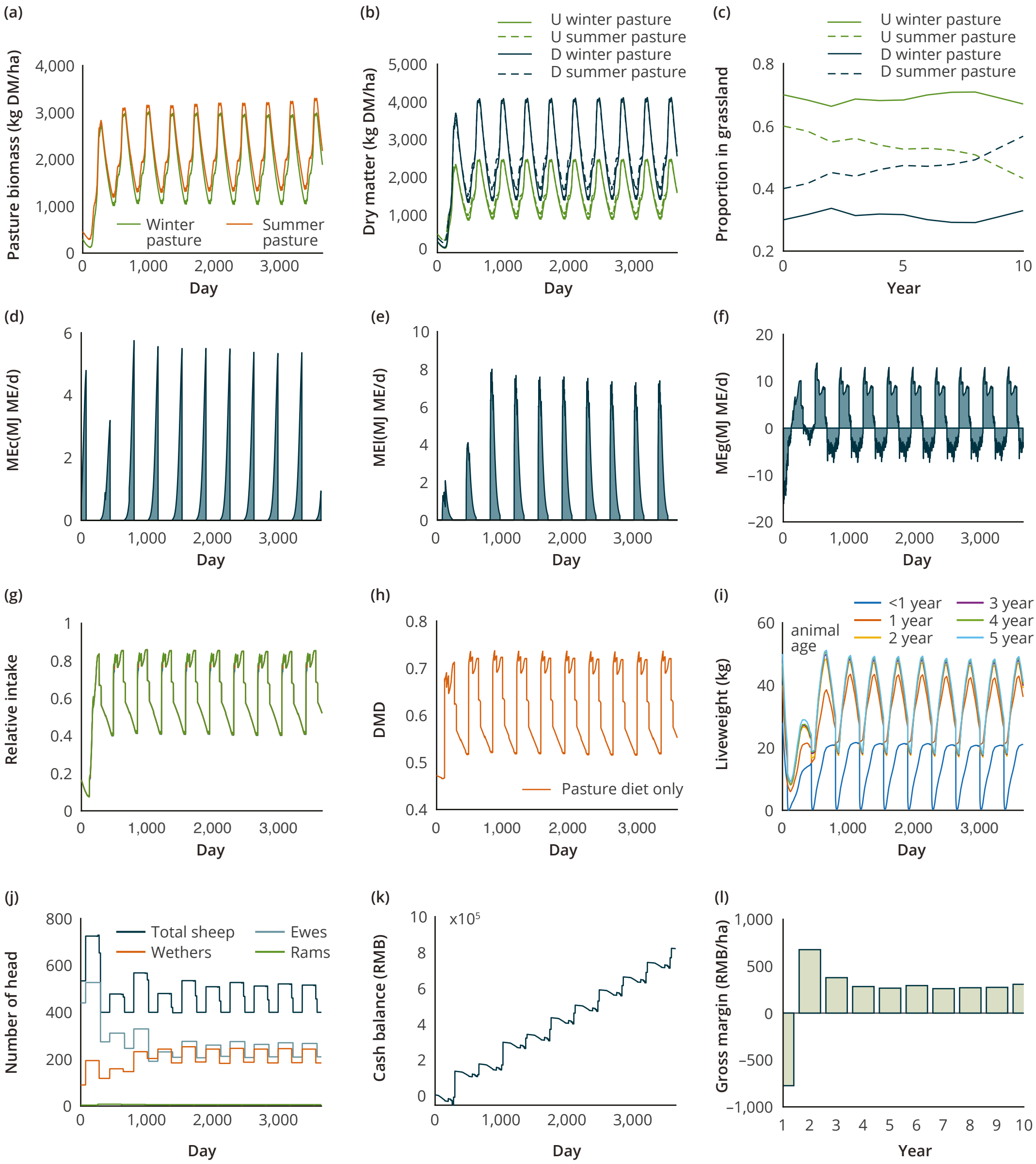

Figure 7.7 **10-year simulation results when target flock size was set as 1.2 sheep/ha, showing effects on (a) grassland biomass, (b) grassland biomass, (c) grassland composition, (d) metabolisable energy for conception, (e) metabolisable energy for lactation, (f) metabolisable energy for weight gain in 3-year-old ewes, (g) relative intake, (h) dry matter digestibility, (i) daily liveweight change, (j) number of animals, (k) daily closing cash balance, and (l) annual gross margin of sheep enterprise**

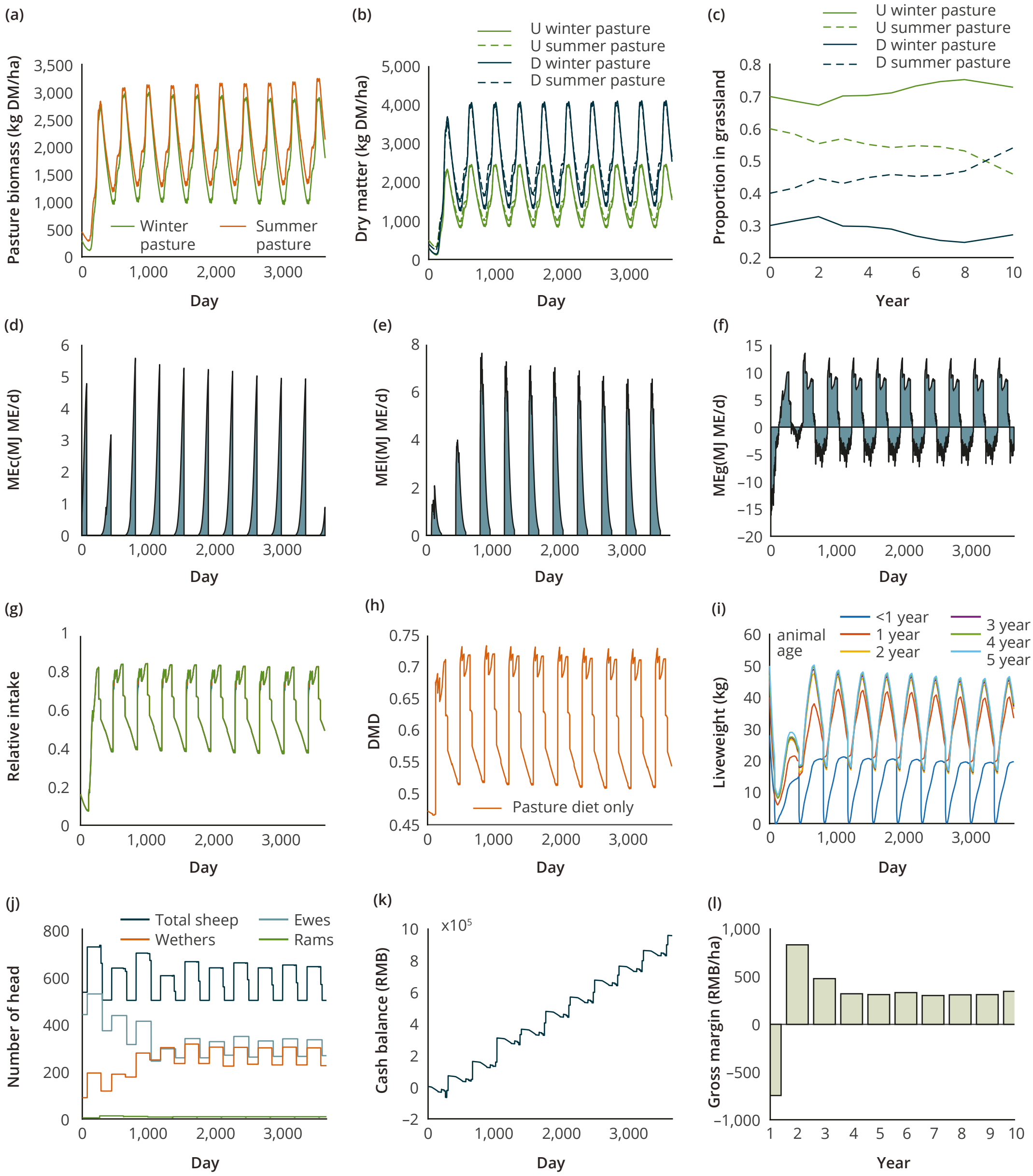

Figure 7.8 10-year simulation results when target flock size was set as 1.5 sheep/ha, showing effects on (a) grassland biomass, (b) grassland biomass, (c) grassland composition, (d) metabolisable energy for conception, (e) metabolisable energy for lactation, (f) metabolisable energy for weight gain in 3-year-old ewes, (g) relative intake, (h) dry matter digestibility, (i) daily liveweight change, (j) number of animals, (k) daily closing cash balance, and (l) annual gross margin of sheep enterprise

When the flock size was increased to 500 sheep (1.5 sheep/ha or 1.4 SE/ha) there was a tendency for less-desirable species to increase in the winter grazing areas. In the summer grazing areas, the reverse happened, while most other parameters remained constant (Figure 7.8). This same trend was accentuated when the flock size increased to 600 or 700 sheep (data not shown). This suggested the target stocking pressure should be 1.2–1.5 sheep/ha (1.1–1.4 SE/ha) and that herders need to reorganise how the winter grazing areas are managed. Winter grazing areas are probably too small for the number of animals that use them and do seem to be the main constraint on better grassland management. If better management of the winter grazing areas can be developed, some increases in total animal numbers would be possible. One option is to introduce more warm sheds where animals are kept over winter, as has occurred in IMAR and other parts of China where cold winters are the norm.

These simulations indicated that the average herbage mass when the grasslands were stocked at 1.2–1.5 sheep/ha or 1.1–1.4 SE/ha was 1,700–1,800 kg DM/ha on winter grasslands and 2,000–2,100 kg DM/ha on summer grasslands. Research is needed to identify the values of herbage mass that maintain the desirable species and sustain livestock production. These simulation values are higher than for the desert or typical steppe (Chapters 8 and 9) but in line with what might be expected in higher rainfall areas and in line with the optimal values for sheep production (Nicol 1987).

Further simulations of different flock sizes revealed deeper insights into expected changes in grassland composition, livestock production and flock financial performance (outputs not shown here, but available in Liu 2017). Generally, as the grazing pressure increased, the proportion of desirable plant species on the winter grassland tended to decrease while less-desirable species showed the opposite tendency, reflecting what is commonly observed (Chapters 8 and 9). When flock size is reduced to around 400 sheep (1.2 sheep/ha), the winter grassland composition remained relatively constant, the proportion of desirable species on summer grassland gradually increased and the proportion of less-desirable species on summer grassland declined. When the flock size was maintained at around 600 sheep (1.7 sheep/ha), the summer grassland composition remained relatively constant, the proportion of desirable species on winter grassland gradually decreased and the proportion of less-desirable species on winter grassland increased over time. Larger flock sizes showed higher annual gross margins, with the long-term gross margin stabilising at around ¥299, ¥310 and ¥320/ha/year respectively, as the flock size increased from 400 to 600 sheep (1.2–1.7 sheep/ha). DMD values were relatively constant when the flock sizes were maintained at 400 and 500 sheep (1.2 and 1.5 sheep/ha) respectively. However, when the flock size increased to 600 sheep (1.7 sheep/ha), peak DMD values were similar, although the lowest DMD values showed the tendency to decline below that seen at lower stocking rates. The average annual minimum relative intake values declined with increasing grazing pressure (Figure 7.5a). When the flock size was around 500 sheep (1.5 sheep/ha), peak relative intake values decreased gradually, while at lower values for 500 and 400 sheep (1.5 and 1.2 sheep/ha) they remained relatively constant.

Risks of increasing grazing pressure

By comparing the outputs from the simulations, it is evident that, given the area and grassland growth pattern for the typical Tibetan sheep herder, the optimal flock size to maintain winter grassland composition is around 400 to 500 sheep (1.2 to 1.5 sheep/ha or 1.1 to 1.4 SE/ha). This is the current typical flock size of Oula Tibetan sheep in the case study area. As noted earlier, animal numbers in this region had not increased to the same extent as in other parts of China (Chapter 2) but the estimated stocking rate in 2016 was 3–3.5 SE/ha, above a desirable, sustainable level. It is expected that overstocking may not only negatively affect grassland production, but also decrease the energy content in the animals' diets by suppressing their ability to selectively graze. This has negative effects on the efficiencies of animal production and herder household incomes. When the ME values drop below 8 MJ/kg DM, the diet is usually regarded as low in metabolisable energy. In the simulations, it was found that ME values were <8 between late October and late May, and when the corresponding DMD values were <0.6. This indicated that Tibetan sheep can only select low-quality diets for half the year. This is the time of year when ewes require considerable energy for gestation, lactation and to maintain body temperatures against the cold.

The evaluation of feed balance needs to consider both the quantity and quality of the available forage. The negative feed balance on winter grassland is mainly from a lack of energy. On summer grassland, the opposite applies—both grassland herbage mass values and herbage DMD are adequate for good animal growth rates, provided the stocking rates remain sustainable and the herbage available per animal is sufficient. From the end of summer through autumn and winter, the continuous reduction in the DMD of selected diets and relative intake with increasing grazing pressure was due to animals being forced to select herbage from lower digestibility pools. From these results, we recommend that the first step to achieve a better feed balance is destocking on winter grassland during the cold season. This ensures livestock are not faced with a constant decline of both the quantity and quality of the herbage when grazing. Overstocking accelerates this negative relationship, as more animals lead to less available grassland per animal. During the main grassland growing season over summer, the model outputs showed that the biomass proportion of desirable and less-desirable species in the sward remained relatively constant. When a sustainable stocking rate was set, animals gained weight even with decreasing amounts of ME. Given the typical management calendar in the case study area, we conclude that the feed balance is more important on winter grassland than summer grassland. A limitation to the model is its ability to capture the detailed complex interactions between different species or functional groups under grazing, which is an ongoing challenge in ecological research and modelling. Future research should investigate the frontiers of summer grassland productivity to maximise the potential productivity per hectare and financial returns of different grazing regimes. The SGM model can be used to design and test the primary treatment strategies.

The economic outcomes from this study differ from other work. Unlike previous work, the price of the product was not based on the typical market price per animal, but rather on the animal sale value as calculated from the price per kg of carcass weight. This pricing method allows for better analysis of the economic returns of the household and creates a more explicit link between price per head and price per kilogram in the market. In the case study area, herders believe that more animals equal more income, which can be checked by examining their annual cash flow and closing bank balances. An examination of gross margins showed that economic efficiency dropped as the stock number increased, contrary to herder expectations. This is due to revenue per head declining in response to decreasing individual liveweight at the time of sale. This demonstrates the sensitivity of economic returns to any fluctuation of farm gate prices and the optimal production system. From this study, we conclude that economic efficiency and grassland condition will be negatively affected by increasing the number of livestock on the grasslands. The simulations presented here indicate that the current conservative stocking rates are close to sustainable levels, though better animal management practices through winter are needed to ensure the grassland do not degrade. Better management practices need to be tested in experiments and farm demonstrations (as in Chapter 4).

Grazing system sustainability

Evaluation of the sustainability of the grassland–livestock system is difficult to do comprehensively in the field. Models like those used in this study are more useful, as the core issues and longer time periods can be investigated within a reasonable time frame. An alternative is to quantify the sustainability of alternative systems by using simple indexes (Scott et al. 2000). However, what defines sustainable management does vary depending upon local conditions and can be assessed at various scales (Kemp, Michalk & Virgona 2000). Shang et al. (2014) proposed 17 potential components for the sustainable development of the Qinghai–Tibetan Plateau, ranging from biophysical aspects to reorganising the industry structure. Increasing human population pressures prioritise the importance of small-scale farmers in meeting the global demands for animal protein. The potential gains from increasing the productivity and efficiency of the more than one billion small-scale livestock producers in the developing world are far greater than those that can be achieved in the developed world (Herrero & Thornton 2013).

The concept of sustainable intensification is popular among agricultural researchers and large potential, positive gains are possible for livestock systems (Herrero & Thornton 2013). Greater efficiencies can be obtained in intensive grassland–livestock systems, which involve high inputs (fertilisation, irrigation) and high utilisation rates (fodder cutting, high stocking rate) (Plantureux, Peeters & McCracken 2005) but they are not relevant to the Qinghai–Tibetan Plateau where planting forages is restricted to only a very small proportion of the landscape and the climate limits options for intensive grassland use. Extensive systems of grazing management (Vallentine 2000) characterised by low input and low utilisation rates are more relevant to the Qinghai–Tibetan Plateau. Sustainable intensification promotes a balance that maximises the efficiency of external inputs (fertiliser, supplementary feeding) and maintains internal resources (environmental services) (Himmelstein, Ares & van Houweling 2016). In the Qinghai–Tibetan Plateau, inputs are generally negligible, while the utilisation rates can vary with stocking rates, often being driven by economic factors as perceived by herders (Metera et al. 2010). Herders believe that more animals raised on the grasslands means more cash (gross income) for the herder households despite the lower quality of the animal products, the degradation of grasslands with lower grassland yields and the loss of biodiversity. Sustainable intensification for the Qinghai–Tibetan Plateau requires the identification of utilisation rates that maintain the proportions of useful plant species and the level of grassland productivity while keeping livestock gross margins at optimal levels. Sustainable utilisation rates of the grassland–livestock system do require a broader consideration of environmental, social and economic components, where socioeconomic development is limited by environmental boundaries (Steffen et al. 2015; Ross et al. 2016). In fragile environments where financial return is linked to the number of animals produced, it is increasingly difficult to achieve sustainability. Slower animal growth rates mean that the efficiency of animal production is not as high as it is in regions where the forage supply is better. To satisfy community desires, environmentally and socioeconomically sustainable farming practices should receive equal attention.

The system simulations shown here provide a good example of how to analyse the problem. When the flock size was maintained at 900 sheep (2.6 sheep/ha—close to the regional average, Chapter 2), the annual gross margin first increased and then decreased to an extremely low level, which agreed with the conceptual model proposed by Jones & Sandland (1974). In the current study, it was concluded that economic returns peaked at a target size of 600 sheep (1.7 sheep/ha) and that it was better to keep the total number of sheep under 500 (1.5 sheep/ha or 1.4 SE/ha), which is about half the district stocking rate. The results showed that a lower flock size resulted in greater stability in economic returns per hectare. This provides a simple indicator of the risk thresholds for livestock management in the case study area, i.e. the critical threshold in stocking rates beyond which the risks of deterioration in the grasslands and household income increased.

In their review, Shang et al. (2014) concluded that the major issue that restricted achieving sustainable grassland–livestock production was the feed imbalance. Overgrazing is generally believed to be the main issue in the rangeland areas of China, and throughout Central Asia, Africa and other similar regions (Kemp et al. 2013). Kemp et al. (2013) reviewed the current situation of the grassland production system in the western parts of China and pointed out that the energy supply in forages and feeds, livestock demand, and cash flows should be the key aspects to focus on. They made recommendations in seven areas:

- grazing systems
- better enterprises
- animal management
- animal nutrition
- infrastructure development
- finance
- policy.

Kemp et al. (2013) considered that the available evidence indicated that lower stocking rates would be necessary to restore grasslands to their longer-term desired states. Dong et al. (2013) a summarised the main drivers for grassland degradation in the water source region of three rivers as long-term overstocking, coupled with weather dryness or climate warming, and the destruction of grasslands by rodents. The combination of these have led to black-soil patches. The case study area has slightly higher annual precipitation (620 mm, Li et al. 2011) compared to that of the source regions of the three rivers in the Qinghai province (550 mm, Dong et al. 2013), but this may not have much effect on grassland growth and the conclusions about risk thresholds are likely to remain valid over large areas. As research has shown that there is a continuous drying trend in Maqu (Wang et al. 2006), the findings from this study highlight the importance of reduced stocking for the sustainable development, biologically and economically, of the grassland production system.

Biodiversity of grassland is important and it is associated with various ecosystem services such as nutrient recycling, microclimate and local hydrological processes regulation, suppression of less-desirable organisms and detoxification of noxious chemicals (Altieri 1999). Regions like the Qinghai–Tibetan Plateau are critical for preserving biodiversity and ecological functions, especially given the increasing rate of biodiversity loss at the global scale (Cardinale et al. 2012). In Europe, intensive grazing systems tend to be incompatible with maintaining a high level of biodiversity. In higher rainfall areas of southern Australia, maintaining the grassland herbage mass above 2 t DM/ha by lowering stocking rates ensured the maintenance of a diverse plant community (Kemp et al. 2003). It can be argued that extensively managed grasslands and meadows are of crucial importance for maintaining grassland biodiversity, and that both the intensive use and abandonment of grasslands would harm global biodiversity. Examples from Europe have shown that grazing animals can be used to maintain or restore landscapes under extensive grazing systems (Metera et al. 2010). In the current study, a reduced flock size does influence the functional group composition of grasslands. This suggests that rational and strategic utilisation (Behrendt et al. 2016) would be a potential way to maintain the ecological services in the case study area. The current study also indicated that reduced grazing pressure has advantages in maintaining the stability of the grazing system over time, in terms of the compositional proportion of plant functional groups, animal performance and economic returns per hectare. These results were achieved under a relatively steady state simulation, where climate could not vary. In practice, there are many variables that mean judgements about sustainable stocking rates need to be flexible and that criteria other than animal numbers should be used to determine when the grassland–livestock system is close to any critical risk threshold. Chapter 10 discusses how a practical, more efficient, criterion is to monitor the average herbage mass over summer and adjust animal numbers to maintain the herbage mass above a critical minimum. Research is needed for alpine meadows to determine the critical herbage mass minimum.

Grazing animals affect grasslands through defoliation, treading, depositing excreta and the transportation of seeds (Metera et al. 2010). The primary role of grazing animals in grassland biodiversity management is the maintenance and enhancement of sward structural heterogeneity and the resulting botanical and faunal diversity. This is achieved by selective defoliation in response to dietary choices, treading, nutrient cycling and propagule dispersal (Rook & Tallowin 2003). It is well established that large ruminants can enhance plant diversity at low stocking rates, where utilisation rates are low, and conversely decrease diversity at higher stocking rates (Olff & Ritchie 1998, Plantureux, Peeters & McCracken 2005). The intensity of grazing activities may exceed the capacity of a natural system and adversely affect the whole system. Rook and Tallowin (2003) concluded that the main mechanism is selective grazing and dietary selection by the grazing animals, which creates and maintains the structural heterogeneity of grassland swards (Metera et al. 2010). Under extensive grazing on the Qinghai–Tibetan Plateau, where the level of utilisation is low, animals can be highly selective. This is why changes in plant species can occur before there is any change in total grassland productivity. The challenge is to minimise any adverse changes, rather than thinking it is feasible to completely eliminate them (Chapter 10). In the current study, when compared with other optimisation solutions, destocking is the most useful strategy for maintaining grassland composition. This demonstrates that appropriate utilisation rates are the key to sustainable grassland management (Kemp et al. 2013). Destocking can be achieved by rotational grazing. Rotational grazing at higher instant stocking rates reduces the selectivity of the grazing animals, which can be an advantage.

The Qinghai–Tibetan Plateau is not the only alpine system that has been historically overstocked. Overgrazing has resulted in the degradation of vegetation and soils across much of the alpine areas of the north Atlantic region, which includes some parts of Greenland and Norway (Ross et al. 2016). In principle, the same mechanisms have applied as considered in this study. It is generally believed that projected future global warming might cause extensive biodiversity and ecosystem losses in high-altitude mountain regions worldwide. Some research suggests that continued warming could be potentially advantageous for alpine vegetation (Crawford 2008) and observations carried out in the subalpine/alpine vegetation of the Swedish Scandinavian mountains supports this position (Kullman 2010). Given the predictions of warmer and hotter weather in the future (Wang et al. 2006), careful attention is needed to identify more optimal grazing regimes and systems in the case study area. Suitable grazing strategies need to be applied to healthy grassland to maintain its structure, function and resilience (Xu & Guo 2015) while researching how the natural grasslands across the vast Qinghai–Tibetan Plateau will change under future climatic uncertainty.

Professor Kemp and Dr Pematso with Tibetan herders near Namtso Lake on the Qinghai–Tibetan Plateau. Photo: D.R. Kemp

References

Altieri, MA 1999, 'The ecological role of biodiversity in agroecosystems', *Impact of grazing on soil carbon*, vol. 74, pp. 19–31.

An, Z, Kutzbach, JE, Prell, WL & Porter, SC 2001, 'Evolution of Asian monsoons and phased uplift of the Himalaya–Tibetan plateau since Late Miocene times', *Nature*, vol. 411, pp. 62–66.

Behrendt, K, Cacho, OJ, Scott, JM & Jones, R 2016, 'Using seasonal stochastic dynamic programming to identify optimal management decisions that achieve maximum economic sustainable yields from grasslands under climate risk', *Agricultural Systems*, vol. 145, pp. 13–23.

Behrendt, K, Liu, HB, Kemp, DR & Takahashi, T 2018, 'StageTHREE Sustainable Grasslands Model: model description and technical manual', *Australian Centre for International Agricultural Research*, Canberra, Australia (in press).

Cacho, OJ 1993, 'A practical equation for grassland growth under grazing', *Grass and Forage Science*, vol. 48, pp. 387–394.

Cao, J, Yeh, ET, Holden, NM, Yang, Y & Du, G 2013, 'The effects of enclosures and land-use contracts on rangeland degradation on the Qinghai-Tibetan plateau', *Journal of Arid Environments*, vol. 97, pp. 3–8.

Cardinale, BJ, Duffy, JE, Gonzalez, A, Hooper, DU, Perrings, C, Venail, P, Narwani, A, Mace, GM, Tilman, D & Wardle, DA 2012, 'Biodiversity loss and its impact on humanity', *Nature*, vol. 486, pp. 59–67.

Crawford, RM 2008, 'Cold climate plants in a warmer world', *Plant Ecology & Diversity*, vol. 1, pp. 285–297.

Dong, QM, Zhao, XQ, Wu, GL, Shi, JJ & Ren, GH 2013, 'A review of formation mechanism and restoration measures of "black-soil-type" degraded grassland in the Qinghai-Tibetan Plateau', *Environmental Earth Sciences*, vol. 70, pp. 2359–2370.

Fitzpatrick, EA & Nix, HA 1970, 'The climate factor in Australian grassland ecology', in RM Moore (ed.), *Australian Grasslands*, ANU Press, Canberra, pp. 3–26.

Freer, M, Dove, H & Nolan, JV (eds) 2007, *Nutrient requirements of domesticated ruminants*, CSIRO Publishing, Collingwood, p. 270.

Freer, M, Moore, AD & Donnelly, JR 1997, 'GRAZPLAN: decision support systems for Australian grazing enterprise. II. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS', *Agricultural Systems*, vol. 54, pp. 77–126.

Harris, N 2006, 'The elevation history of the Tibetan Plateau and its implications for the Asian monsoon', *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 241, pp. 4–15.

Harris, RB 2010, 'Rangeland degradation on the Qinghai-Tibetan plateau: a review of the evidence of its magnitude and causes', *Journal of Arid Environments*, vol. 74, pp. 1–12.

Herrero, M & Thornton, PK 2013, 'Livestock and global change: emerging issues for sustainable food systems', *Proceedings National Academy of Sciences*, vol. 110, pp. 20878–20881.

Himmelstein J, Ares A & van Houweling, E 2016, 'Sustainable intensification: a multifaceted, systemic approach to international development', *Journal of the Science of Food and Agriculture*, vol. 96(15), pp. 4833–4839.

Johnson, IR 2013, *DairyMod and the SGS Pasture Model: a mathematical description of the biophysical model structure*, IMJ Consultants, Dorrigo, NSW, Australia.

Jones, RJ & Sandland, RL 1974, 'The relation between animal gain and stocking rate: derivation of the relation from the results of grazing trials', *The Journal of Agricultural Science*, vol. 83(2), pp. 335–342.

Kemp, DR, Michalk, DL & Virgona, JM 2000, 'Towards more sustainable grasslands: lessons learnt', *Animal Production Science*, vol. 40, pp. 343–356.

Kemp, DR, King, WMcG, Lodge, GM, Murphy, SR, Quigley, P & Sanford, P 2003, 'SGS Biodiversity Theme: the impact of plant biodiversity on the productivity and stability of grazing systems', *Australian Journal of Experimental Agriculture*, vol. 43(8), pp. 962–975, doi: 10.1071/EA02200.

Kemp, DR & Michalk, DL (eds) 2011, *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 189.

Kemp, DR, Han, GD, Hou, XY, Michalk, DL, Hou, FJ, Wu, JP & Zhang, YJ 2013, 'Innovative grassland management systems for environmental and livelihood benefits', *Proceedings of the National Academy of Sciences of the United States of America*, vol. 110 (21), pp. 8369–8374, doi: 10.1073/pnas.1208063110.

Kullman, L 2010, 'A richer, greener and smaller alpine world: review and projection of warming-induced plant cover change in the Swedish Scandes', *Ambio*, vol. 39, pp. 159–169.

Li, Q & Xue, Y 2010, 'Simulated impacts of land cover change on summer climate in the Tibetan Plateau', *Environmental Research Letters*, vol. 5(1), 015102.

Li, Q, Yang, X, Soininen, J, Chu, CJ, Zhang, JQ, Yu, KL & Wang, G 2011, 'Relative importance of spatial processes and environmental factors in shaping alpine meadow communities', *Journal of Plant Ecology*, vol. 4, pp. 249–258.

Li, XL, Gao, J, Brierley, G, Qiao, YM, Zhang, J & Yang, YW 2013, 'Rangeland degradation on the Qinghai-Tibet plateau: implications for rehabilitation', *Land Degradation & Development*, vol. 24, pp. 72–80.

Liang, J, Jiao, T, Wu, JP, Gong, X, Du, WH, Liu, HB & Xiao, Y 2015, 'The relationship between seasonal forage digestibility and forage nutritive value in different grazing grasslands' [Chinese with English abstract], *Acta Prataculturae Sinica*, vol. 24(6), pp. 108–115.

Liu, HB 2017, 'Simulation and application of the Sustainable Grasslands Model in the meadow area of Qinghai-Tibetan Plateau', PhD thesis, Gansu Agricultural University, Lanzhou, China.

Liu, HB, Li, L, Pu, X & Du, WH 2017, 'Study on the feed balance situation of the alpine meadow area on the eastern edge of the Qinghai-Tibetan Plateau: based on a steady state model simulation', [Chinese with English abstract], *Grassland and Turf*, vol. 37(4), pp. 26–37, 46.

Liu, HB, Wu, JP, Tian, X & Du, WH 2016, 'Dynamic of aboveground biomass and soil moisture as affected by short-term grazing exclusion on eastern alpine meadow of Qinghai-Tibet plateau, China', *Chilean Journal of Agricultural Research*, vol. 76, pp. 321–329.

Liu, X & Chen, B 2000, 'Climatic warming in the Tibetan Plateau during recent decades', *International Journal of Climatology*, vol. 20, pp. 1729–1742.

Lu, H, Wang, SS, Zhou, QW, Zhao, YN & Zhao, BY 2013, 'Damage and control of major poisonous plants in the western grasslands of China – a review', *The Rangeland Journal*, vol. 34, pp. 329–339.

Lu, J, Dong, Z, Li, W & Hu, G 2014, 'The effect of desertification on carbon and nitrogen status in the northeastern margin of the Qinghai-Tibetan Plateau', *Environmental Earth Sciences*, vol. 71, pp. 807–815.

Mayer, DG & Butler, DG 1993, 'Statistical validation', *Ecological Modelling*, vol. 68, pp. 21–32.

Metera, E, Sakowski, T, Sloniewski, K & Romanowicz, B 2010, 'Grazing as a tool to maintain biodiversity of grassland – a review', *Animal Science Papers and Reports*, vol. 28, pp. 315–334.

Miehe, G, Miehe, S, Kaiser, K, Reudenbach, C, Behrendes, L, La Duo, F & Schlütz, F 2009, 'How old is pastoralism in Tibet? An ecological approach to the making of a Tibetan landscape', *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 276, pp. 130–147.

Miller, DJ 1990, 'Grasslands of the Tibetan Plateau', *Rangelands*, vol. 12, pp. 159–163.

Ni, J 2002, 'Carbon storage in grasslands of China', *Journal of Arid Environments*, vol. 50, pp. 205–218.

Nicol, A (ed.) 1987, *Livestock feeding on pasture*, Occasional Publication 10, New Zealand Society of Animal Production, Hamilton, New Zealand.

Olff, H & Ritchie, ME 1998, 'Effects of herbivores on grassland plant diversity', *Trends in ecology & evolution*, vol. 13, pp. 261–265.

Plantureux, S, Peeters, A & McCracken, D 2005, 'Biodiversity in intensive grasslands: effect of management, improvement and challenges', *Agronomy Research*, vol. 3, pp. 153–164.

Rook, AJ & Tallowin, JRB 2003, 'Grazing and grassland management for biodiversity benefit', *Animal Research*, vol. 52, pp. 181–189.

Ross, LC, Austrheim, G, Asheim, L-J, Bjarnason, G, Feilberg, J, Fosaa, AM, Hester, AJ, Holand, O, Jonsdottir, IS, Mortensen, LE, Mysterud, A, Olsen, E, Skonhoft, A, Speed, JDM, Steinheim, G, Thompson, DBA & Thorhallsdottir, AG 2016, 'Sheep grazing in the North Atlantic region: a long-term perspective on environmental sustainability', *Ambio*, vol. 45, pp. 551–566.

Scott, JM, Hutchinson, KJ, King, K, Chen, W, McLeod, M, Blair, GJ, White, A, Wilkinson, D, Lefroy, RDB, Cresswell, H, Daniel, H, Harris, C, MacLeod, DA, Blair, N & Chamberlain, G 2000, 'Quantifying the sustainability of grazed pastures on the Northern Tablelands of New South Wales', *Australian Journal of Experimental Agriculture*, vol. 40, pp. 257–265.

Shang, ZH, Gibb, MJ, Leiber, F, Ismail, M, Ding, LM, Guo, XS & Long, RJ 2014, 'The sustainable development of grassland-livestock systems on the Tibetan plateau: problems, strategies and prospects', *The Rangeland Journal* , vol. 36, pp. 267–296.

Steffen, W, Richardson, K, Rockström, J, Cornell, SE, Fetzer, I, Bennett, EM, Biggs, R, Carpenter, SR, de Vries, W & de Wit, CA 2015, 'Planetary boundaries: guiding human development on a changing planet', *Science*, vol. 347(6223), doi: 10.1126/science.1259855.

Tang, L, Dong, S, Sherman, R, Liu, S, Liu, Q, Wang, X, Su, X, Zhang, Y, Li, Y, Wu, Y, Zhao, H, Zhao, C & Wu, X 2015, 'Changes in vegetation composition and plant diversity with rangeland degradation in the alpine region of Qinghai-Tibet Plateau', *The Rangeland Journal*, vol. 37, pp. 107–115.

Thornley, JHM & France, J 2007, *Mathematical models in agriculture: quantitative methods for the plant, animal and ecological sciences*, 2nd edn, CABI Publishing, Wallingford.

Vallentine, JF 2000, *Grazing management*, 2nd edn, Elsevier.

Wang, C, Lang, X & Liu, Z 2012, *Genetic selection and production of Oula Tibetan sheep*, Gansu science and technology press, Lanzhou.

Wang, P, Lassoie, JP, Morreale, SJ & Dong, S 2015, 'A critical review of socioeconomic and natural factors in ecological degradation on the Qinghai-Tibetan Plateau, China', *The Rangeland Journal*, vol. 37, pp. 1–9.

Wang, S, Song, L, Han, Y & Feng, J 2006, 'Impacts of climate change on ecological environment in Maqu grassland, Gansu' (Chinese with English abstract), *Journal of Glaciology and Geocryology*, vol. 28, 556–561.

Wen, L, Dong, S, Li, Y, Li, X, Shi, J, Wang, Y, Liu, D & Ma, Y 2013, 'Effect of degradation intensity on grassland ecosystem services in the alpine region of Qinghai-Tibetan Plateau, China', *PLoS ONE*, vol. 8(3), e58432, doi: 10.1371/journal.pone.0058432.

Wu, J, Yang, P, Zhang, X, Shen, Z & Yu, C 2015, 'Spatial and climatic patterns of the relative abundance of poisonous vs non-poisonous plants across the Northern Tibetan Plateau', *Environmental Monitoring and Assessment*, vol. 187(8), doi: 10.1007/s10661-015-4707-z.

Wu, T, Wu, J, Zhao, S, Jiao, T, Liang, J, Liu, Z Y & Ka, Z. 2016, 'Seasonal dynamics research on grazing intake of Oula Tibetan sheep at different ages in Gannan Maqu' (Chinese with English abstract), *Acta Agrestia Sinica*, vol. 24, pp. 317–321.

8 Desert steppe grazing management

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Grazing by domestic or large herbivores is the primary method for livestock production in semi-arid grasslands of the world (eds Kemp & Michalk 1993; Herrero & Thornton 2013). This has a major influence on determining plant community composition in the grassland (Milchunas et al. 1989; Cheng et al. 2011). Grazing influences the balance between different species and population dynamics (Barkham 1980; Pitelka, Hansen & Ashmun 1985; Weiner 1988; Kemp et al. 2003; Pärtel, Bruun & Sammul 2005) and has a direct effect on plant development and species composition (Austrheim & Eriksson 2001; Cousins & Eriksson 2001).

The botanical composition and standing herbage mass are the key indicators of grassland condition for livestock production (Chapter 10) and indicators of the outcomes of environment–grassland interactions from factors such as grazing management, hay cuts, fertiliser and other interventions, plus the influence of natural factors such as soil fertility, climatic conditions and fire. Grazing practices are known to change plant species composition; for example, causing shifts in dominant species from perennial bunchgrasses to annual species and grazing-tolerant perennial species (Moore 1970; Kemp et al. 2003; Gao et al. 2009; Hoffmann et al. 2016). Grassland management strategies need to identify ways of improving the botanical composition and herbage mass to satisfy the needs of livestock production within the constraints of natural environmental factors.

The role of plant species richness in determining the productivity of grasslands has been the subject of a range of studies in arid and semi-arid regions. There has often been a clear relationship between soil water availability and plant species richness (Adler & Levine 2007; Kutiel, Kutiel & Lavee 2000; Shmida & Wilson 1985; Ward & Olsvig-Whittaker 1993; unpublished work of the senior authors) but that does not mean that productivity is a simple function of species richness. Grazing interacts with these relationships and can be the main determinant of plant community productivity, which declines as stocking rates increase (Fernandez-Gimenez & Allen-Diaz 2001; Hoshino et al. 2009; Sasaki et al. 2005, 2008; Van Staalduinen, During & Werger 2007; Cheng et al. 2011). Often productivity is determined by a few dominating species, whereas, when richness increases, the extra species are often less productive (Kemp et al. 2003; Fraser et al. 2015). Within the group of more productive species, there is some complementarity which lessens any relationship between species richness and herbage mass. Productivity can then decline as richness increases, as shown in a series of experiments (Kemp et al. 2003). However, recent studies have indicated that there is a unimodal relationship (i.e. optimal) between productivity and species richness (Flombaum & Sala 2008; Fraser, Jentsch & Sternberg 2014; Fraser et al. 2015). These differences among various studies depend in part on the range in species richness, how disturbed some sites are and the scale of the study. Rather than a simple measure of species richness, productivity is often better related to plant functional groups (Kemp et al. 2003; Tilman, Isbell & Cowles 2014) where, within any group, there is some redundancy among species. The plant functional traits within a functional group are useful in predicting grazing responses within grassland. Grazing intensity can change the composition of plant functional groups (Irisarri et al. 2016). Plant functional groups are often easier for herders to recognise and manage than trying to monitor all species in the grassland.

Many grasslands are the prime resource that sustains livestock and herder households. The grasslands need to be managed so that livestock production and household incomes are optimised and sustained. This chapter reports on a longer-term grazing study on the desert steppe in IMAR that aimed to answer the following questions:

- Can grazing management optimise plant species composition to sustain productivity?
- Which plant functional groups are the more important to manage?
- How variable is grassland production in response to precipitation?
- What level of utilisation is optimal for grassland sustainability?
- How does the optimal animal stocking rate relate to the optimum management of plants?

Methods

Site description

The experiment was carried out on a degraded desert steppe grassland in Siziwang, IMAR (41.78°N, 111.89°E, elevation 1460 m). The site is characterised by a continental climate with a mean annual precipitation of 223 mm, a mean annual ambient air temperature of 3.6 °C, cold winters, dry and windy springs and hot summers. The majority of precipitation occurs as rainfall between June–September, during the frost-free period of about 175 days. Soils are classified as Kastanozems and have a sandy loam texture. The grasses *Stipa breviflora* Griseb. and *Cleistogenes songorica* (Roshev.) Ohwi and the semi-shrub *Artemisia frigida* are the commonly dominant plant species followed by *Kochia prostrata* (L.) Schrad, *Convolvulus ammannii* Desr. and *Allium tenuissimum* L. Together these six species produce a mean vegetation cover of 7–20% at a mean height of about 5 cm. Further details about this site can be found in Wang et al. (2014). This experimental site was chosen to represent rangeland that had been degraded as a result of long-term overstocking (≥ 60% utilisation rate) that has resulted in the number of vascular plant species being reduced from over 50 to less than 30 across the site.

Project team inspecting the Siziwang desert steppe grazing experiment in late spring. Photo: D.R. Kemp

Experiment design

The 12 years of study reported here began in June 2004, using four stocking rate treatments laid out in a randomised complete block design with three replications (12 fenced plots in total). Due to topographical considerations, plot sizes varied from 4–5.4 ha with one plot being 1.9 ha. Animal numbers per plot were adjusted to achieve the desired stocking rates. Local adult Mongolian wether sheep were used at stocking rates that averaged 0, 0.9, 1.6 and 2.3 SE/ha. These stocking rates are referred to as the nil, non-grazed exclosure (CK), and light (LG), moderate (MG) and heavy (HG) grazed treatments respectively. The HG treatment was set at the stocking rate average for local herders at the time the experiment commenced. For analyses, stocking rates were standardised to the equivalent of a 50kg sheep (1 SE), based in average weights measured through summer. A new group of one-year-old animals were introduced onto the plots every three years. Grazing only occurred during summer and autumn (June–November), except in the first winter when the local village sheep inadvertently heavily grazed all the plots. Livestock management details can be found in Wang et al. (2011). The data on livestock grassland interactions were analysed by considering the grazing period each year as two phases. The first phase was during summer, when the grass was green. The second phase was in autumn after the first frosts. In general, livestock growth occurred in summer, then ceased, and weight loss occurred through autumn. Animals were weighed at the start of summer, then in mid summer (late August/early September) and late October/early November when grazing finished for the year. While animal production was recorded, the main interest was to investigate the effects of different stocking rates on grassland condition.

Sampling and analysis

Grasslands were sampled each year from 2004, in June and then in late August/early September when they were at peak growth. In each of the 12 paddocks, 10 portable cages (1.5 m x 1.5 m) in a relatively flat area of each plot were randomly located each year (ensuring no repeat sampling of any area from year to year). In the cages, individual vascular plants (current year's growth) were identified, counted, recorded and clipped to ground level within a 1 m^2 quadrat to determine net growth of above-ground biomass. On each occasion, a 1 m^2 quadrat was also sampled nearby, outside each cage. Dry matter was obtained by oven-drying samples at 65 °C for 48 hours or more, until the herbage mass remained constant. These data were used to estimate total plant growth and estimated utilisation rates through summer. Meteorological data were measured using a micro-weather station (GroWeather, Version 1.2, Davis Instruments Corporation, USA) that was at the experimental site.

The estimated grassland utilisation rate for each treatment, derived from cage data, was calculated as:

U = ((HMi – HMo)/HMi) x 100 (%)

where:

U = utilisation rate

HMi = herbage mass inside cage

HMo = herbage mass outside cage.

This method of estimating utilisation rates is known to overestimate actual consumption by animals, often by a factor of two (Kemp et al. 2018) as the utilisation losses include the herbage consumed by micro- and meso-herbivores, disease and other losses from different leaf age structures. In this monograph, this calculation is referred to as an estimate of utilisation, whereas consumption is directly calculated from the likely DMI by animals, derived from standard equations (Chapter 10; eds Freer, Dove & Nolan 2007).

Plant species were classified into four plant functional groups (PFGs) based on their ecological and biological characteristics:

- perennial grasses and sedges that were a major part of the biomass (PG)
- shrubs and semi-shrubs that were a major part of the biomass (SS)
- perennial forbs and other minor species (PF)
- annuals and biennials (intermittent species) (AB).

Additional data on tiller numbers were obtained in 2014 and 2015, using three fixed quadrats in each plot, and counting the tiller density of dominant species in each quadrat in May at the start of growth and again in September, at peak growth.

The effects of stocking rate treatments, year and their interactions on the dry matter yield of PFGs were examined using the analysis of variance with a MIXED model (PROC MIXED, SAS Institute Inc., 2008). Stocking rate, year, and their interactions were fixed effects, while replication and replication x stocking rate were random effects. When treatment effects were significant ($P < 0.05$), the means were separated with the least significant difference test of the LSMEANS procedure. Analysis of variance procedures were used to examine general effects, but as the treatments were part of a continuum, the data was often combined and analysed using regression models to show trends (using SAS and Excel).

Results

Botanical composition and species diversity

There were 55 plant species found at the site:

- 7 perennial grasses and sedges
- 6 shrubs and semi-shrubs
- 36 perennial forbs and other minor species
- 6 annuals and biennials.

Most species were found in all treatments (Table 8.1) though this was more variable among the minor species. The main treatment differences found were in the biomass of each PFG between treatments and over the 12 years of this study. The total biomass of most PFGs declined from the nil to heavy grazing treatments. The exceptions were perennial grasses and sedges, and the annual/biennial PFG where the total herbage mass under light grazing remained similar to nil grazing. This suggested that, under light grazing, shrubs, semi-shrubs and other minor perennials and forbs were being grazed in preference to perennial grasses, sedges, annuals and biennials.

Table 8.1 Mean botanical composition in different stocking rate treatments, Siziwang, IMAR, 2004–15

Plant functional group and species	Nil grazing (g/m^2)	Light grazing (g/m^2)	Moderate grazing (g/m^2)	Heavy grazing (g/m^2)	Forage preference
Total perennial grasses and sedges	**120.99**	**127.23**	**87.86**	**50.56**	
Agropyron cristatum	5.39	3.06	1.55	2.35	moderate
Carex pediform (sedge)	1.49	1.74	0.49	0.67	high
Cleistogenes songorica (C4)	14.07	15.21	20.38	14.27	high
Cleistogenes squarrosa (C4)	16.26	30.97	22.37	4.56	high
Leymus chinensis	6.49	3.91	1.18	1.16	high
Stipa breviflora	28.78	27.09	22.33	19.69	low
Total shrubs and semi-shrubs	**88.37**	**64.81**	**36.41**	**28.5**	
Artemisia frigida Willd.	33.95	24.77	18.84	12.48	moderate
Caragana microphylla Lam (legume)	10.32	6.00	6.24	3.26	low
Caragana stenophylla Pojark. (legume)	4.59	2.14	1.09	1.96	low
Ceratoides latens (J.F. Gmel) Reveal et. Holmgren	17.19	17.88	5.85	6.27	low
Kochia prostrata (L.) Schrad	15.97	8.44	2.87	3.55	moderate
Lagochilus ilicifolius Bunge	6.35	5.58	1.52	0.98	low
Total perennial forbs and other minor species	**163.82**	**96.81**	**44.92**	**37.96**	

Plant functional group and species	Nil grazing (g/m²)	Light grazing (g/m²)	Moderate grazing (g/m²)	Heavy grazing (g/m²)	Forage preference
Allium mongolicum regel	5.65	1.31	0.56	2.49	high
Allium polyrhizum	2.95	0.87	0.23	0.30	high
Allium tenuissimum L.	3.61	1.04	0.77	0.85	high
Artemisia commutata Bess.	0.90	0.93	0.63	0.71	high
Artemisia sieversiana Ehrh. ex Willd.	0	8.00	0	0	high
Artemisia tanacetifolia	17.01	4.72	1.89	1.31	high
Asparagus cochinchinensis (Lour.) Merr.	7.05	0.24	0	0	high
Astragalus galactites Pall. (legume)	2.75	1.19	1.41	1.02	high
Astragalus scaberrimus Bunge (legume)	2.31	3.75	1.10	1.37	high
Bupleurum Linn.	0	0.05	0	0	high
Convolvulus ammannii Desr.	9.87	5.35	4.34	4.24	high
Corispermum mongolicum Iljin	0.68	0	0.20	0	high
Cymbaria dahurica L.	14.14	0	0	0.80	high
Galium verum L.	0.36	0	0	0.08	high
Gentiana dahurica	0.66	0.17	0.14	0	high
Haplophyllum dauricum (L.) Juss.	2.79	1.03	0.89	0.43	high
Heteropappus altaicus (Willd.) Novopokr.	12.25	9.24	2.03	3.18	high
Iris lactea Pall.	0	1.60	1.74	0.11	high
Iris tenuifolia Pall.	2.05	3.04	5.30	5.72	high
Linum stelleroides Planch.	2.98	1.28	0.55	3.50	high
Melilotoides ruthenica (L.) Sojak	1.54	0.65	0.42	1.01	high
Oxytropis tenuis Palib.	3.65	2.40	0	0	high
Parthenocissus tricuspidata	0.45	0.95	0.42	0.81	high
Phlomis mongolica Turcz	1.47	3.94	0.55	1.39	high
Portulaca oleracea Linn.	0.38	0.28	0.66	0.51	high
Potentilla acaulis L.	2.03	14.00	2.47	2.12	high
Potentilla anserina L.	0	0	10.60	0	high
Potentilla bifurca Linn.	3.00	1.35	1.21	0.95	high
Potentilla tancetifolir	0.24	0.08	1.20	0	high
Potentilla verticillaris Steph. ex Willd.	0	1.05	0.70	0.08	high
Scorzonera austiaca Willd.	1.92	0	0	0	high

Plant functional group and species	Nil grazing (g/m²)	Light grazing (g/m²)	Moderate grazing (g/m²)	Heavy grazing (g/m²)	Forage preference
Silene conoidea Linn.	0	0	0	0	high
Ixeris denticulata (Houtt.) Stebbins	10.80	11.48	0	1.02	low
Anemarrhena asphodeloides Bunge	0.17	0	0	0	low
Cymbaria dahurica L.	3.25	5.93	0.93	0.08	low
Allium ramosum Linn.	4.23	1.00	0.45	0	low
Artemisia tanacetifolia Linn.	0.35	2.63	0	1.40	low
Artemisia pubescens L.	7.55	0	0.71	0	low
Artemisia gmelinii	17.01	4.72	1.89	1.31	low
Sibbaldia procumbens	0	0	0	0.74	low
Medicago sativa	0	0.71	0	0	low
Allium bidentatum Fisch. ex Prokh.	1.32	0.94	0	0	low
Androsace incana Lam.	0.37	0	0	0.19	low
Artemisia scoparia Waldst. et Kit	1.05	0.89	0.25	0	low
Artemisia capillaris Thunb.	15.03	0	0.68	0.24	low
Total annuals and biennials	**32.53**	**29.34**	**7.85**	**19.49**	
Androsace umbellate (Lour.) Merr.	2.34	0.99	0.35	0.89	moderate
Chenopdium glaucum Linn.	1.06	0.63	0.70	1.15	moderate
Lappula myosotis V. Wolf.	1.16	1.42	0.28	0	moderate
Neopallasia pectinata	5.78	7.41	3.61	1.31	moderate
Ribes burejense Fr. Schmidt	0.36	6.18	0	3.19	moderate
Salsola collina Pall.	21.83	12.71	2.91	12.95	moderate
Total herbage mass (all species)	**405.71**	**318.19**	**177.04**	**136.51**	

Notes:
- Forage preference is based on observations within the experiment.
- Data after 12 years of grazing treatments.

The total species number/m² measured in each treatment varied over the years (Figure 8.1). The ungrazed control (CK) tended to have more species, generally extra minor species (Table 8.1). This difference first became significant after 10 years of the experiment. There were no consistent significant differences in species number among the grazed treatments.

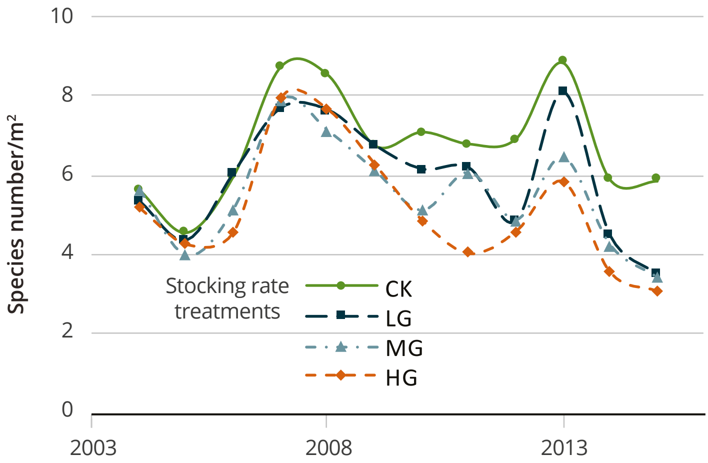

Figure 8.1 Species number for different stocking rate treatments, Siziwang, IMAR, 2004–15

An analysis of the rank abundance curves for the different stocking rate treatments, showed a small non-significant effect in the control treatment where the dominant species marginally exceeded the proportions of total biomass that applied in the other treatments (Figure 8.2). In general, all treatments had similar curves, with 5–6 species each contributing more than 90% of the total biomass.

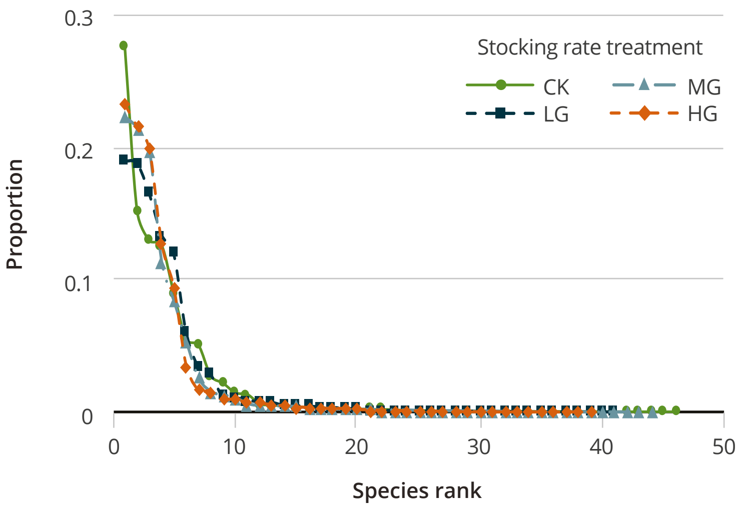

Figure 8.2 Rank abundance curves for different stocking rate treatments, Siziwang, IMAR, 2004–15

Productivity of plant functional groups

The productivity of plant functional groups varied considerably over the 12 years of this experiment. The site was initially degraded and peak herbage mass for all species was very low (Figure 8.3). The perennial grasses and shrubs and semi-shrubs were the most productive plant groups. In 2004, the shrubs dominated the biomass. Over time, perennial grasses increased in all grazing treatments, exceeding the average herbage mass of shrubs after 2010, except for shrubs in the nil and lightly grazed treatments. The herbage mass of perennial grasses showed very little effect of grazing treatments, indicating that the dominant species, *Stipa breviflora*, was not noticeably being grazed by the sheep. The shrubs herbage mass remained low in the moderate and heavy grazing treatments and increased most under nil grazing. Annual and biennial species made little contribution to the herbage mass, except for 2008 when there was a substantial increase. The other perennial forbs also contributed little to the total herbage mass, until 2012 in the nil and lightly grazed treatments, but thereafter declined.

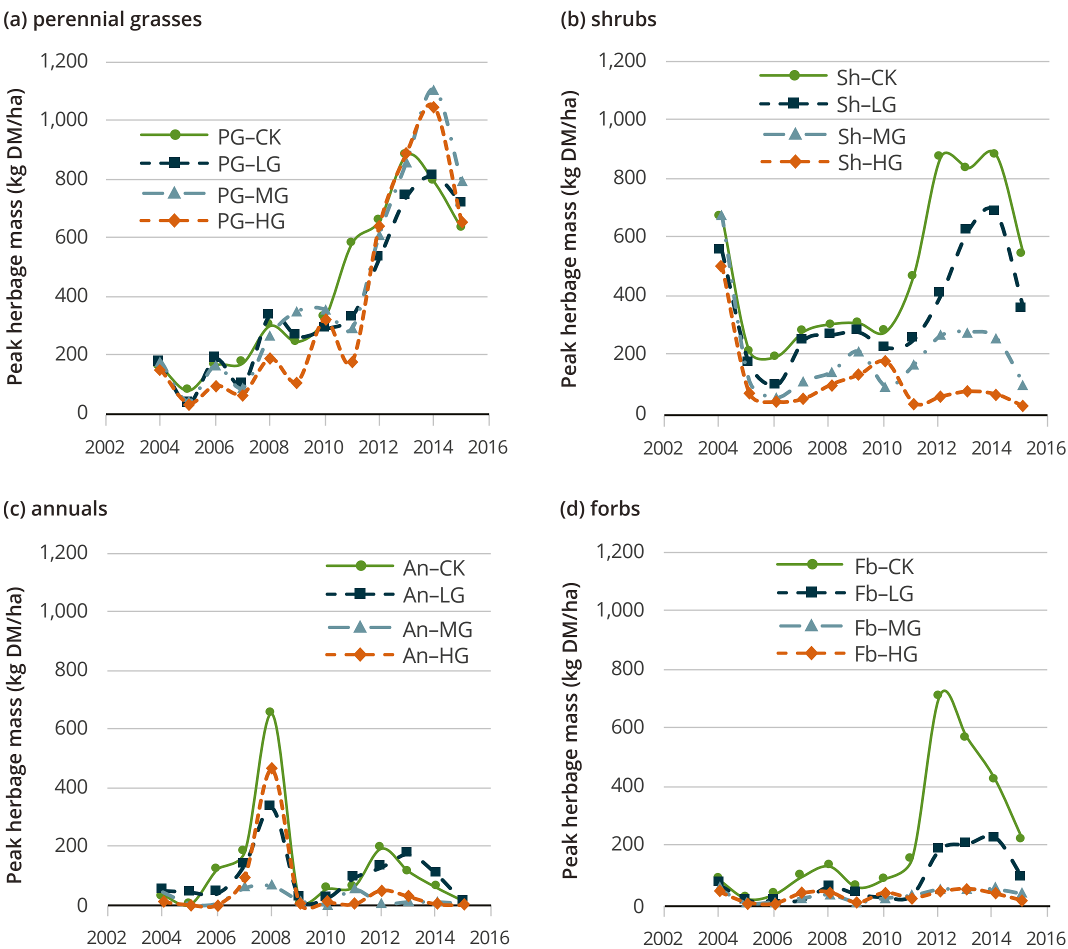

Figure 8.3 Peak herbage mass of (a) perennial grasses, (b) shrubs and semi-shrubs, (c) annuals and biennials and (d) perennial forbs and others under four stocking rate treatments, Siziwang, IMAR, Aug/Sep 2004–15

Siziwang desert steppe grazing experiment in mid summer, in a year of above average rainfall (upper) and a dry year (lower). The high stocking rate treatment is on the left and low stocking rate on the right. Photos: D.R. Kemp

Plant group interactions

The most important interaction in the desert steppe plant community was the one between perennial grasses and shrubs and how that was influenced by grazing (Figure 8.4). All treatments showed similar values for both plant functional groups in 2004. This remained similar under all grazing treatments until 2011, when treatments diverged significantly. The nil and lightly grazed treatments remained close to the 1:1 line in subsequent years. The trajectory for the moderately grazed treatment was close to a 3–4:1 ratio (perennial grasses had 3–4 times the herbage mass of shrubs). The heavily grazed treatment resulted in considerably less shrubs with an average ratio for the trajectory of 12:1 (12 times more herbage mass from the perennial grasses than from the shrubs). This clearly showed that the shrubs were being grazed in preference to the perennial grasses, notably *Stipa breviflora*.

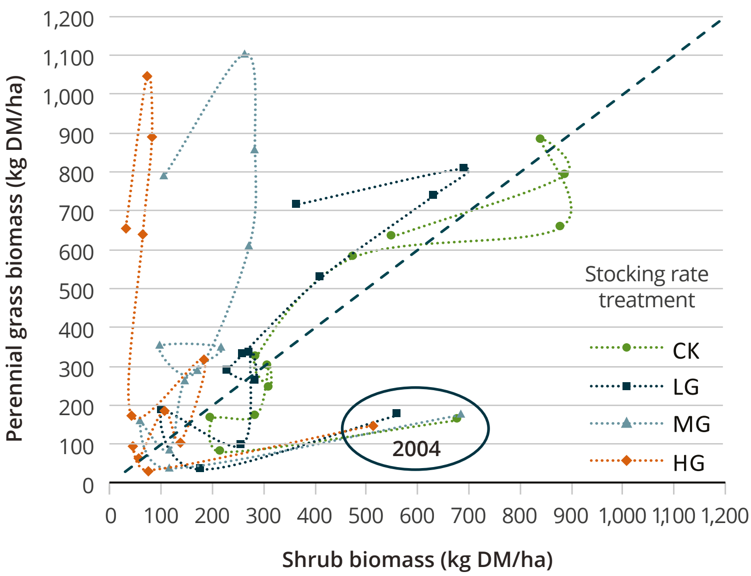

Figure 8.4 Trends in the interaction between shrub and perennial grass herbage mass response to different stocking rate treatments, Siziwang, IMAR, Aug/Sep 2004–15

Note: The starting point for all treatments in 2004 is identified with an oval. The dashed line indicates the 1:1 ratio of these two plant groups.

Plant productivity between and within years

There were significant differences between and within year effects on plant productivity. The peak herbage mass measured in one year was significantly related to the growth in June (the start of summer) in the following year (Figure 8.5). The exception was the data for 2004–5, when the plots were heavily grazed during the intervening winter. The mean effect of the 2004–5 data was that herbage mass in June 2005 was only about one-third of that predicted from the other years. In addition, the initial growth in June was significantly related to the total peak herbage mass produced in the same year (Figure 8.6), though not as significant as in Figure 8.5. All grazing treatments conformed to the same relationships in both cases and were consistent over the years where plant productivity varied considerably.

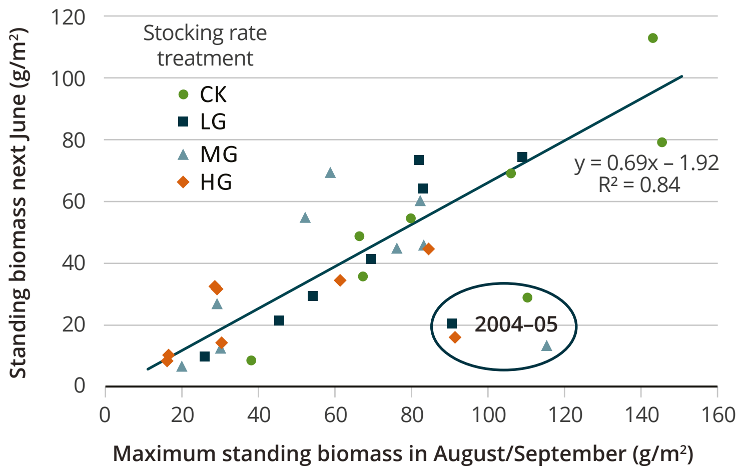

Figure 8.5 Relationship between maximum herbage mass in August/September and herbage mass in June of the following year under different stocking rate treatments, Siziwang, IMAR, 2004–15

Note: Data for 2004–05 has been excluded from fitted line.

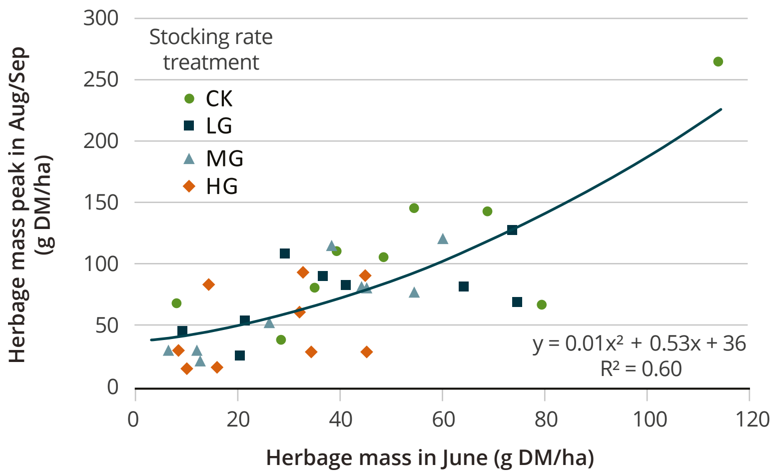

Figure 8.6 Relationship between herbage mass measured in June and peak herbage mass in August/September in the same year under different stocking rate treatments, Siziwang, IMAR, 2004–15

Note: Data from all grazing treatments.

Plant growth, especially for the dominant grasses, was related to the density and growth of tillers. Measurements in 2014 and 2015 showed that the initial tiller density in May, before grazing commenced, was significantly related to the peak herbage mass later that summer in August (Figure 8.7). Initial tiller densities at the start of summer would reflect the plant size of the previous year (Figure 8.5) and their management through winter. The relationship between tiller numbers and peak biomass for *Cleistogenes songorica* suggests a smaller tiller size than for *Stipa breviflora*, but this is probably due to *C. songorica* being grazed more than *S. breviflora*.

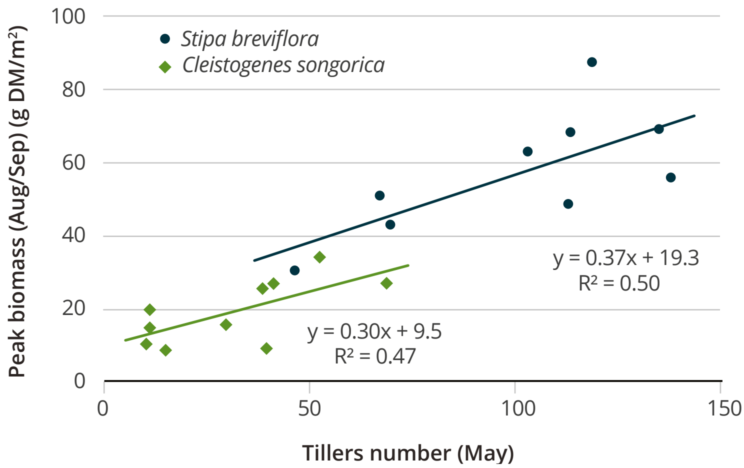

Figure 8.7 Relationship between peak biomass and tiller numbers for *Stipa breviflora* and *Cleistogenes songorica*, Siziwang, IMAR, 2014 and 2015

Precipitation from May–July was related to peak growth, measured in August (Figure 8.8). The slope of the fitted lines varied from 13.7 to 7.8 kg DM/ha for each millimetre of rainfall. The higher response was for the ungrazed plots and the lowest was for the highest stocking rate. For the grazing treatments, the slope of the response was 8.4, 8.6 and 7.8 (mean of 8.3) kg DM/ha per millimetre of rainfall (not significantly different between treatments), though the highest peak DM levels reached on each treatment show a small (not significant) decline as stocking rates increased from LG to MG to HG treatments. The similarities in peak yield from each grazing treatment reflect the earlier data showing that the dominant perennial grass content was not influenced by grazing treatments (Figure 8.3). These relationships show that there would have been no growth if the precipitation declined to an average of approximately 25 mm, an indicator of what might be needed to initiate grassland growth each year. The variability in response to summer precipitation evident in Figure 8.8 reflects the additional factor of how growth in one year was also related to growth in the previous summer (Figure 8.5).

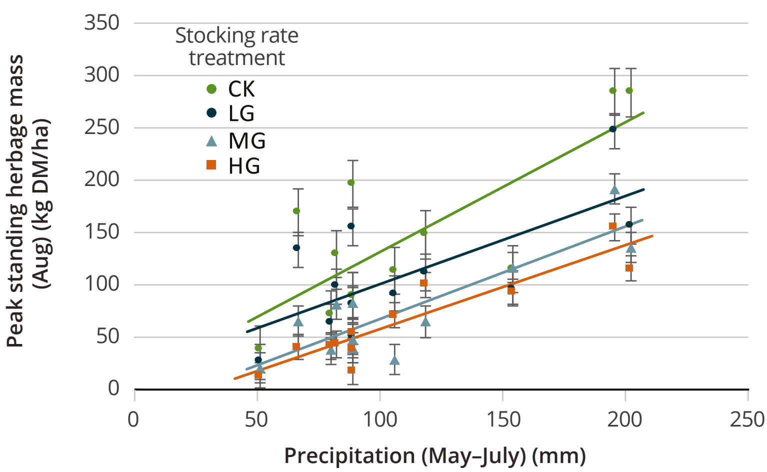

Figure 8.8 Relationship between peak standing herbage mass and early summer rainfall under different stocking rate treatments, Siziwang, IMAR, 2004–15

Animal production

Animal growth rates were linearly related to standardised stocking rates, in line with the model found to fit Chinese grasslands (Figure 8.9). Previous work in this program found that the net financial returns from livestock were generally optimal at the point where animal production per head was about 75% of the maximum. That is about 1 SE/ha, which was half that of the district stocking rate (Chapter 2) when this experiment started in 2004.

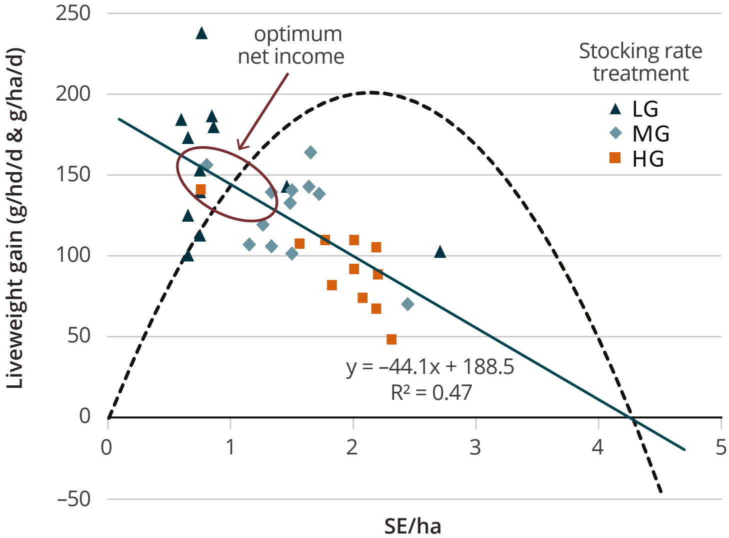

Figure 8.9 Liveweight gain for 1–2-year-old sheep on the desert steppe grazing experiment

Note: Liveweight gain is for per head (data points, fitted solid line and the regression shown) and per hectare (dashed line calculated from the fitted solid line). Data is for three stocking rate treatments. Four separate groups of animals were used, changed every three years from 2004.

To achieve growth rates of 75% of the potential requires higher levels of forage on offer (herbage mass). For sheep grazing pastures of good quality forage, this will need to be > 0.5 t DM/ha (ed. Nicol 1987; eds Freer, Dove & Nolan 2007). If there are unpalatable plant species within the grassland (e.g. *Stipa breviflora*, which often approached 50% of the total herbage mass), the total herbage mass would need to be 1 t DM/ha. As forage quality deteriorates through summer, the herbage mass on offer needs to substantially increase to sustain the target animal growth rates (Badgery et al. 2017). Because there is often some compensatory gain in Chinese livestock through early summer, this may slightly reduce the herbage mass on offer required to sustain growth rates.

An average herbage mass of 0.5–1.0 t DM/ha through summer would require a low grazing pressure. This was achieved with the light grazing treatment, which also resulted in better botanical composition and ground cover. These results support the conclusion that the optimal management of the grassland for livestock production also results in optimising the grassland condition.

These experiment results reflect optimising the system within current constraints. Simulation modelling (Chapter 6) suggested that long-term sustainable stocking rates aimed at restoring a more desirable botanical composition would need to be about half the optimum found in the grazing experiment. That conclusion needs to test the assumption in the models about how a shift to more desirable grass species can be managed.

Forage utilisation rate

The herbage utilisation rate over summer, estimated as the difference in biomass inside and outside cages, increased with the increase in stocking rate. Forage utilisation rates were 0%, 24%, 44% and 57% as stocking rates increased from low to high. The utilisation rate in the highest stocking rate treatment was twice that of the light stocking rate treatment. Utilisation rates measured by the differences inside and outside a cage can be about twice that of actual consumption by livestock (Kemp et al. 2018) as herbage losses occur from many sources, in addition to that consumed by livestock. The actual consumption rates by livestock could then be closer to 12, 22 or 29% for LG, MG and HG respectively.

An alternative estimate for consumption rates can be derived from standard values (eds Freer, Dove & Nolan 2007). The average stocking rates were approximately 0.9, 1.6 and 2.3 SE/ha for LG, MG and HG respectively. As these were young growing animals, but not pregnant or lactating, and assuming they selected better-quality forage, their daily consumption rate would be approximately 1 kg DM/SE. This allows for a small reduction in potential intake rates as the forage on offer would be below that required to maximise intake. As the main interest in deriving sustainable consumption rates is the usage over summer, we allow 100 days of grazing over summer (90, 160 and 230 SE grazing days/ha (approximately equivalent kg DM/ha consumed)). The average peak herbage mass over 12 years on LG, MG and HG was 941, 745 and 566 kg DM/ha respectively. That means the average summer consumption rates were 10, 22 and 41% for LG, MG and HG. These values are similar to those estimated from the utilisation calculations, except for the HG treatment. The consumption calculations assume a higher daily intake rate for the HG treatment than may have been possible, given the low levels of herbage mass on that treatment. As LG was closest to the sustainable stocking rate, this indicates the average sustainable consumption rate of summer would be approximately 10%. Actual consumption rates would be less than this, as the peak herbage mass is the net outcome after grazing. However, for practical purposes, the use of peak herbage mass is justified on the grounds that it is often the only measure readily taken. The consumption rates are then an index for comparative purposes, and a calculation that could be done by local officials and herders.

The aim is often to define consumption rates that helped to optimise the botanical composition. As previously shown (Figure 8.4), treatment effects on the main plant species only started to separate from 2011. That suggested the consumption rates from 2004 to 2010 may have been higher than sustainable for most treatments. The increase in peak herbage mass from the first seven years (2004–10, Table 8.2) to the next five years (2011–15) was substantial on all grazing treatments. The SE grazing days/ha over summer varied due to seasonal factors, but remained within the objectives for each treatment. The estimated consumption rates, using the peak herbage mass as a measure of forage supply, declined substantially during the period 2011–15, reflecting the greater herbage growth. During the later five-year period, the light grazing treatment had an estimated consumption rate of 9%, similar to the earlier calculations and less than half that measured using the cage technique. In contrast, on the high grazing treatment during 2004–10, livestock were estimated to have consumed 100% of the peak herbage mass, leaving no cover over winter. This is typical of local experience.

Table 8.2 Indexed consumption rates for different stock rate treatments, Siziwang, IMAR, 2004–10 and 2011–15

	Peak herbage mass (kg DM/ha)		SE grazing days/ha		Consumption rate (%)	
Treatment	2004–10	2011–15	2004–10	2011–15	2004–10	2011–15
CK	877	1,798	0	0	0	0
LG	684	1,247	89	104	16.0	9.1
MG	580	976	164	175	41.3	22.2
HG	470	701	274	221	100.2	43.0

Of additional interest is the average herbage mass over summer, as that provides a useful management guideline for herders and officials to adjust stocking rates. The available data was limited, but in general the indications were that the average herbage mass on a treatment was about half the measured peak herbage mass. As the period 2011–15 was more important for considering when the desert steppe was being managed sustainably, the light grazing treatment had an average herbage mass of about 0.6 t DM/ha (i.e. half of the peak 1247 kg DM/ha). Thus, stocking rates that consumed approximately 10% of the peak herbage mass over summer and maintained an average herbage mass of 0.6 t DM/ha through summer are then likely to achieve sustainable outcomes.

Discussion

The desert steppe is one of the major grassland types within the Eurasian grasslands of China. Much of the desert steppe is classified as degraded. That was evident in the site used for this experiment, where half of the plant biomass were less-desirable species that were not eaten by livestock unless the other species, notably the shrub *Artemisia*, was less available. The low initial plant growth at the experiment site indicated that it had probably been heavily grazed prior to this study, a point further emphasised by the increasing plant growth, year by year throughout the 12 years presented here, even under the heavy grazing treatment that had been set at the initial district average rate. During that recovery period, the less-desirable *Stipa breviflora*, when lightly or not-grazed, still maintained nearly half of the total herbage mass. This reinforced the view that, on much of China's grasslands, herders and officials need to work with what they have got, rather than expect to greatly change the grasslands botanical composition to a dominance of desirable species. In this case, that means managing the grasslands to retain a higher proportion of *Artemisia* species. That is in contrast to the typical steppe site (Chapter 9), where minimising the *Artemisia* species is the goal. Normally, management of these grasslands would aim to favour the grasses, but, in this case, the shrubs, while not ideal, were the mainstay of livestock production. Management should aim to sustain them in a competitive position against the less palatable grass. This was achieved just as effectively through the light grazing treatment as through no grazing. Low stocking rates would be useful to sustain this grassland in a reasonable state. The previous district stocking rate would result in a grassland dominated by low-palatability species and reduced animal production.

Sheep on desert steppe farm in mid summer on grassland, after three years stocked at the low rate.
Photo D.R. Kemp

An interesting recent trend in this experiment has been the emergence since 2012 of a more palatable grass species (*Stipa klemenzi*), which has increased more in the nil and lightly grazed treatments (Table 8.1). It remains to be seen if this species will become dominant over *Stipa breviflora*. The interaction between perennial grasses and shrubs showed that the initial heavy grazing in the winter of 2004–05 significantly reduced both plant groups. The herbage mass of both groups remained low for the next seven years. It was only after 2011 that treatment differences became clearer. This is the first evidence for how long it can take to initiate change in the botanical composition of the desert steppe under grazing.

This work has shown that there are significant feed-forward effects arising from how the grasslands are grazed that need to be managed. The inadvertent heavy grazing of the plots in the first winter of this experiment provided valuable information and showed that research is needed to better quantify the impact of winter grazing. In this case, it is estimated that heavy grazing in winter reduced growth in the next summer by more than 50%. The link between years was evident in how grass growth in summer related to the tiller density at the start of summer, which would in turn have been influenced by how the grasslands had been managed through the previous year. There is likely to be a relationship between the intensity of grazing through autumn, winter and spring, and regrowth in the following early summer that needs to be defined. Growth over summer was related to both the early summer plant growth and rainfall over May–July. Growth of the desert steppe is clearly as dependent upon how it is managed with livestock as it is on seasonal conditions.

To sustainably manage the desert steppe at the optimal stocking rate (approximately 1 SE/ha), the average herbage mass over summer needed to exceed 0.5 t DM/ha. At that level, the botanical composition was the best possible, given the high proportion of less-desirable *Stipa* species present. The higher stocking rate treatment averaged much less herbage mass and there would have been an increased risk of soil erosion. Some soil erosion is still likely in spring when the grassland is managed to retain 0.5t DM/ha over summer, as the residual biomass even without grazing, will deteriorate during the cold winter and be blown away. But it is anticipated, as shown by modelling (Chapter 6), that wind erosion will be usefully reduced. Setting an optimum level of herbage mass for management has two important implications. The first is that the start of grazing in summer could be delayed until the grassland reaches this target. At present, officials use a calendar date, which does not change with seasonal conditions. The second is that herders do not have to use a fixed stocking rate. As long as they maintain the average herbage mass above the target value, they can have more or less animals (i.e. use flexible stocking rates around the optimum). Further research is needed to refine the estimates of the minimum herbage mass to maintain, as the target given here is based on 12 years of data where plant growth varied considerably. Research needs to investigate the mechanisms whereby the botanical composition can be changed to a dominance by desirable species. Modelling (Chapter 6) indicated that stocking rates may need to be closer to 0.5 SE/ha to achieve that change.

To sustain the desert steppe, plants need to be able to capture and recycle nutrients in order to complete their life cycles and persist. If herbivores, including livestock, consume too much plant material, species become extinct. Exclosure cages were used to estimate how much of the grassland was being utilised. However, this technique overestimates the amount actually consumed by livestock, often by a factor of two (Kemp et al. 2018). Knowledge of the actual consumption rates by livestock enables more accurate calculation of stocking rates. For the desert steppe, it was estimated that a consumption rate of 10–15% of the peak herbage mass, measured in mid summer, was the sustainable level of use. It is reasonable to assume that as grassland environments become more difficult (e.g. cold and dry), the sustainable consumption rate should decline.

Herder households depend upon livestock production to sustain their livelihoods. Data obtained in this research showed that animal production per head was close to the expected maximum net financial returns in the light grazing treatment. That reinforced the view that, to optimise the profitability of livestock production, the grassland needs to be in the best condition possible. The results from analysing animal production found the sustainable stocking rate was also appropriate for optimising the botanical composition. This stocking rate (approximately 1 SE/ha) was similar to the current district stocking rate (Chapter 2). During the course of the desert steppe experiment, initial modelling suggested that stocking rates should be halved to this lower level. This was demonstrated on farms (Chapter 4) and continual discussions with local officials and herders helped build their knowledge and confidence in reducing stocking rates. This experiment has played a vital part in achieving change. In the Siziwang district, the grasslands now appear to be in much better condition than they were, and better than in surrounding districts.

Acknowledgments

This work was funded by the National Nature Science Foundation of China (31560140, 31270502, 31760143, 31260124) Sino-Australia collaboration project (ACIAR Sustainable Chinese Grasslands Program), Innovation Research Team of Ministry of Education (IRT17R59), National key research project (2016YFC0500504), Excellent Young Scientist Foundation of Inner Mongolia Agricultural University (IMAU) of China (2014XYQ-7), and supported by West Light Foundation of Chinese Academy of Sciences and a grant from Inner Mongolia Science and Technological Committee, China. We want to thank all students of IMAU for their efforts in collecting and analysing field samples and all staff members of Siziwang Grassland Research Station for their help in our study, and all of co-authors, co-workers and peered reviewers who contributed to the paper.

References

Adler, PB & Levine, JM 2007, 'Contrasting relationships between precipitation and species richness in space and time', *Oikos*, vol. 116, pp. 221–232.

Austrheim, G & Eriksson, O 2001, 'Plant species diversity and grazing in the Scandinavian mountains – patterns and processes at different scales', *Ecography*, vol. 24, pp. 683–695.

Badgery, W, Millar, G, Broadfoot, K, Martin, J, Pottie, D, Simmons, A & Cranney, P 2017, 'Better management of intensive rotational grazing systems maintains pastures and improves animal performance', *Crop and Pasture Science*, vol. 68(12), 1131–1140, doi: 10.10171/CP16396.

Barkham, JP 1980, 'Population dynamics of the wild daffodil (*Narcissus pseudonarcissus*). I. Clonal growth seed reproduction, mortality and the effects of density', *Journal of Ecology*, vol. 68, pp.607–633.

Cheng, Y, Tsubo, M, Ito, TY, Nishihara, E & Shinoda, M 2011, 'Impact of rainfall variability and grazing pressure on plant diversity in Mongolian grasslands', *Journal of Arid Environments*, vol. 75, pp. 471–476.

Cousins, SAO & Eriksson, O 2001, 'Plant species occurrences in a rural hemiboreal landscape: effects of remnant habitats, site history, topography and soil', *Ecography*, vol. 24, pp. 461–469.

Fernandez-Gimenez, ME & Allen-Diaz, B 2001, 'Vegetation change along gradients from water sources in three grazed Mongolian ecosystems', *Plant Ecology*, vol. 157, pp. 101–118.

Flombaum P & Sala OE 2008, 'Higher effect of plant species diversity on productivity in natural than artificial ecosystems', *PNAS*, vol. 105(16), pp. 6087–6090.

Fraser, LH, Pither J, Jentsch, A, Sternberg, M, Zobel, M, Askarizadeh, D, Bartha, S, Beierkuhnlein, C, Bennett, JA, Bittel, A, Boldgiv, B, Boldrini II, Bork, E, Brown, L, Cabido, M, Cahill, J, Carlyle, CN, Campetella, G, Chelli, S, Cohen, O, Csergo, AM, Díaz, S, Enrico, L, Ensing, D, Fidelis, A, Fridley, JD, Foster, B, Garris, H, Goheen, JR, Henry, HAL, Hohn, M, Jouri, MH, Klironomos, J, Koorem, K, Lawrence-Lodge, R, Long, R, Manning, P, Mitchell, R, Moora, M, Müller, SC, Nabinger, C, Naseri, K, Overbeck, GE, Palmer TM, Parsons S, Pesek M, Pillar VD, Pringle RM, Roccaforte K, Schmidt A, Shang ZH, Stahlmann R, Stotz, GC, Sugiyama, SI, Szentes, S, Thompson, D, Tungalag, R, Undrakhbold, S, van Rooyen, M, Wellstein, C, Wilson, JB & Zupo, T 2015, 'Worldwide evidence of a unimodal relationship between productivity and plant species richness', *Science*, vol. 349(6245), pp. 302–305, doi: 10.1126/science.aab3916.

Fraser, LH, Jentsch, A & Sternberg, M 2014, 'What drives plant species diversity? Tackling the unimodal relationship between herbaceous species richness and productivity', *J. Vegetation Science*, vol. 25, pp. 1160–1166.

Freer, M, Dove, H & Nolan, JV (eds) 2007, *Nutrient requirements of domesticated ruminants*, CSIRO Publishing, Collingwood.

Gao, YZ, Giese, M, Han, XG, Wang, DL, Zhou, ZY, Brueck, H, Lin, S & Taube, F 2009, 'Land use and drought interactively affect interspecific competition and species diversity at the local scale in a semiarid steppe ecosystem', *Ecological Research*, vol. 24, pp. 627–635.

Herrero, M & Thornton, PK 2013, 'Livestock and global change: emerging issues for sustainable food systems', *Proceedings National Academy of Sciences*, vol. 110, pp. 20878–20881.

Hoshino, A, Yoshihara, Y, Sasaki, T, Okayasu, T, Jamsran, U, Okuro, T & Takeuchi, K 2009, 'Comparison of vegetation changes along grazing gradients with different numbers of livestock', *Journal of Arid Environments*, vol. 73, pp. 687–690.

Hoffmann, C, Giese, M, Dickhoefer, U, Wan, HW, Bai, YF, Steffens, M, Liu, CY, Butterbach-Bahl, K & Han, XG 2016, 'Effects of grazing and climate variability on grassland ecosystem functions in Inner Mongolia: synthesis of a six-year grazing experiment', *Journal of Arid Environments*, vol. 135, pp. 50–63.

Irisarri, JGN, Derner, JD, Porensky, LM, Augustine, DJ, Reeves, JL & Mueller, KE 2016, 'Grazing intensity differentially regulates ANPP response to precipitation in North American semiarid grasslands', *Ecological Applications*, vol. 26(5), pp. 1370–1380, doi: 10.1890/15-1332.

Kemp, DR & Michalk, DL (eds) 1993, *Pasture management: technology for the 21st century*, CSIRO Publishing, Melbourne, pp. 177.

Kemp, DR, King, WMcG, Lodge, GM, Murphy, SR, Quigley, P & Sanford, P 2003, 'SGS Biodiversity Theme: the impact of plant biodiversity on the productivity and stability of grazing systems', *Australian Journal of Experimental Agriculture*, vol. 43(8), pp. 962–975, doi: 10.1071/EA02200.

Kemp, DR, Han, GD, Hou, FJ, Hou, XY, Li, ZG, Sun, Y, Wang, ZW, Wu, JP, Zhang, XQ, Zhang, YJ & Gong, XY 2018, 'Sustainable management of Chinese grasslands: issues and knowledge', *Frontiers of Agricultural Science and Engineering*, vol. 5, pp. 9–23, doi: 10.15302/J-FASE-2018204.

Kutiel, P, Kutiel, H & Lavee, H 2000, 'Vegetation response to possible scenarios of rainfall variations along a Mediterranean-extreme arid climatic transect', *Journal of Arid Environments*, vol. 44, pp. 277–290.

Milchunas, DG, Lauenroth, WK, Chapman, PL & Kazempour, MK 1989, 'Effects of grazing, topography, and precipitation on the structure of a semi-arid grassland', *Vegetation*, vol. 80, pp. 11–23.

Moore RM 1970, 'Australian grasslands', in Moore RM (ed), *Australian Grasslands*, Australian National University Press, Canberra, pp. 87–100.

Nicol, A (ed.) 1987, *Livestock feeding on pasture*, Occasional Publication 10, New Zealand Society of Animal Production, Hamilton, New Zealand.

Pärtel, M, Bruun, HH & Sammul M 2005, 'Biodiversity in temperate European grasslands: origin and conservation', in R Lillak, R Viiralt, A Linke & V Geherman (eds), *Integrating efficient grassland farming and biodiversity*, vol. 10 'Grassland science in Europe: proceedings of the 13th International Occasional Symposium of the European Grassland Federation', pp. 1–14.

Pitelka, LF, Hansen, SB & Ashmun, JW 1985, 'Population biology of *Clintonia borealis*. I. Ramet and patch dynamics', *Journal of Ecology*, vol. 73, pp. 169–183.

Sasaki, T, Okayasu, T, Takeuchi, K, Jamsran, U & Jadambaa, S 2005, 'Patterns of floristic composition under different grazing intensities in Bulgan, South Gobi, Mongolia', *Grassland Science*, vol. 51, pp. 235–242.

Sasaki, T, Okayasu, T, Undarmaa, J & Takeuchi, K 2008, 'Threshold changes in vegetation along a grazing gradient in Mongolian rangelands', *Journal of Ecology*, vol. 96, pp. 145–154.

Shmida, A & Wilson, MV 1985, 'Biological determinants of species diversity', *Journal of Biogeography*, vol. 12, pp. 1–20.

Tilman, D, Isbell, F & Cowles, JM 2014, 'Biodiversity and ecosystem functioning', *Annual Review Ecology Evolution Systematics*, vol. 45, pp. 471–93.

Van Staalduinen, MA, During & H, Werger, MJA 2007, 'Impact of grazing regime on a Mongolian forest steppe', *Applied Vegetation Science*, vol. 10, pp. 299–306.

Ward, D & Olsvig-Whittaker L 1993, 'Plant species diversity at the junction of two desert biogeographic zones', *Biodiversity Letters*, vol. 1, pp. 172–185.

Wang, ZW, Jiao, SY, Han, GD, Zhao, ML, Ding, HJ, Zhang, XJ, Wang, XL, Ayers, EL, Willms, WD, Havstad, K, Lata, A & Liu, YZ 2014, 'Effects of stocking rate on the variability of peak standing crop in a desert steppe of Eurasian grassland', *Environmental management*, vol. 53(2), pp. 266–273.

Wang, ZW, Jiao, S, Han, GD, Zhao, ML, Willms, WD, Hao, X, Wang J, Din, H & Havstad, KM 2011, 'Impact of stocking rate and rainfall on sheep performance in a desert steppe', *Rangeland Ecology and Management*, vol. 64, pp. 249–256.

Weiner, J 1988, 'The influence of competition on plant reproduction', in J Lovett Doust & L Lovett Doust (eds) *Plant Reproductive Ecology*, Oxford: Oxford University Press, pp. 228–245.

9 Managing the typical steppe

Zhang Yingjun, Chen Wenqing, Liu Nan, Huang Ding, Rong Yuping, Zhang Hao, Kan Haiming, David Kemp

The steppe ecoregion of China is part of the vast eastern Eurasian grasslands, spanning the north-east (32–45°N) to the south-west (104–115°E) and occupying a large zonal distribution across north China (Figure 9.1). The same grassland types extend across the Mongolian Plateau through central Mongolia. The temperate typical steppe covers 40 million ha and occupies approximately 10% of grassland in China, supporting the livelihoods of approximately 6.5 million people and sustaining 24 million sheep. Nearly 70% of the steppe area is situated in IMAR (Du 2006). The climatic conditions of the steppe ecoregion are characterised by a continental, semi-arid, monsoon climate in the temperate zone with windy, dry and cold winters and springs, and warm and comparatively rain-rich summers followed by a short and cool autumn. Annual precipitation ranges from 350 to 450 mm, about 80% of which falls between June and September. The steppe ecoregion acts as an ecological protective screen for eastern China, and is also one of the most important national production bases for animal husbandry.

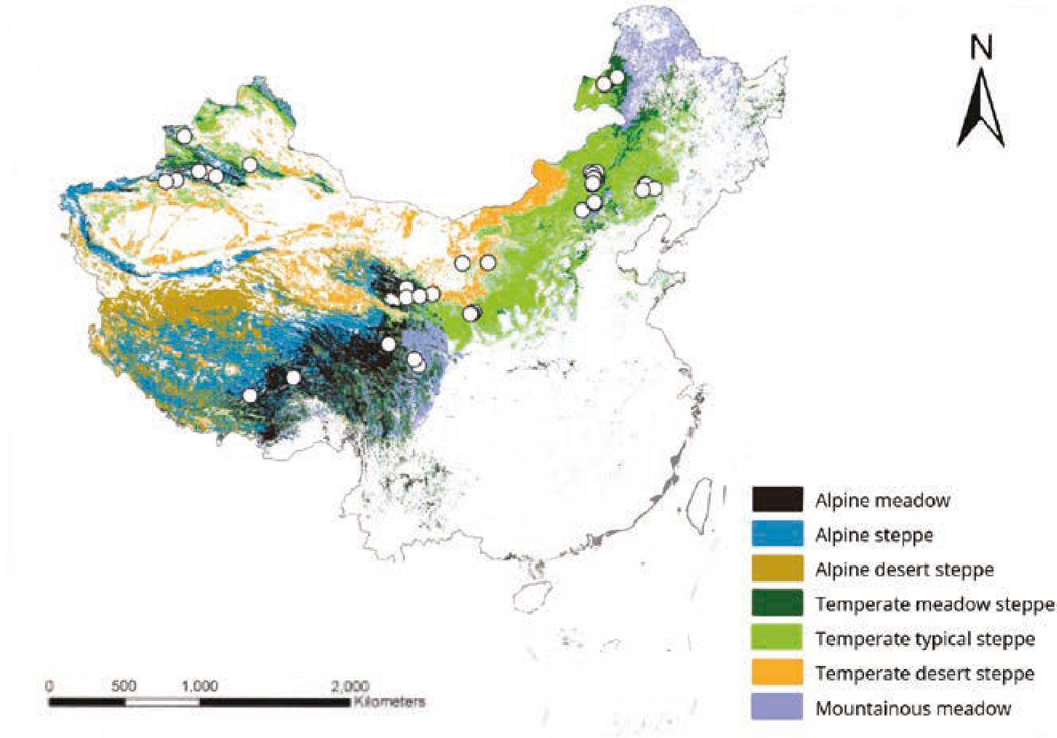

Figure 9.1 The temperate typical steppe in China and other major grasslands and major grassland experiment sites

Note: White circles indicate the major grassland experiment sites used in the program outlined in this monograph.

However, nearly 90% of the steppe area is considered to be degraded, with significant areas of increasing desertification (12%) and salinisation (5%) (Zhao et al. 2005). It is widely agreed that the major cause of grassland degradation is overgrazing, and that degradation is further exacerbated by severe climatic conditions. Degradation of the steppe results initially in vegetation changes (to less palatable species), then decreased ground cover and increased soil erosion, progressively reducing the income of animal herders. A decline in the steppe functionality and an increase in degradation has attracted widespread concern about the declining environmental conditions and need to improve regional household incomes. There is growing recognition that this decline has been driven by initiatives taken at a range of levels, from national policy to the individual herder. Since the start of this century, the Chinese Government and local farmers have implemented a series of projects, such as 'Grassland protection by grazing ban or rest', 'Grassland ecological compensation mechanism' and 'National grass and forage industry technology system', designed to rehabilitate vast areas of the steppe and identify optimal solutions for ecological conservation and productivity in these regions. These policies and programs have typically included a reduction in stocking rates as part of their strategies to rehabilitate grasslands, but limited research had been done to determine which practices would deliver good environmental outcomes and at least maintain, or improve, herder incomes. This chapter aims to give an overview of recent research, designed to identify optimal practices, done on the steppe.

Evaluating developing livestock management practices from economic and environmental perspectives

Livestock production

Livestock production is the main agricultural activity across the typical steppe in China. Livestock systems that achieve the maximum liveweight gain per hectare are commonly seen as the optimum production system. However, a livestock system that maximises short-term animal production per unit area usually results in a decrease of long-term grassland productivity and therefore animal production (Kemp et al. 2018). Traditional livestock management practices that maximise the number of animals on the steppe have resulted in overutilisation of the grassland and a decline in livestock production. The seriousness of this problem has been gradually recognised over the past two decades by individual herders and the Chinese Government.

Typical steppe in summer (30 °C) at Taipusi, IMAR. One herder is looking after the flocks for several households.
Photo: D.R. Kemp

Institute for Grassland Research field station at Taipusi in winter (–20 °C). Traditionally, animals were taken to graze under these conditions, but now they can be kept in a warm shed. Photo: D.R. Kemp

Stocking rate has a major impact on animal performance and overall profitability of livestock production systems. It is therefore essential to consider the relationship between the liveweight gain of grazing livestock and the corresponding stocking rate. A basic model to describe the relationships between stocking rate and animal production per head and per hectare, developed from Jones & Sandland (1974), has been used to guide much of the research reported in this monograph (eds Kemp & Michalk 2011), as it was shown to represent the results found. With the consideration of this accepted model, studies covering a wide range of grazing intensities have been applied in the steppe region to evaluate impacts on liveweight gain and identify stocking rates that are more likely to result in an improvement of livestock production (Wang 2000; Glindemann et al. 2009; Muller et al. 2014). Results obtained from these studies showed that animal production per head decreased, often in a linear trend, with increasing stocking rate. This resulted in a quadratic response in animal production per hectare to increasing stocking rates. A representative example is the five-year grazing experiment on the steppe of IMAR done by Lin et al. (2012) (Figure 9.2). The biological maximum livestock production per hectare occurred at stocking rates that ranged from 6.7–9.8 sheep/ha depending on herbage availability each year. This data only applies over the summer months when green forage is available. Very different relationships apply in winter when animals all lose weight due to the tough conditions.

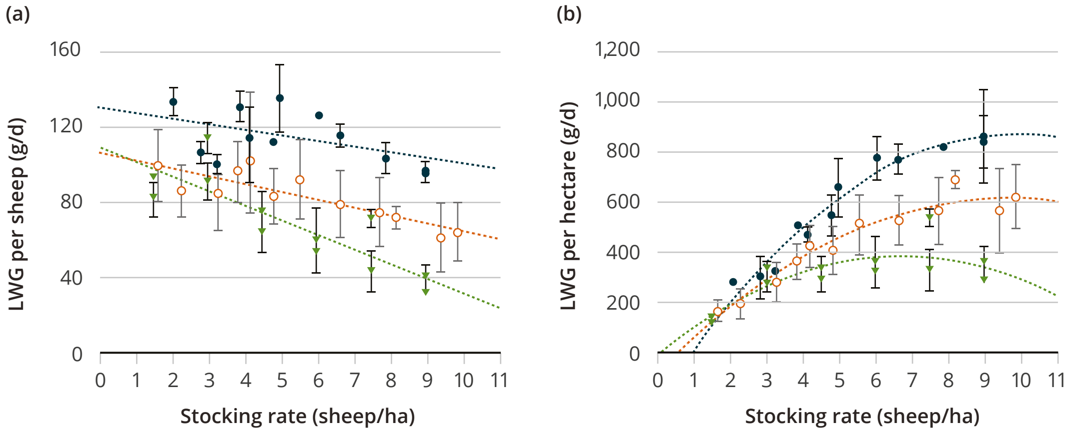

Figure 9.2 Relationships between stocking rate and (a) liveweight gain per sheep and (b) liveweight gain per hectare, 2005–09

Note: Inverted triangle = 2005; open circle = 2006, 2008 and 2009; closed circle = 2007

Source: Lin et al. (2012)

Given that the biological maximum does not coincide with maximising net profit, when taking account of the costs of animal maintenance and sustainability of grassland production (Kemp & Michalk 2007), a downward adjustment of the stocking rate from that at the biological maximum production per hectare is appropriate to estimate the financially optimal stocking rate. At the biological maximum production per hectare, the marginal gain in production for each extra sheep is zero. Each extra sheep entails extra costs, therefore net profits are not optimal at that point. A reasonable estimate of where net profit is maximised is where animal production is about 75% of the biological maximum per head production (Kemp et al. 2018). That suggests an optimum stocking rate) would be approximately 6 sheep/ha (weighted average of the fitted regressions). Using this lower number helps to further reduce stocking rates on these grasslands. The study by Lin et al. (2012) did not examine the impact of grazing pressures on the grassland ecosystem, which would further influence the optimal stocking rate. When this was done, the optimum stocking rate was reduced to approximately 4 sheep/ha (Zhang et al. 2015).

Relative to current continuous grazing practices, seasonal grazing is a system that considers grassland condition and sustainability. A delay in grazing in spring/early summer has become a common practice to improve grassland growth (Chen, Michalk & Millar 2002). Compared to continuous grazing, a grazing ban in the early growth stage of grasslands can have a significant improvement on the growth rate of herbage and total annual yields (Chen et al. 2015).

However, the length of any non-grazing period can have an effect on the time available for growth and development of the livestock. Even if a grazing ban through early summer had significant benefits for grassland condition, herders may be reluctant to do this if their total animal production was less. It may require herders to purchase additional supplementary fodder, reducing their profitability. Optimising the design of seasonal grazing bans is clearly important in order to help rehabilitate the grasslands and maintain herder incomes.

An alternative strategy that can provide opportunities for grassland improvement in the steppe is seasonal rotation of grazing, in which animals graze different areas in different seasons. This management practice can provide rest periods for the grassland that could help regrowth and reseeding (Wang et al. 2009. Animal production using rotational grazing has often resulted in similar responses to continuous grazing, when both are at the same average stocking rate, and maintained similar levels of total animal production. However, seasonal rotational grazing could enable improvements in the grassland condition, justifying the extra organisation required for rotational grazing.

A case (modelling) study done in the steppe of the Loess Plateau made a financial comparison between seasonal grazing and a continuous grazing system. The results showed that the net financial return from one field used all year (continuous grazing) and three fields used for rotational grazing increased up to an optimal stocking rate, but with no financial differences between those systems (Figure 9.3). However, the feeding costs for a two-field system with a grazing ban (one field used in summer and the other used in autumn) were higher than costs for the other systems, leading to a lower net income. Therefore, while seasonal rotational grazing showed no advantages over continuous grazing in animal production or financial return, it did provided opportunities for resting and rehabilitating areas of grassland. These results suggest that seasonal rotational grazing could be a valuable grassland management strategy in the steppe region, providing opportunities for grassland protection without reducing household income.

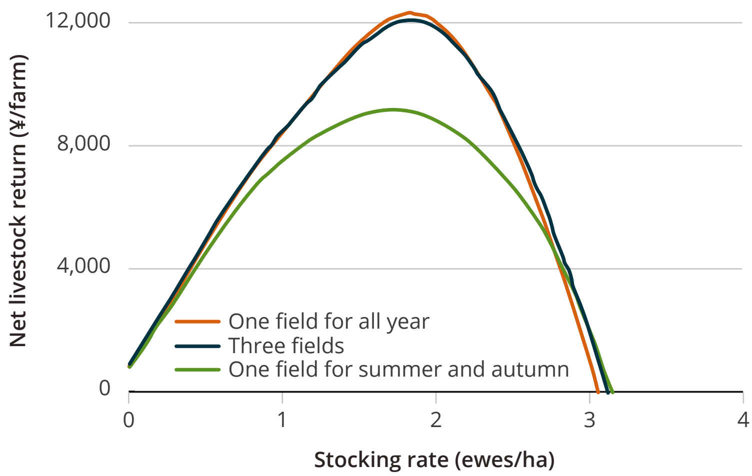

Figure 9.3 Net livestock return of different grazing strategies for animal production
Source: Wang, Hou & Nan (2011)

Other options, such as changing the timing of lambing and selecting different livestock types can further improve livestock production. Lambs born in warmer seasons have reduced energy demands and they take advantage of grass growth soon after lambing, which reduces feeding costs. Introducing more productive livestock types better suited to foraging in a region can also increase financial returns.

These investigations identified a range of realistic management options that could be implemented by herders on the typical steppe. These options are compatible with current systems and are potentially adoptable. By considering a reduction in stocking rate, adopting seasonal grazing management, changing the type of livestock to better match forage and financial resources, and using current existing technologies, herders can achieve an optimal financial return without incurring penalties in grassland sustainability.

Soil carbon sequestration

Soils of grasslands represent a large potential reservoir for storing carbon (C). Nearly 90% of total carbon is stored in the soil in grassland ecosystems. However, this potential reservoir depends on vegetation type, soil and climatic conditions, and how grasslands are managed for herbivore grazing. A review of 47 investigations (McSherry & Ritchie 2013) found that soil texture, precipitation, grass type, grazing intensity, study duration and sampling depth accounted for 85% of a large variation (± 150 g C/m^2/yr) in soil carbon. An increase in mean annual precipitation to 600 mm on fine textured soils resulted in a 24% decrease in grazing impact. The same increase in precipitation for sandy soils produced a 22% increase in grazing impact on soil organic carbon (SOC). Increasing grazing intensity increased SOC by 6–7% on C4-dominated and C4–C3 mixed grasslands, but decreased SOC by an average of 18% on C3-dominated grasslands.

Soil carbon storage has decreased substantially with grassland degradation in the steppe ecoregion due to long-term heavy grazing. To investigate the relationship between grazing intensity and soil carbon sequestration in the steppe, long-term field studies on grazing intensity have been done in the Mongolian Plateau in northern China. Results revealed soil carbon sequestration increased with light grazing intensity and carbon loss occurred under heavy grazing intensity. There was a general linear decline in soil carbon as grazing intensity occurred, though a comparison of when soil carbon levels were significantly less than the ungrazed control found this to be when grazing exceeded 3.0 SE/ha (Figure 9.4) (He, Han & Yu 2012). However, the mechanism where grazing intensity affects soil carbon sequestration is complicated. Grazing can directly or indirectly influence carbon inputs, turnover and retention in grassland soil. Herbivore grazing involves three mechanisms: defoliation (removal of plant shoot tissue), dung and urine return, and trampling. Trampling can lead to increased microbial growth, especially that of fungi and arbuscular mycorrhizal fungi. This allocation is critical for the below-ground processes of soil carbon sequestration. Defoliation decreased plant production, soil respiration and altered vegetation composition. However, dung and urine return led to increasing plant carbon inputs to the soil. Simultaneously, any potential loss of soil carbon due to an increase in the abundance of bacteria and soil respiration eventually accelerated soil carbon cycling (Liu et al. 2015).

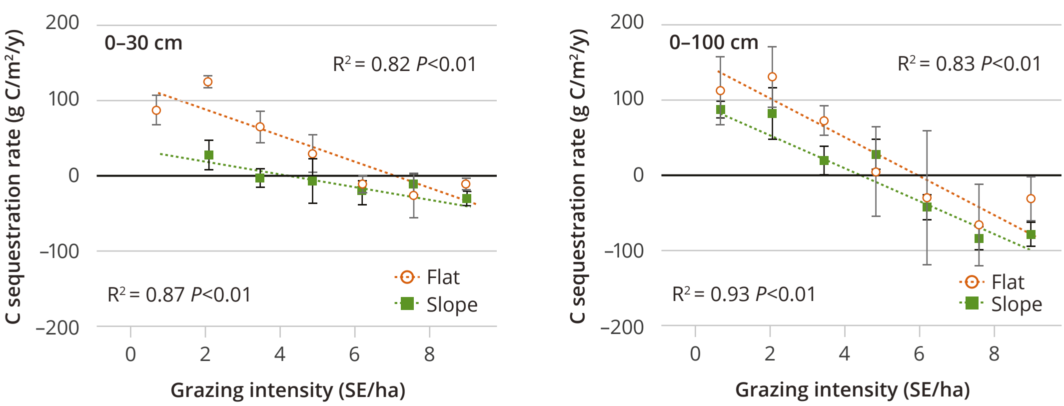

Figure 9.4 Response of soil carbon sequestration rates in grazing grasslands to increasing grazing intensity

Note: Samples were taken 0–30 cm and 0–100 cm and expressed as rates per annum.

Source: He et al. (2012)

The exclusion of grazing played a positive role in soil carbon sequestration in temperate steppe and temperate meadow-steppe regions. However, it had small effects in water-limited temperate desert steppe regions. This response pattern was similar to that found in below-ground biomass, which indicated that root mass may be a primary source of soil carbon input contributing to SOC change (Xiong et al. 2016). Soil carbon sequestration increased relatively quickly in temperate steppe soils following a period of grazing exclusion, but then remained relatively constant at a low rate of change (Figure 9.5), suggesting that short exclusion periods were better strategies. The exclusion of grazing on the grasslands should be integrated with other appropriate management practices rather than being a standalone solution, such as periodic grazing (restricted grazing in certain seasons) and/or rotational grazing (restricted grazing in certain areas).

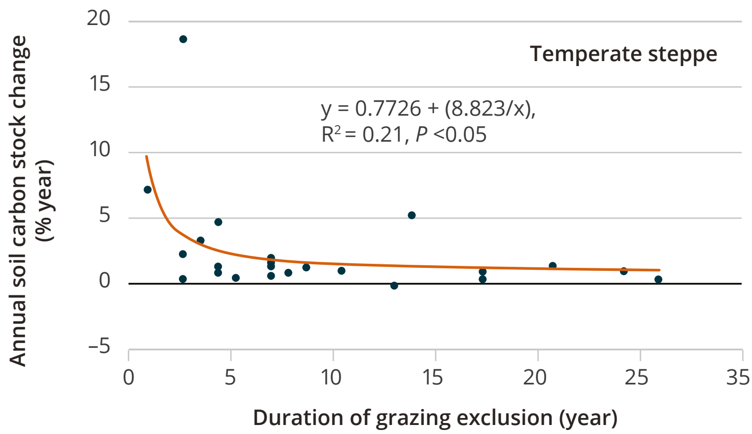

Figure 9.5 Percentage change in annual SOCs sequestration rates in temperate steppe under grazing exclusion practice

Source: Xiong et al. (2016)

Traditional grazing management practices using a constant grazing intensity (e.g. light, moderate and heavy grazing) throughout the growing season have been used to investigate grazing pressure effects on grassland ecosystems. However, forage supply changes dynamically throughout the short growing season (3–4 months) while animal food demand is relatively more constant. Management regimes aiming to improve grasslands need to be based on understanding the effects of varying seasonal grazing pressures on grassland productivity and species interactions. Results from a grazing management experiment that combined rest, moderate and high grazing pressures in the early summer season, and moderate or heavy grazing in the mid and late season, aimed to improve the vegetation on the steppe. Findings from this experiment showed that constant moderate grazing accumulated the most soil carbon. No grazing resulted in less soil carbon being sequestered compared to constant moderate grazing, despite no grazing resulting in a higher root mass, the maintenance of a more desirable pasture composition and the soil retaining more nitrogen. Constant high grazing pressures and reducing grazing pressures in the last grazing stage had a negative impact on soil carbon. A stocking rate of approximately 4 SE/ha with approximately 20% vegetation consumption rate was shown to result in the most carbon accrual in this steppe environment (Chen et al. 2015).

Mowing and reclamation as a land-use pattern in the IMAR steppe affects soil carbon sequestration. Soil carbon and nitrogen storage increased by 15.3% and 10.2% respectively after mowing for a 10-year period, and 19.2% and 7.1% after mowing for a 26-year period, respectively. However, after 49 years, soil carbon and nitrogen storage had declined by 10.6% and 11.4% (He, Han & Yu 2012). These effects on soil carbon and nitrogen storage would depend upon how much mown material was being removed in hay and the proportion of total biomass removed, though they do suggest that in the long run, mowing practices can lead to a decline in sequestration rates.

Methane emissions

Methane (CH_4) is a potent greenhouse gas that has a global warming potential 34 times greater than carbon dioxide (CO_2) over a 100-year timescale (IPCC 2013). Increasing atmospheric CH_4 concentrations have a serious impact on ecosystem–atmosphere energy budgets and global climate change. There are two major environmental CH_4 sinks: oxidation by OH radicals is the primary sink for atmospheric CH_4 and consumption by methanotrophs in soils is the secondary sink. This secondary sink accounts for a global estimate of 28 Tg CH_4/yr (9–47 Tg CH_4/yr) (Spahni, Wania & Neef 2011; IPCC 2013).

A two-year field experiment measuring CH_4 flux using mobile greenhouse gas analysers was undertaken on an area of steppe in northern China (Wang et al. 2014. Experiment conditions were:

- no grazing (UG) – 0 sheep/ha/yr
- light grazing (LG) – 1.0 sheep/ha/yr
- moderate grazing (MG) – 1.4 sheep/ha/yr
- heavy grazing (HG) – 2.4 sheep/ha/yr.

Results showed that there was a significant grazing effect on CH_4 uptake by soils despite a distinctive seasonal variation in CH_4 uptake being detected for both years (Figure 9.6). Grazing intensity significantly affected soil CH_4 uptake. MG significantly enhanced annual soil CH_4 uptake compared to results from the UG site, and no significant difference of annual CH_4 uptake between HG and UG was recorded. Annual soil CH_4 uptake was significantly correlated with stocking rates and root biomass of the vegetation.

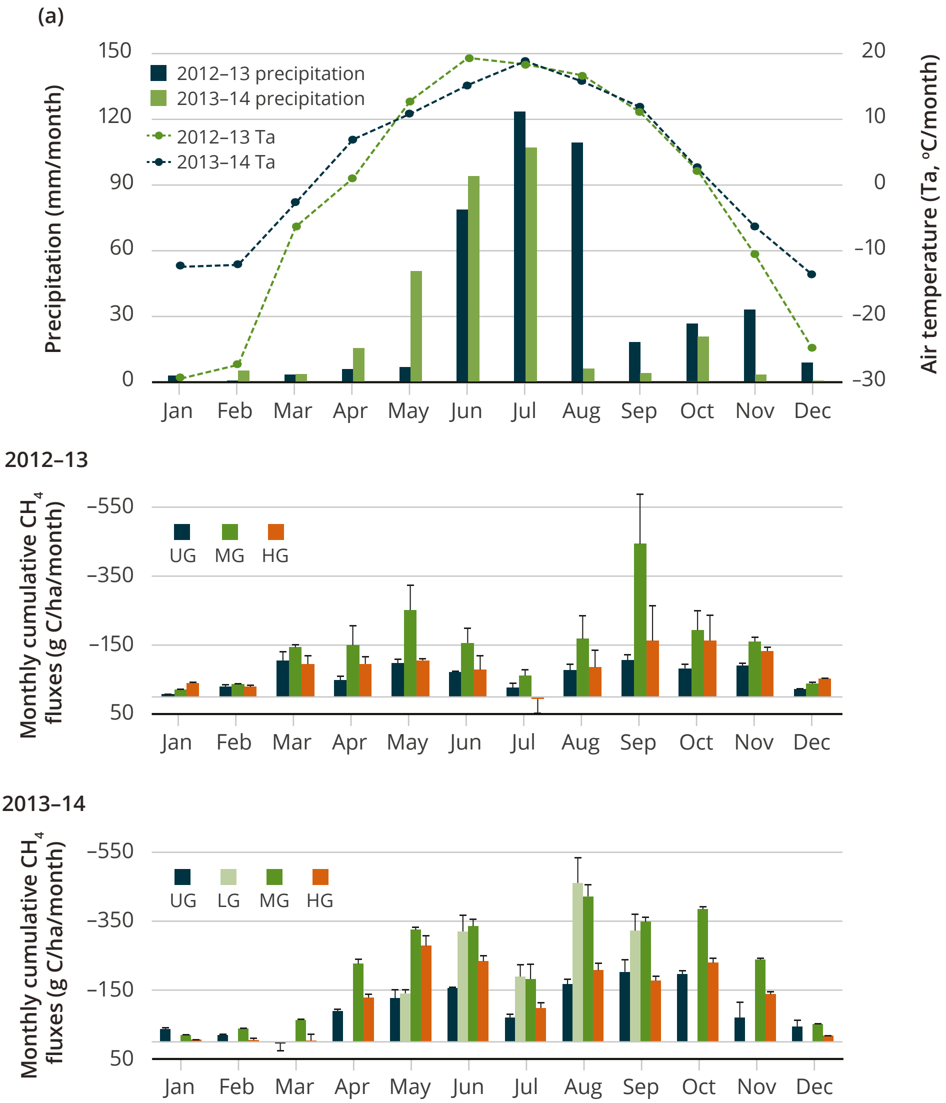

Figure 9.6 (a) Monthly air temperature and precipitation, 2012–14; monthly cumulative CH_4 fluxes in (b) 2012–13 and (c) 2013–14 at different grazing levels

Note: Data for LG site was only measured during the growing season in 2013–14. Negative values represented soil CH_4 uptake. Data are means ± SE.

The large inter-annual variations of CH_4 uptake can be explained by the inter-annual variations of precipitation. Although a stocking rate between 1.0–1.4 sheep/ha/yr is beneficial for grassland soil CH_4 uptake, compared to no grazing or heavier grazing, long-term CH_4 measurements are required to accurately estimate the CH_4 budget in this region. These data show that most of the CH_4 fluxes are over summer, when temperatures are above zero and biological systems are active.

Grassland production and biodiversity

Improving productivity and maintaining biodiversity, especially of the main plant functional types, is a central goal in the management of grassland ecosystems throughout the world and the steppe ecoregion in China is no exception (Tilman 1999; Bai et al. 2001; Grace et al. 2016). Net primary production (NPP) and biodiversity have a strong association, and both reflect important functions of grassland ecosystems. The relationship of grassland production and biodiversity has been dominated by the hypothesis of a hump-shaped mode, which was proposed by Grime (1973). This assumes that the greatest diversity occurs in the moderate or middle range of a physical gradient. However, a long-term case study on the IMAR steppe by Bai et al. (2007), showed that biodiversity and grassland productivity have a positive linear relationship rather than a hump-shaped mode. The results of Bai et al. (2007) demonstrate different organisational levels and spatial scales. In other environments, it has been shown in a series of experiments that productivity declines as species number increases (Kemp et al. 2003), supporting the view that there is an optimum density of species at which productivity is maximised and this depends upon the plant functional types present and site fertility.

Grazing is the main disturbance in the steppe environment that can decrease both primary productivity and species richness (Wang et al. 2009; Chen et al. 2015). Several studies have reported that the productivity and biodiversity of the steppe environment is negatively affected by high grazing intensity. For example, Bai et al. (2007) found that both above-ground net primary productivity (ANPP) and species richness decreased significantly with increasing grazing intensity (Figure 9.7), especially in summer, at the regional scale in a long-term and large-scale experiment. Among the four land use types (hayfields, winter-grazing grasslands, year-round grazing grasslands and summer-grazing grasslands), hayfields that had no animal grazing showed the highest average ANPP and species richness. In contrast, summer-grazing grasslands with the highest grazing intensity exhibited the lowest average ANPP and species richness. A six-year grazing experiment on the steppe showed that the effect of grazing intensity accounted for most of the variation in ANPP (Ren et al. 2016). With increased grazing intensity, ANPP decreased from 200 to 104 g DM/m at the highest intensity. The relationship between ANPP and grazing intensity showed a general negative linear decline with increasing grazing intensity (Figure 9.8).

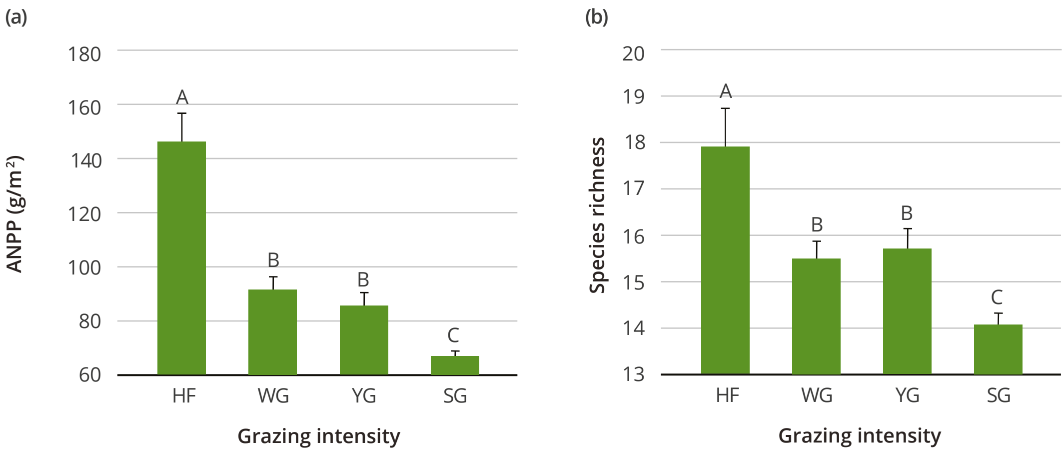

Figure 9.7 Effect of grazing intensity on ANPP and species richness on a typical steppe

Note: HF = hayfields; WG = winter-grazing grasslands; YG = year-round grazing grasslands; SG = summer-grazing grasslands

Source: Bai et al. (2007)

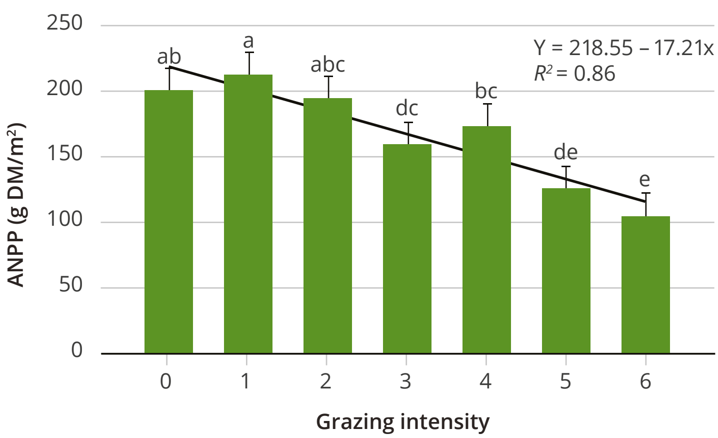

Figure 9.8 Effect of grazing intensity on ANPP on a typical steppe

Note: 0 = not-grazed, 1 = very light, 2 = light, 3 = light-moderate, 4 = moderate, 5 = heavy, 6 = very heavy. Bars show the means of six experiment years (2005–10).

Source: Ren et al. (2016)

The combination of poor climatic conditions and human activities (particularly overgrazing) have led to different degrees of degradation across a large area of the steppe ecoregion (Figure 9.9). Degradation coupled with a loss of associated functional groups has ultimately affected grassland production and its environmental service function. This has resulted in overgrazing and large-scale reclamation of grassland, which needs to be strictly controlled with a reduction in stocking rates year by year. More research about grassland production and biodiversity is still required, especially in the semi-arid steppe regions as these regions are representative of the widely-distributed Eurasian steppe.

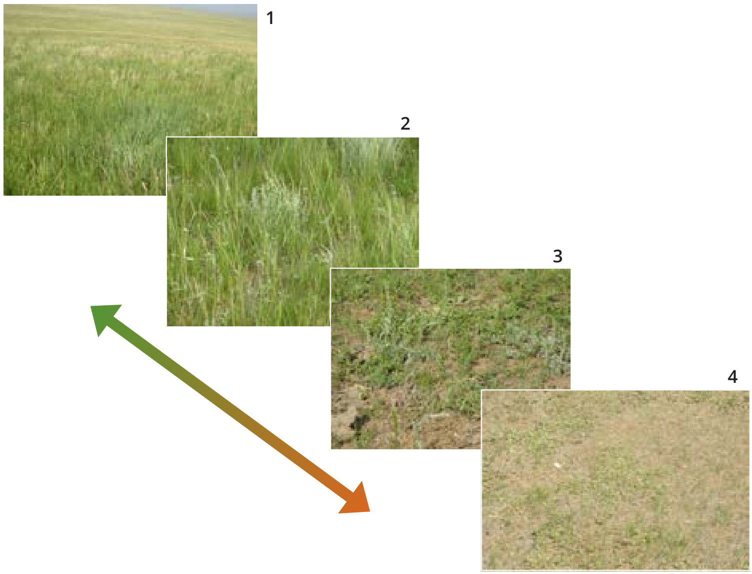

Figure 9.9 Degradation stages for a typical steppe showing the decline in the desirable grass *Leymus chinensis* as grazing pressure increases

Delivering optimal economic and environmental outcomes: indicators for desirable steppe conditions

The dilemma faced in the steppe ecoregion is how to achieve high levels of animal production while attaining environmental benefits. Currently, the main challenge is to develop a common framework that delivers livestock production and environmental benefits while simultaneously providing suitable solutions for livestock herders. To date, the majority of research has focused on investigating components of the grassland systems, often using poorly integrated approaches. Consequently, previous studies targeting sustainable use of the steppe ecosystem have achieved limited success, with few positive proposals providing livestock herders an opportunity to increase their financial income and conserve grassland.

In grasslands, maximising individual factors is likely to degrade other components, and optimising the interaction between profitability and environmental goals is the core issue. Overgrazing can reduce the productivity of grassland but the greatly reduced stocking rates required to improve grassland productivity may be detrimental to net financial income of livestock herders. The optimal grazing pressure for carbon sequestration does not necessarily coincide with the optimal pressure for biodiversity or productivity conservation. A practical point that balances the profitability of livestock systems and environmental benefits should be assessed and identified.

A recent study that considered the multiple components of a grassland system demonstrated that improving the profitability of the livestock system and enhancing the ecosystem service can be achieved by applying the appropriate management practice (Figure 9.10; Zhang et al. 2015). Results from this study concluded that setting a stocking rate of approximately 400 SE grazing days per hectare per year throughout the summer grazing season was closest to the optimum rate to obtain the best balance between maintaining a desirable grassland condition, a profitable livestock system, mitigating greenhouse gases through increased soil carbon sequestration and

CH_4 uptake, and having efficient CH_4 emissions per unit of weight gain (Figure 9.10). Furthermore, a minimum standing herbage mass criteria above 0.5 t DM/ha with about 20% consumption rate of grass grown in the grazing period was proposed to define and manage an optimal grazing strategy for the steppe region. This utilisation rate would be adjusted to a higher level in more-productive environments and a lower level in less-productive ones.

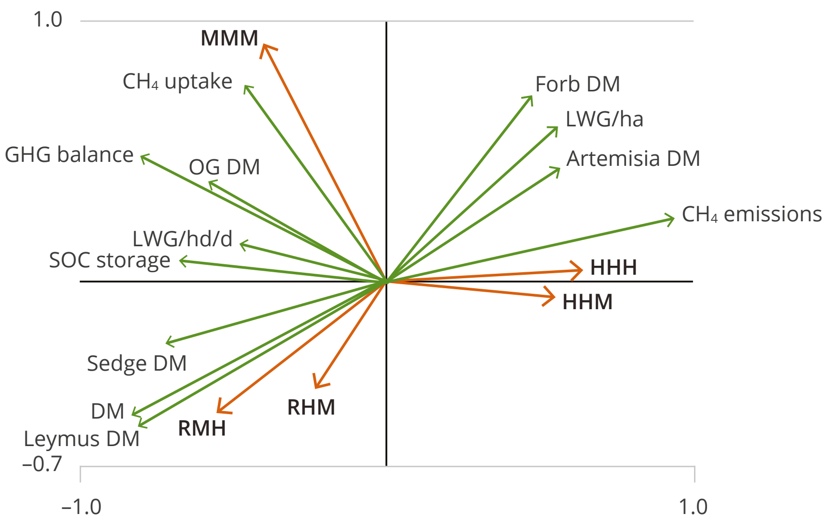

Figure 9.10 Partial redundancy analysis of field data in axis1 x axis2 ordination planes constrained by different grazing treatments

Note: Grazing pressure varied in treatment combinations from H = high, M = moderate, to R = rest/no grazing. Each treatment is the combination of these practices through three continuous summer grazing stages: early-, mid- and end-summer.

Maintaining herbage mass above a critical level optimised pastoral outcomes, as many key environmental and livestock components of the steppe ecoregion are directly associated with herbage mass. This provides a measure of the state of the system for both production and environmental criteria. There is a need to determine the critical values of herbage mass for other areas in the steppe region. Standing herbage mass and utilisation levels depend on the productivity of the environment, the length of growing seasons and how well plant species adapt to grazing disturbance. The herbage mass criteria identified in different regions of the steppe can be translated into tools that herders can use daily to track their progress and determine if their systems are sustainable.

Directions for promoting sustainable steppe management in the future

The Chinese Government has implemented a series of policies and programs to reduce degradation of the steppe environment and restore its ecosystem functions. These policies generally limit early-season grazing or promote rest in spring to restore grasslands to a desirable state. However, studies in steppe regions indicate that current stocking rates could be reduced considerably. The use of bans early in the summer growing season may not be desirable in this environment, when all aspects of the grazing system are considered. Results presented here indicate that a moderate stocking rate throughout the summer grazing season (Zhang et al. 2015) provides the best balance between maintaining a productive grassland, desirable plant species, a profitable livestock system and mitigating greenhouse gases through increased soil carbon. A moderate stocking rate also results in soil CH_4 uptake, rather than release, and provides desirable intensity measures of efficient CH_4 emissions per unit of weight gain by livestock. Moderate continuous grazing during the grazing season from June to October is a more suitable method to sustainably manage grasslands in this environment, as this can maintain or enhance the incomes of herders. Rather than setting a time limit for rest periods, it would be preferable to set a value of herbage mass that needs to be reached before grazing commences. Maintaining herbage mass above 0.5 t DM/ha optimises pastoral outcomes and suggests that rest periods aiming to achieve this target mass before grazing commences may be a better tactic than time-based rest. Higher levels of herbage mass with moderate grazing pressures enable animals to select better-quality diets, especially when management has achieved a dominance of desirable plant species.

The criteria considered here may not be suitable to return severely degraded grasslands to a desirable composition with reduced grazing pressure. In such cases, other rehabilitation strategies, such as reseeding and long-term grazing exclusion, may need to be considered. A moderate grazing pressure would result in livestock consuming about 20% of the grass grown in the growing season. Lower utilisation rates could be anticipated in less-productive environments and higher utilisation rates in more-productive ones. Actual losses of plant material over the growing season could be 2–3 times this value, as these calculations do not include normal plant and tissue death rates, losses from micro- and meso-organisms, ageing plant organs and physical damage from grazing livestock. Management of the steppe ecoregion should consider a whole system of grazing systems, including sown pasture or forage supplement in winter, livestock management in grassland and feedlot and market information. Market-based instruments are increasingly being used as a mechanism to pay farmers for environmental services. These markets are being developing for greenhouse gases in agriculture and may also provide incentives to improve management of steppe regions in the future.

References

Bai, YF, Li, LH, Huang, JH & Chen, ZZ 2001, 'The influence of plant diversity and functional composition on ecosystem stability of four stipa communities in the Inner Mongolia Plateau', *Chinese Bulletin of Botany* (English version), vol. 43, pp. 280–287.

Bai, YF, Wu, JG, Pan, QM, Huang, JH, Wang, QB, Li, FS, Buyantuyev, A & Han, XG 2007, 'Positive linear relationship between productivity and diversity: evidence from the Eurasian Steppe', *Journal of Applied Ecology*, vol. 44, pp. 1023–1034.

Chen, L, Michalk, DL & Millar, GD 2002, 'The ecology and growth patterns of *Cleistogenes* species in degraded grasslands of eastern Inner Mongolia, China', *Journal of Applied Ecology*, vol. 39, pp. 584–594.

Chen, WQ, Huang, D, Liu, N, Zhang, YJ, Badgery, WB, Wang, XY & Shen, Y 2015, 'Improved grazing management may increase soil carbon sequestration in temperate steppe', *Scientific Reports*, 5, 10892, doi: 10.1038/srep10892.

Du, QL 2006, *The strategy of sustainable development of grassland in China*, China Agricultural Press, Beijing.

Glindemann, T, Wang, C, Tas, BM, Schiborra, A, Gierus, M, Taube, F & Susenbeth, A 2009, 'Impact of grazing intensity on herbage intake, composition, and digestibility and on live weight gain of sheep on the Inner Mongolian steppe', *Livestock Science*, vol. 124(1–3), pp. 142–147.

Grace, JB, Anderson, TM, Seabloom, EW, Borer, ET, Adler, PB, Harpole, WS, Hautier, Y, Hillebrand, H, Lind, EM, Pärtel, M, Bakker, JD, Buckley, YM, Crawley, MJ, Damschen, EI, Davies, KF, Fay, PA, Firn, J, Gruner, DS, Hector, A, Knops, JMH, MacDougall, AS, Melbourne, BA, Morgan, JW, Orrock, JL, Prober, SM & Smith, MD 2016, 'Integrative modelling reveals mechanisms linking productivity and plant species richness', *Nature*, vol. 529(7586), pp. 390–393.

Grime, JP 1973, 'Competitive exclusion in herbaceous vegetation', *Nature*, vol. 242, pp. 344–347.

He, NP, Han, XG & Yu, GR 2012, 'Soil carbon sequestration rates and potential in the grazing grasslands of Inner Mongolia', *Acta Ecologica Sinica*, vol. 32(3), pp. 844–851.

Intergovernmental Panel on Climate Change 2013, 'Climate change 2013: the physical science basis', in TF Stocker, D Qin, GK Plattner, M Tignor, SK Allen, J Boschung, A Nauels, Y Xia, V Bex & PM Midgley (eds), *Contribution of Working Group I to the fifth assessment report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK & New York, NY, USA, pp. 507–508.

Jones, RJ & Sandland, RL 1974, 'The relation between animal gain and stocking rate: derivation of the relation from the results of grazing trials', *The Journal of Agricultural Science*, vol. 83(2), pp. 335–342.

Kemp, DR, King, WMcG, Lodge, GM, Murphy, SR, Quigley, P & Sanford, P 2003, 'SGS Biodiversity Theme: the impact of plant biodiversity on the productivity and stability of grazing systems', *Australian Journal of Experimental Agriculture*, vol. 43(8), pp. 962–975, doi: 10.1071/EA02200.

Kemp, DR & Michalk, DL 2007, 'Towards sustainable grassland and livestock management', *The Journal of Agricultural Science*, vol. 145(6), pp. 543–564.

Kemp, DR & Michalk, DL (eds) 2011, *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 189.

Kemp, DR, Han, GD, Hou, FJ, Hou, XY, Li, ZG, Sun, Y, Wang, ZW, Wu, JP, Zhang, XQ, Zhang, YJ & Gong, XY 2018, 'Sustainable management of Chinese grasslands: issues and knowledge', *Frontiers of Agricultural Science and Engineering*, vol. 5, pp. 9–23, doi: 10.15302/J-FASE-2018204.

McSherry, ME & Ritchie, ME 2013, 'Effects of grazing on grassland soil carbon: a global review', *Global Change Biology*, vol. 19, pp. 1347–1357.

Muller, K, Dickhoefer, U, Lin, L, Glindemann, T, Wang, C, Schönbach, P, Wan, HW, Schiborra, A, Tas, BM, Gierus, M, Taube, F & Susenbeth, A 2014, 'Impact of grazing intensity on herbage quality, feed intake and live weight gain of sheep grazing on the steppe of Inner Mongolia', *The Journal of Agricultural Science*, vol. 152(1), pp. 153–165.

Lin, LJ, Dickhoefer, U, Muller, K, Wang, CJ, Glindemann, T, Hao, J, Wan, HW, Schönbach, P, Gierus, M & Taube, F 2012, 'Growth of sheep as affected by grazing system and grazing intensity in the steppe of Inner Mongolia, China', *Livestock Science*, vol. 144(1–2), pp. 140–147.

Liu, N, Kan, HM, Yang, GW & Zhang, YJ 2015, 'Changes in plant, soil, and microbes in a typical steppe from simulated grazing: explaining potential change in soil C', *Ecological Monographs*, vol. 85(2), pp. 269–286.

Ren, HY, Han, GD, Schönbach, P, Gierus, M & Taube, F 2016, 'Forage nutritional characteristics and yield dynamics in a grazed semiarid steppe ecosystem of Inner Mongolia, China', *Ecological Indicators*, vol. 60. pp. 460–469.

Spahni, R, Wania, R & Neef L 2011, 'Constraining global methane emissions and uptake by ecosystems', *Biogeosciences*, vol. 8, pp. 1643–1665.

Tilman, D 1999, 'The ecological consequences of changes in biodiversity: a search for general principles', *Ecology*, vol. 80, pp. 1455–1474.

Wang, CJ, Tas, BM, Glindemann, T, Mueller, K, Schiborra, A, Schönbach, P, Gierus, M, Taube, F & Susenbeth, A 2009, 'Rotational and continuous grazing of sheep in the Inner Mongolian steppe of China', *Journal of Animal Physiology and Animal Nutrition*, vol. 93, pp. 245–252.

Wang, CJ, Han, GD, Wang, SP, Zhai, XJ, Brown, J, Havstad, KM, Ma, XZ, Wilkes, A, Zhao, ML, Tang, SM, Zhou, P, Jiang, YY, Lu, TT, Wang, ZW & Li, ZG 2014, 'Sound management may sequester methane in grazed rangeland ecosystems', *Science Reports*, vol. 4(4444), doi: 10.1038/srep04444.

Wang, SP 2000, 'Relationships between body gains and stocking rates of grazing sheep on typical Inner Mongolian grassland', *Acta Prataculture Sinica*, vol. 9, pp. 10–16.

Wang, XY, Hou, FJ & Nan, ZB 2011, 'Grazing systems on loess soils: options for Huanxian county, Gansu Province', in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 46–57.

Xiong, DP, Shi, PL, Zhang, XZ & Zou, CB 2016, 'Effects of grazing exclusion on carbon sequestration and plant diversity in grasslands of China: a meta-analysis', *Ecological Engineering*, vol. 94, pp. 647–655.

Zhang, YJ, Huang, D, Badgery, WB, Kemp, DR, Chen, WQ, Wang, XY & Liu, N 2015, 'Reduced grazing pressure delivers production and environmental benefits for the typical steppe of north China', *Scientific Reports*, 5, doi: 10.1038/srep16434.

Zhao, H, Zhao, X, Zhou, R, Zhang, T & Drake, S 2005, 'Desertification processes due to heavy grazing in sandy rangeland, Inner Mongolia', *Journal of Arid Environments*, vol. 62, pp. 309–319.

10 Devising sustainable grasslands grazing management practices for the future of Chinese grasslands

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There are 400 Mha of Chinese grasslands (Jia & Su 1996), of which 90% are considered degraded by overgrazing due to the large increase in the people and animals that have depended on them since the 1950s (Chapters 1 & 2; eds Kemp & Michalk 2011). It is acknowledged that a reduction in stock numbers is required to prevent further degradation (Kemp et al. 2013), but this must be balanced against an imperative to increase the production of red meat globally by 50% by 2050 to meet the demands of a growing population (Thornton 2010), many of whom will be in China. To meet these dual objectives of increasing production and reducing degradation, we must investigate ways to improve efficiency by closing the yield gaps on underperforming lands (Alexandratos & Bruinsma 2012) while reducing the number of animals grazing in the landscape. This provides an opportunity for Chinese small holders to sustainably intensify their production based on new technologies, practices and production systems and produce more from less (eds Kemp & Michalk 2011; Michalk et al. 2015). While the area excluded from grazing in China has now reached 26 Mha (11% of China's natural grasslands) since the 'returning grazing land to grassland' policy was implemented in 2003 (Xiong et al. 2016), low to moderate grazing levels might still give similar benefits in many areas and help maintain herder incomes.

One of the key issues from previous studies investigating grassland composition change and grazing pressure is that composition shifts are often described in terms of species number, diversity and evenness indexes (Zhang & Zhao 2015; Xiong et al. 2016). However, these measures do not give a useful indication of biomass or the biophysical mechanisms that are involved, nor of how animal production may be affected. It is often not clear which species are more sensitive to grazing, what level and timing (winter vs summer) of grazing is required to drive composition change, what roles climate (Bai et al. 2004) and landscape patch dynamics (Badgery 2017) plays, or whether composition change reaches thresholds that are irreversible (Friedel 1991; Briske, Fuhlendorf & Smeins 2005). The diversity measures often do not give a clear indication of which management strategies are effective. For instance, Xiong et al. (2016) found that grazing exclusion had little long-term effect on recovering plant diversity in a meta-analysis with 447 data points from across China's grasslands, yet the response of grazing sensitive, high-value plants was not reported. The degradation pathway is understood for some steppe types (Tong et al. 2004), but it is not clear how reversible this process is when grazing pressure is removed or reduced. A better understanding is needed.

Grasslands are a major part of the world's land-based ecosystems, with functions that go beyond sustaining the livelihoods of herders (Badgery et al. 2015). There are greenhouse gas (GHG) mitigation benefits from reducing grazing pressure. Increases to soil carbon (Xiong et al. 2016) as a result of greater root production (Gao et al. 2008; Chen et al. 2015) and higher CH_4 fluxes into the soil and reduced methane emissions from livestock (Wang et al. 2014) have all been documented with reduced grazing pressure. However, while it is clear that grazing bans have many of these same benefits at specific sites, if they are imposed across large areas of grassland simply to improve carbon storage this will displace production to other areas, or intensive feedlot production systems that can have a greater contribution to the production of GHGs (Plevin, Delucchi & Creutzig 2014). Moreover, there is evidence of soil carbon actually being lower when grazing is removed, compared to light or moderate grazing (Liu, Zhang et al. 2012; Orgill et al. 2016; Zhang et al. 2015) due to decreases in root turnover (Chen et al. 2015). Therefore, it is important to understand these implications for GHGs when managing grassland composition and livestock numbers. If there are to be successful outcomes for the grasslands and for herder livelihoods, grassland management recommendations need to take a systems-level approach that links plant and animal components.

Overgrazing in some areas, like this desert grassland in Gansu, is so extensive that inedible shrubs that even camels do not eat dominate. Fortunately, most grasslands are not in this state. Photo: D.R. Kemp

In China, the grassland areas are categorised as steppe. The four main types are alpine, meadow, typical and desert (Kang et al. 2007; Wang & Ba 2008). These extend from the meadow steppe and alpine meadow, which generally have higher rainfall, grading through to the typical and desert steppe on a decreasing rainfall gradient. In most steppe areas, there are both C3 and C4 grasses. Sedges and semi-shrubs and perennial plants dominate. The desert steppe, located throughout large areas of IMAR, has an average production of 400–1500 kg DM/ha/yr and carries 0.25–1.2 SU/ha[5]. A typical steppe in central regions on the Mongolian Plateau has an average production of 1000–3000 kg DM/ha/yr and carries 1.5–2 SU/ha. The meadow steppe in north-eastern China produces up to 4000 kg DM/ha/yr and carries 2–4 SU/ha. Alpine meadows on the Qinghai–Tibetan Plateau have an average production of 150–1000 kg DM/ha/yr and carry 0.2–1.4 SU/ha (Ren et al. 2008). In practice, the ASRs can be higher than this, as demonstrated in other chapters. The dominant plant species vary across and within these regions. A general description of the species was given by Kang et al. (2007). The desert steppe is often dominated by *Stipa* spp. (*S. gobica*, *S. klemenzii*), *Cleistogenes songorica* (C4), *Allium polyrhizum*, *Hippolytia trifida*, *Ajania fruticulosa* and *Artemisia* spp. The typical steppe comprises *Leymus chinensis*, *Stipa* spp. (*S. grandis*; *S. krylovii*), *Festuca sulcata*, *Cleistogenes squarrosa*, *Agropyron cristatum* and *Artemisia frigida*. Alpine meadows/ steppe also have *Stipa* spp. (*S. purpurea*, *S. subsessiliflora*), *Festuca* spp. (*F. kryloviana*), *Carex moorcroftii* and *Artemisia salsoloides*. The response of these grasslands to grazing depends on the proportion of desirable and less-desirable species. The low productivity of many grasslands and

5 One Chinese sheep unit (SU) is equivalent to a 40 kg reference weight sheep in moderate condition, often also defined as a lactating ewe, which implies that an SU more commonly reflects grazing pressures over summer. Elsewhere in this monograph, sheep equivalents (SE), based on a 50k g reference weight, are used for many of the analyses. A 40 kg lactating ewe and a 50 kg SE are similar in average energy requirements for maintenance.

well-established perenniality means that it does take several generations and seasons to change the proportions of species, arguably longer than the five years imposed by grazing bans. That means, in practice, that techniques must focus on optimising the combination of species present rather than aiming to increase desirable species that may have a significant presence in the grassland. The first sign of degradation in a grassland is an increase in less-desirable plant species, which means the more preferred plant types have become minor components.

The first phase of the program from which this monograph has come (eds Kemp & Michalk 2011) sought to understand how farmers (herders) managed their livestock. Models were then developed to analyse the livestock farming system and investigate options to improve management, including reducing stocking rates, improving feeding, introducing warm sheds, changes to enterprise and the timing of operations such as lambing (eds Kemp & Michalk 2011). On-farm demonstrations were established to verify the improvement in herders' livelihoods with new management systems. The initial focus was on the organisation of livestock, because it is easier to make those changes than to focus only on grassland improvement. Any changes made in the livestock system were those that had implications for grassland improvement. In general, the reducing livestock densities would reduce consumption rates by livestock, while increasing productivity per animal and net financial returns. However, further verification of the changes to grassland composition and ecosystem services as a result of improved management were required. These processes can be difficult to model, and data was needed to develop functions for the *StageTHREE* SGM to investigate the sustainability of new management practices (Chapter 6). Grazing experiments were established at Guyuan in Hebei Province (typical steppe; Zhang et al. 2015) and Maqu in Gansu (alpine meadow; Sun, Angerer & Hou 2015) along with a long-term experiment at Siziwang in IMAR that commenced in the first phase of this program (desert steppe; Wang, Jiao et al. 2011). These experiments primarily examined the influence of stocking rate and grazing management on livestock production, grassland composition and associated ecosystem services (including greenhouse gas mitigation) across the three less-productive grassland types. Previous chapters provide more details on these studies.

The aim of this chapter is to synthesise the information from the research on managing grasslands to develop criteria for the optimal grazing management and utilisation that will enhance grassland composition while maintaining livestock production and essential ecosystems services (GHG mitigation and prevention of erosion). Optimised scenarios are assessed against current district average stocking rates and the implementation of partial or total grazing bans, policies currently used to restore grassland degradation. The main hypothesis being tested was that enhancing grassland composition, improving the efficiency of livestock production and improving ecosystem services (GHG mitigation and erosion control) could be done by optimising the stocking rate at levels 30 to 50% lower than the current district averages. We also consider the management principles that could be taught to herders to enable them to adjust stocking rates and other practices more effectively. Often recommendations are made about stocking rates that are rigid and not easily adapted to changing conditions.

Criteria used to manage grasslands

The program reported in this monograph had a clear focus on defining better ways of managing grasslands that could also improve herder incomes. This involved not only grazing experiments but also modelling and the development of theory about how best to define the conditions where grasslands are likely to be managed sustainably. The two main system components involved are grassland condition and animal productivity. These components need to be defined in ways that allow grassland managers to easily know when the grassland is in a desirable state (Kemp & Michalk 2007).

The desired grassland condition is one with an optimal proportion of desirable species, with less-desirable species being confined, where possible, to minor components. The biomass of plant species needs to be at a level that optimises animal production and maintains sufficient ground cover to limit soil erosion, within what is feasible for the environment, to sequester carbon in the soil, minimise CH_4 release to the environment and optimise biodiversity. Simple measures of biodiversity (e.g. total species) are often inadequate, as they do not consider plant functional types (Chapter 8) or if there is an optimum number of species, or if more desirable species are increasing or decreasing under management practices.

Optimum animal production is best defined as the point where net incomes of herders are maximised, but in a way that links directly to the condition of the grassland. The focus in this work has been on defining optimal grazing practices for the period over summer when livestock graze the grasslands. Whole-year optimal animal production is a separate issue, as it depends on developing feeding strategies and the best use of warm sheds through the nine months of low temperatures when plant growth is nil and grassland forage quality is below animal maintenance requirements. Grazing through autumn, winter and spring is of doubtful value, as the energy costs of grazing typically exceed the energy obtained from the available forage. At best, animal liveweight loss is slowed from autumn grazing, when the quantity of available forage is higher. Grazing through winter is likely to damage grassland condition (Chapter 8).

Each component of grassland condition and animal productivity can be defined in its own terms, but this presents herders and grassland managers with the need to continually optimise their management across a range of components, which all need to be monitored. That rarely works in practice in any field, least of all with herders who do not have all the skills required. The alternative strategy developed here was to examine all the main components of grassland condition and animal production in terms of common variables. The aim was to identify a single measure that indicated whether or not the grasslands are being sustainably managed. The measure needed to be something that herders could readily monitor and understand in terms of how it influenced other system components, and that officials could also use to check management practices and apply policies. The common factor that is related to many grassland components and animal production is herbage mass (Kemp et al. 2015, 2018).

In grassland studies, the biomass of all plants should always be recorded at frequent intervals, as the primary measure along with plant cover, soil data, diversity measures, etc. Unfortunately, many ecological studies have recorded species in terms of cover, frequency and other measures, with no biomass data. That information is very difficult to use. Animals eat biomass, not frequency or cover, so a relationship with animal production and grassland state cannot be determined. The average standing herbage mass of a grassland through the growing season relates to total plant growth, the proportions of key species, the amount of carbon sequestered, general biological activity in the root zone, biodiversity (Kemp et al. 2003) and animal production (Kemp & Michalk 2007; Kemp, Badgery & Michalk 2015; Kemp et al. 2018).

Animal production in many studies over many years, and in models, has generally been assessed as the output of animals, meat, milk, skins or fibre per hectare. That is a highly relevant measure when land is a major limiting factor, as is now the case in much of China. However, many herders have not traditionally understood or focused on productivity per unit land area. The work reported in Chapter 5 suggests that they think more about stocking rates as the number of animals per farm. However, herders do understand the productivity of individual animals. This is becoming more important in China and elsewhere, where market prices reflect the quantity and quality of animal products per head. Animal production per head is the primary measure of performance used in research and by modern farmers. It is then multiplied by the stocking rate to estimate productivity per unit area of land. Animal production per head is a more relevant measure for herders traditionally used to common grazing practices. The research done here generally derived animal production per hectare, and the same measure was used in models to estimate optimal stocking rates. In general, it is often the case that the financially optimal stocking rate is when animal production per head is around 75% of the potential possible for those animals on that grassland system (Kemp, Badgery & Michalk 2015; Kemp et al. 2018).

Many experiments have shown that there is a hyperbolic relationship between herbage mass, animal intake and production (eds Freer, Dove & Nolan 2007; Kemp, Badgery & Michalk 2015; Badgery et al. 2017). Maximum animal production is reached when the herbage mass of grassland is at or above 1500 kg (green) DM/ha for *Lolium perenne/Trifolium repens* (ed. Nicol 1987). The financially optimal position of 75% of potential is around 1000 kg DM/ha for temperate higher rainfall pastures. However, the exact relationship will depend upon the grassland type, condition and type of livestock (Badgery et al. 2017). The key point is that, to achieve 75% of the potential per head production, the grassland needs to have readily prehended forage, which means more biomass than the typical overgrazed grasslands of China provide. Maintaining the average herbage mass above the levels required to optimise plant system components would enable herders to manage their livestock closer to the target value. Grazing experiments can be analysed to determine the values of herbage mass where animal production/head was around the target value.

Grazing experiments

A national program lead by Professor Zhang at China Agricultural University was established with many grazing experiments, in association with the program reported in this monograph. Much of that work is still being analysed and will be reported elsewhere.

(Left) Professors Kemp and Hou F. (Lanzhou University) at the grazing experiment in eastern Gansu on the Loess soil. (Right) Dr Michalk and Dr Badgery at the grazing experiment on the meadow steppe at Hailar in IMAR. These experiments are part of wider national programs that collaborated with the ACIAR program.
Photos: D.R. Kemp

The main three sites used for grazing management experiments in this program were in Siziwang, IMAR, on a degraded desert steppe site; Guyuan, Hebei, on representative typical steppe grassland, and Gannan, Gansu, on a well-used alpine meadow. This chapter highlights some of the effects that help develop the principles for interpreting grassland management studies and general considerations.

Desert steppe, Siziwang

The experiment at Siziwang (41°N, 111°E, elevation 1460 m) was established in 2004 to investigate the influence of grazing pressure on grassland composition and livestock production (Chapter 8). The site has an annual precipitation of 223 mm per year and mean annual temperature of 3.6 °C. Four grazing treatments were established over the growing season:

- nil
- light (notionally 0.75 SU/ha)
- moderate (1.5 SU/ha)
- heavy (2.25 SU/ha).

Heavy grazing represented the average stocking rate in the district at the beginning of the experiment.

The dominant desert steppe plant species typically found are *Stipa breviflora* and *Artemisia frigida*. They both progressively increased throughout this experiment, dominating the experiment and indicating that the site was probably previously grazed at stocking rates above the highest stocking rate treatment. That suggestion is further supported by the increase in grassland growth year by year throughout this study. In the desert steppe, the loss of palatable perennial grasses and increasing shrubs and semi-shrubs (*Artemisia* spp.) are a common sign of the first phase of degradation associated with overgrazing. With continued overgrazing, decreasing plant coverage, increasing bare ground and patch size occurs (Lin, Han et al. 2010; Lin, Hong et al. 2010). The edible semi-shrubs decline, leaving unpalatable grasses and other species. Soil erosion increases with these changes. As stocking rates are reduced, this process is somewhat reversed, though it is unlikely to return to an ideal state for livestock production. The desert steppe experiment, after 12 years and best management, has still not returned to its probable original state.

The value of long-term studies has been clearly demonstrated with this experiment. *Stipa breviflora* increased on all treatments from 2004 to 2016, but there was no stocking rate effect on the biomass of this relatively unpalatable grass (Figure 8.5). The exception was in the winter of 2004–05, when the whole site was inadvertently heavily grazed by many animals, which reduced the *S. breviflora* content. That heavy grazing period reduced the edible semi-shrub *Artemisia frigida* to a much greater extent than the grass. The content of *A. frigida* then increased on grazing treatments over time, mostly in the ungrazed control and least under the heavy grazing treatment. These results indicated that the sheep preferred to graze *A. frigida* and avoided *S. breviflora*, which was confirmed with observational studies (Wang ZW, unpublished). S. breviflora was eaten in October (autumn) when plant growth was frosted, but this had no effect on the subsequent botanical composition.

It took eight years of this desert steppe experiment before the relative proportions of *S. breviflora* and *A. frigida* started to differentiate (Figure 8.4). This was significantly longer than the normal five-year grazing bans used in IMAR to rehabilitate grasslands. After 12 years, *S. krylovii*, a more palatable grass, has started to increase within the nil and light grazing treatments, but not those with higher stocking rates. *S. krylovii* is a preferred species and in time it may become more important within this grassland. The mechanisms that allowed *S. krylovii* to become dominant need to be identified. Within the grassland, there were also some, generally minor, annual plant species and other forbs. However, the plant community has remained dominated by *S. breviflora* and *A. frigida*. While this combination may not be ideal for livestock production, animal growth rates have been reasonable on the light grazing treatment, where *A. frigida* was maintained in equal proportions to *S. breviflora*. In contrast, under heavy grazing (at the original district average stocking rates), the ratio of *S. breviflora* to *A. frigida* was 12:1 (Figure 8.4). This work clearly emphasises the need to work within the current state of the system, rather than trying to aim for an ideal. In the medium to long term, *S. breviflora* may be replaced by a more palatable grass, but that will require careful management to avoid overgrazing. It may be possible to use heavy grazing in winter (as occurred in 2004–05) every five years or so to reduce *S. breviflora*, but further research will be needed to identify better ways of using such techniques.

The desert steppe experiment found that the grassland growth in one year was more dependent upon growth in the previous summer (Figures 8.5 and 8.6) and less so on the current summer rainfall. This was a larger effect than could be discerned from rainfall alone. This effect seems to come from the condition of plants in early summer, possibly from the number of buds/tillers that survive the winter, which then influences growth in early summer that in turn influences the whole of summer growth in this dry environment.

Sheep liveweight gain data indicated that the optimum sustainable stocking rate was likely to be around 1 SE/ha over summer, slightly above the low stocking rate. This is the stocking rate over summer that averaged around 75% of the maximum per head production, around the point where net income per hectare is often maximised (Kemp et al. 2018). A stocking rate of 1 SE/ha is about half the average stocking rate in the district when the experiment began, but is now close to the regional average (Chapter 2). At 1 SE/ha, the average herbage mass remained about 0.5 t DM/ha throughout the summer and livestock consumed 10% of the total herbage growth.

There was no clear evidence of changes to soil carbon with differences in grazing pressure (or no grazing) over a four- or six-year period at Siziwang (Lin, Hong et al. 2010; Liu, Zhang et al. 2012). However, heavy grazing reduced the size of vegetation patches, increased the homogeneity of the spatial distribution of plant biomass and soil carbon (Lin, Hong et al. 2010) and suggested there could be declining levels of soil carbon. The desert steppe soils at Siziwang have been demonstrated to be a small CH_4 sink (Wang, Hao et al. 2011), and increasing grazing pressure decreased the proportion of CH_4 uptake once stocking rates were higher than 0.75 SU/ha in this experiment (Wang et al. 2012). Soil erosion and deposition may also be a cause of SOC differences. A previous study in the desert steppe by Pei, Fu and Wan (2008) showed lower SOC with grazing compared to two- and six-year exclusions. This was due to increasing sand fractions (> 0.1 mm) and less fine-soil fractions (< 0.1 mm) in the grazed area than exclosures (Pei, Fu & Wan 2008), supporting erosion (or deposition) as a contributing factor. However, due to a lack of true replication in the design of that experiment, the differences may actually represent spatial variability in soil properties and vegetation patterns.

The desert steppe experiment has clearly supported the view that lower stocking rates are needed to optimise the existing botanical composition, maintain more profitable rates of animal growth and reduce adverse effects on soil carbon. These components were optimal when the average herbage mass over summer was above approximately 0.5 t DM/ha. The optimal consumption rate of forage by livestock averaged 10%. This was the first study with evidence that grazing in winter has adverse effects on grassland productivity, though more information on that interaction is needed. The interesting result that grassland productivity in one year directly relates to growth in the next summer shows there is a clear feed-forward effect that justifies lower stocking rates in order to rehabilitate the grassland. District stocking rates are now of the same order as this experiment showed (Chapter 2).

Typical steppe, Guyuan

The typical steppe (simply called steppe in Mongolia) grazing experiment was done at Guyuan, Hebei (41°N 115°E, elevation 1430 m). The area has an average annual precipitation of 430 mm, mostly occurring between July and September and the annual mean temperature is 1.4 °C. *Leymus chinensis* and *Artemisia frigida* were the main plant species, plus *Carex duriuscula*. The grassland condition prior to the experiment was considered desirable, due to the high proportion of *L. chinensis*. The treatments investigated selected combinations of rest (R), moderate (M) or heavy grazing (H) pressure through the summer growing season. Five grazing treatments were implemented (RMH, RHM, MMM, HHM and HHH) through early, mid and late summer. In 2013, after three years, the stocking rates on all grazed treatments were reduced by 25%. Because of the varying stocking rates and length of time plots were grazed, the grazing pressure was calculated as the number of SE grazing days over summer. Further details of the experiment can be found in Zhang et al. (2015) along with other research on managing the typical steppe (Chapter 9).

Grassland production was directly related to the SE grazing days/ha/yr (Figure 10.1). There were different relationships between years. Herbage mass was highest in 2010 but decreased in subsequent years. The slope of the log-linear relationship increased in 2013, due mostly to the lowest stocking rates having greater improvements in average levels of herbage mass. The other data points had the same slope as the 2012 data. These changes in relative production between years were not a function of rainfall. These data indicate how in 2010 and 2011 the grassland was adjusting to the treatments and management of the experiment, reflecting the good grassland condition at the start of this study. By 2012–13, the combined data suggest an increased curvilinear, declining relationship (not shown) between total herbage mass and SE grazing days that reached a minimum similar to that found at the highest SE grazing days in the previous year. At 400 SE grazing days, the mean herbage mass (approximately 0.5 t DM/ha) in 2012–13 was about 60% of that achieved with the lowest SE grazing days in those years.

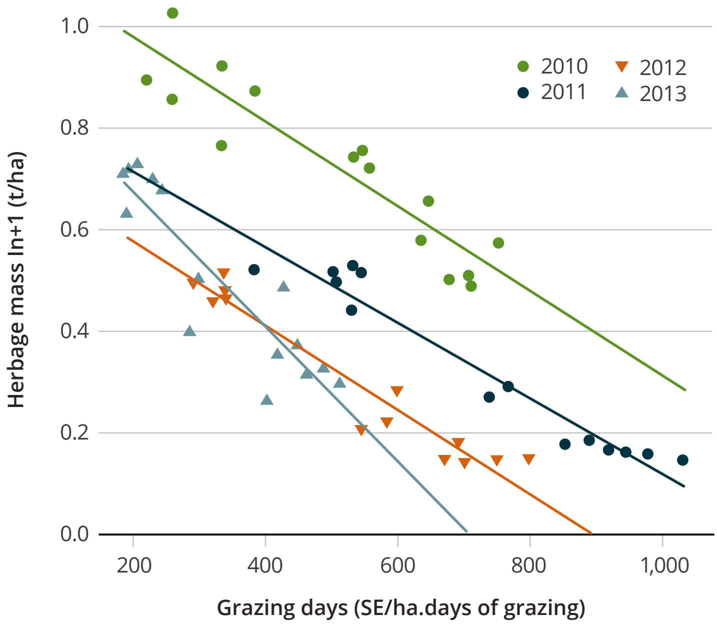

Figure 10.1 Relationship between average grazing season herbage mass and grazing days on a typical steppe, Guyuan, Hebei, 2010–13

Source: Zhang et al. (2015)

The composition of the grassland was closely related to biomass, with consistent relationships over treatments and years. There was an exponential decrease in the proportion of *L. chinensis*, declining below approximately 1 t DM/ha of herbage mass (Figure 10.2a) and below 70% when the herbage mass was < 0.5 t DM/ha. In contrast (Figure 10.2b,c), *Artemisia* spp. increased above 5% when the herbage mass was below approximately 0.5 t DM/ha and forbs increased above 10% at the same point. The change in grassland composition witnessed in this study shows the common pattern of species shift from overgrazing. This has been previously documented by Liang et al. (2009), who found that on a grazing gradient from no grazing to heavy grazing vegetation changed from the original dominant grass species *L. chinensis* to the semi-shrub species *A. frigida*. There is evidence that the species composition change in typical steppe is reasonably resilient, within the realms of this short-term experiment. When stocking rates were reduced in 2013, both *L. chinensis* and *Artemisia* spp. reversed treatment trends with reduced grazing pressure, but forbs were not reduced to a lower level. Rest treatments maintained similar, desirable proportions of plant species across all four years.

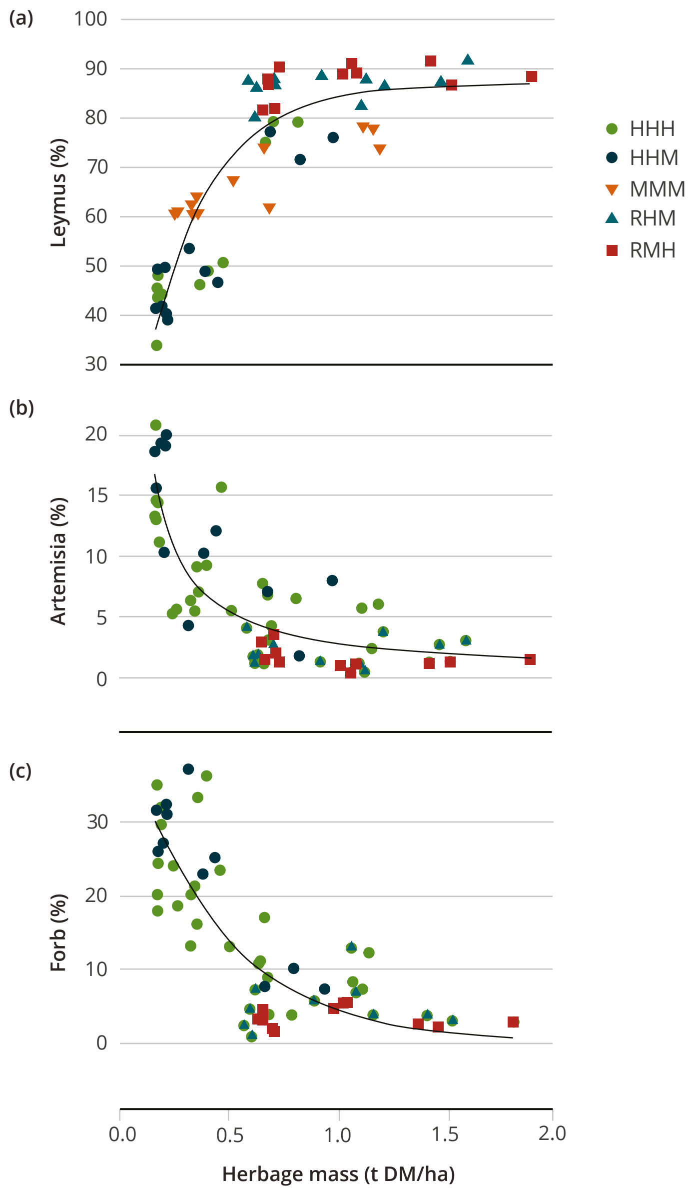

Figure 10.2 Average proportion of (a) *Leymus chinensis*, (b) *Artemisia* spp. and (c) forbs on a typical steppe under different grazing treatments, Guyuan, Hebei, 2010–13

Note: The grazing treatments are combinations of H = heavy, M = moderate and R = rest/no grazing through the three months of summer.

Source: Zhang et al. (2015)

Because of the design used in the typical steppe experiment (Zhang et al. 2015), it was not reasonable to simply use the liveweight gains from each treatment to determine the optimum. Instead the SEw grazing days/ha/yr were calculated and productivity was related to that. The optimum SE days/ha/yr for grassland condition was approximately 400, which meant a stocking rate of 4 SE/ha over 100 days of grazing. At this stocking rate, the herbage mass averaged > 0.5 t DM/ha and animal growth rates were > 100 g/hd/day.

Methane fluxes were estimated on all treatments. Heavily grazed treatments had significantly higher CH_4 emissions from animals over the grazing season (22 kg/ha/yr), compared to moderately grazed (17 kg/ha/yr) and early-season rest treatments (approximately 14 kg/ha/yr). The moderately grazed treatment was a little above the optimum stocking rate of 400 SE days/ha/yr. This treatment also recorded a higher uptake of CH_4 into the soil (3.7 mg/m^2/day) compared to other treatments (approximately 1.5 mg/m^2/day) (Wang et al. 2015; Zhang et al. 2015) and greater sequestration of SOC (1.2 Mg/ha/yr) than for treatments with an early summer rest (approximately 0.6 Mg/ha/yr) or high stocking rates (approximately 0.1 Mg/ha/yr). The higher SOC sequestration can be explained by greater root turnover (Chen et al. 2015). The main sources and sinks of GHGs were combined throughout the grazing season to estimate the systems level emissions. The moderately grazed treatment had the highest net sequestration of GHGs at 4 t CO_2/ha/yr, while the high stocking rates actually emitted GHGs (Table 10.1). The largest sink in GHGs was due to increases in SOC, though the benefits are likely to decrease over time (He et al. 2008). Assuming all treatments reach an equilibrium soil carbon level at a similar time, moderate grazing pressure would still have lower GHG emissions than the high treatments.

Table 10.1 Average GHG fluxes under different grazing treatments

GHG fluxes	HHH	HHM	MMM	RHM	RMH	lsd
SOC sequestration (kg CO_2-e/ha/yr)	–164.7	-410.1	–4,343.0	–2,219.9	–2,072.2	1,156.7**
CH_4 uptake (kg CO_2-e/ha/yr)	–36.6	–34.5	–103.0	–51.2	–39.4	28.0*
CH_4 sheep emissions (kg CO_2-e/ha/yr)	651.6	597.8	470.7	424.2	380.7	43.9**
GHG flux (kg CO_2-e/ha/yr)	384.4	92.9	–4014.7	–1,886.8	–1,767.4	1,164.9**

Notes:

- GHG fluxes have been standardised as carbon dioxide equivalents (CO_2-e).
- Least significant differences are indicated as *= $P < 0.01$, ** = $P < 0.001$.

Source: Zhang et al. (2015)

The typical steppe experiment demonstrated that a moderate grazing pressure through summer of approximately 400 SE grazing days/ha (4 SE/ha over 100 days) maintained higher animal growth rates, an average herbage mass above 0.5 t DM/ha that kept the content of *L. chinensis* above 70% and *A. frigida* below 10% of the grassland and achieved the highest net level of carbon sequestration. In contrast with the desert steppe study, where *A. frigida* was the more desirable species for animal production in the grassland, management in this case can focus on minimising the amount of *A. frigida* and optimising the content of the desirable grass, *L. chinensis*. At 400 SE grazing days/ha, this meant that the consumption rate by sheep of the grassland was approximately 20%. Of interest was the result on the desert steppe that the sustainable stocking rate of 1 SE/ha over summer also resulted in an average herbage mass of 0.5 t DM/ha. However, considerable further work is required to determine what would be the critical values for herbage across other grassland types. The conclusions from this work are broadly supported by other research on the typical steppe (Chapter 9).

Alpine meadow, Maqu

The alpine meadow grazing experiment was done in Maqu, Gansu, on the east of the Qinghai–Tibetan Plateau (35°N, 101°E, elevation 3500 m). The average precipitation is 616 mm and annual temperature is 2.4 °C, with 270 frost days/yr over the past 13 years. This region has recorded significant changes in grassland cover over the last 25 years (Lu et al. 2016). The grazing experiment investigated continuous grazing (July–December) with a stocking rate of 4 sheep/ha vs short duration seasonal rotation (SDSR) treatments with 4 or 8 sheep/ha that were grazed through summer (July–September) in the growing-season pasture and then in autumn (October–December) in a separate autumn pasture when there is no plant growth and frosts occur. Within the SDSR treatments in summer, animals were grazed around three subplots, moving every 10 days. In autumn they were grazed around two subplots, moving every 15 days. The SDSR treatments also compared a heavy stocking rate in the growing season and light stocking rate in the cold season (SDSR-HL) with a light stocking rate in the growing season and heavy stocking rate in the cold season (SDSR-LH). Measurements of herbage mass were done before and after each graze period, or at monthly intervals (in the continuously grazed plots). Further details of the experiment can be found in Sun et al. (2015).

Within the main continuous grazing treatments, other smaller experiments were done using an open communal grazing design (Kemp & Dowling 2000) to test month-by-month effects of grazing or rests on grassland composition. This chapter only gives a summary of a couple of the main results that influence how best to graze alpine meadows. Detailed plant measurements of species were done in August each year, when plants could be readily identified. This meant that results in one year better reflected the medium-term effects of treatments in previous years than the current-year effects.

Within alpine meadows, there has been a concern that less-desirable (unpalatable/toxic) plants increase in proportion as overgrazing increases. However, the data from two years of the experiment across a range of treatments showed that the supposed less-desirable species were at higher levels in the treatments that were mostly rested (3.1 t DM/ha compared to 1.8 t DM/ha of desirable species) than in grazed treatments (2.3 t DM/ha compared to 2.2 t DM/ha of desirable species). This indicated that less-desirable species are grazed. In other years, the results suggested no consistent treatment differences in plant species proportions. This raised the question of what herders consider a less-desirable species. No detectable effects on animal health were found in this experiment, even though these species made up a high proportion of the grassland. It was not possible to clarify if the definition was confounded by translation from Tibetan to Chinese then English. The plants in this category may be those that are less productive, or that at other times are rejected by livestock. The interesting result is that control of this less-desirable plant group is arguably achieved by grazing. A grazing ban would then be inappropriate for managing these species. Tactical heavier grazing could prove to be an effective technique for improving grassland condition, as observed in the desert steppe experiment.

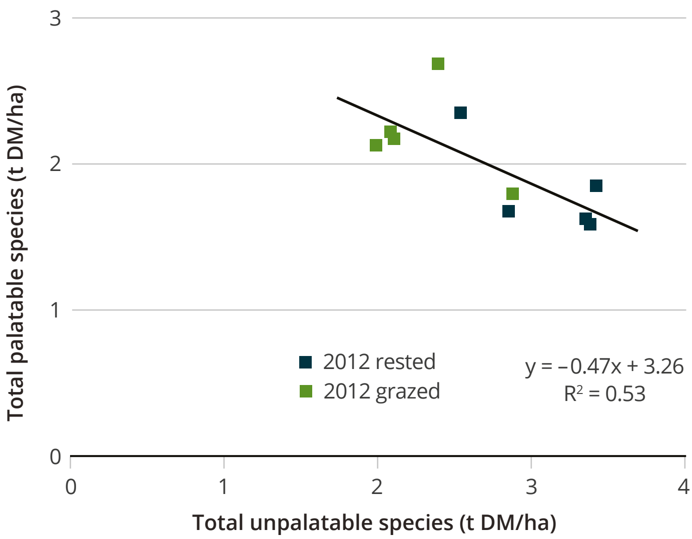

Figure 10.3 Desirable and undesirable species during the 2013 growing season, Maqu, Gansu

In the main grazing experiment, seven-month-old Tibetan sheep were purchased in June, grazed on treatments until December, then sold. Under light stocking rates (4 sheep/ha) there was no difference in liveweight gain (LWG) per head between continuous stocking and SDSR treatments (Figure 10.4). Over the three years of this study, animals, on average, gained weight between July and September then lost weight from October through December, irrespective of grazing management treatment (Sun, Angerer & Hou 2015). The average daily LWG over three years in the main contrasting stocking rates showed a similar pattern of response to that found in other experiments (Figure 10.4). The average potential sheep growth rate was 127 g/hd/d, 75% of which is 95 g/hd/d, which is about the value where livestock production is more profitable (Kemp et al. 2018). This was estimated to be at a stocking rate of 13–14 sheep/ha over summer. This result supports the view that, for this site, the average stocking rates are arguably sustainable and not overstocked. This result was further refined by considering the residual herbage mass after grazing, which averaged 1.6–2.3 t DM/ha. These values suggest that animal intake would not be greatly restricted (Badgery et al. 2017) though, at the higher stocking rates, the availability of green forage may have been marginally limiting (Figure 10.4). Sun, Angerer and Hou (2015) concluded that the sustainable stocking rate was a seasonal forage allowance of 310 SU d/t DM of peak herbage growth, which applied to the six months from July to December. As the average level of residual herbage mass across treatments was close to 2 t DM/ha, that suggests the sustainable carrying capacity could be approximately 600 SU grazing days/ha or only 3.3 SU/ha over the 180 days from July to December. This is a conservative result in comparison to the results shown in Figure 10.4. Setting stocking rates based on the peak forage allowance is problematic as animal numbers need to be determined a few months before peak growth. Hence, in this monograph, there is more emphasis on managing to average a critical level of herbage mass. Further work on alpine meadows is needed to identify what those critical levels are.

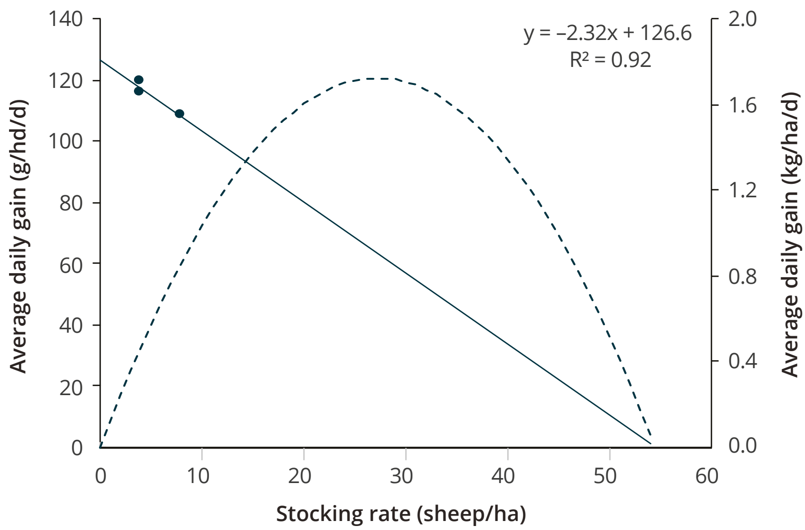

Figure 10.4 Average liveweight gain over summer at two stocking rates over three years for young Tibetan sheep grazing an alpine meadow, Maqu

Note: Solid line is the response per head and the dashed line is the response per hectare calculated from the equation for solid line.

Data estimated from Sun, Angerer and Hou (2015)

When this experiment started, the higher stocking rate treatments were set at the district average stocking rates. The field site on the valley floor near the local village had been typically grazed throughout the year, as herders had regular access. After two years of the experiment, the herbage mass within the experiment, even on the highest stocking rate treatment, was two to four times greater than that of the surrounding areas. This is reflected in the experiment results. An investigation found that the effective stocking rate on farms on the valley floor was much greater than the district average suggested. This very high local stocking rate occurred because herders obtained permission to bring their animals into that area so they could sell them to traders. Overgrazing was then only occurring in part of the region. The overall livestock numbers could be sustained (as shown in the experiment) when evenly distributed. To reduce overgrazing on the valley floor, the local community needs to work out better ways for herders to sell their livestock without increasing pressure on the valley floor.

In general, alpine meadows have a higher carbon content than other soils and a shorter time of the year above freezing. The rate of CH_4 uptake by the soil was lower than for other grasslands and best under moderate grazing (Liu, Sun et al. 2012). The highest soil carbon content was under no grazing (58 g C/kg soil; 0–15 cm), reducing to 37 g C/kg soil under heavy grazing (Sun 2012; Nie et al. 2013). Further work is needed to refine how these effects relate to herbage mass.

The research on alpine meadows suggested that average stocking rates may not lead to overgrazing, but that local practices that affect distribution of animals are a problem. Stocking rates were more important than the patterns of grazing.

Discussion

Grazing management research has a long history in the developed world, but less so for the grasslands of China. The challenge is to advance knowledge about what practices would improve the grasslands and the livelihoods of millions of herders who depend on them. Grazing management not only improves the sustainability of grasslands, but also sustains the millions of people who depend upon grasslands for their livelihoods, food, fibre and fuel. Those combined aims mean that grazing has multiple aims that need to be resolved in practical ways. Practical in this sense meaning deriving methods that can be understood and used by the herders directly engaged in managing grasslands and livestock.

Grazing management involves managing both animals and the grassland. Animals are the main tool used by herders. This tool involves varying the density of animals (stocking rate), the intensity and frequency with which they graze any given area of grassland, and the timing of when grazing starts and stops. These components need to be standardised in terms of impact, usually by expressing them as a standard sheep equivalent. The work done in China, summarised in this monograph, shows the main components of grazing management that are important are the stocking rate, the time when grazing starts in summer, and no grazing in winter. An important result from this work is that grazing practices need to focus on working with the current state of a grassland, rather than trying to restore it to some ideal state, which is unlikely to be feasible in the medium term. As argued by Westoby, Walker & Noy-Meir (1989), the rehabilitation pathway for a degraded grassland would rarely be the same as for the initial degradation, hence it cannot simply be reversed.

In the desert and typical steppe, reduced stocking rates are vital for sustaining the grasslands. In general, a 50% reduction in stocking rates from the high levels reached in the 1990s (Chapter 2) is needed to improve or maintain a desired species composition and increase income from livestock. This has been promoted to officials in various meetings over the years. The exception found was in the alpine meadows, where overgrazing is a local problem in only parts of the landscape. Infrastructure changes (e.g. access roads, special stock routes, holding fields and market organisation) are likely to be important parts of solving the local overgrazing in valley floors. The data on livestock numbers (Chapter 2) for the alpine meadow area of Maqu showed there had been a smaller increase in animal numbers in recent decades than elsewhere in China.

While reduced stocking rates are clearly needed for most grassland types, setting an ideal stocking rate may not be the optimum strategy, as that only defines forage demand, not the supply. A better strategy, promoted through this monograph, is to focus on managing livestock to maintain grasslands above a critical level of herbage mass through the summer plant growth period. Standing herbage mass in a grassland is the net balance between consumption and growth. Both the desert and typical steppe experiments defined this level as above 0.5 t DM/ha. In practice, this would mean herders need to maintain an even higher value, as it would be difficult to be precise and achieve exactly 0.5 t DM/ha across all their grasslands. This critical value is related to optimising plant species composition, optimising soil carbon and CH_4 uptake, reducing the soil erosion risk and achieving animal growth rates near the financially optimum level. Herbage mass can be monitored remotely by officials and others to determine the state of grasslands, and used to advise herders what to do and when. In poor seasons, livestock numbers would need to be less than the average optimal stocking rates to maintain critical values of herbage mass. Herders would get prior warning about when to sell livestock. In many instances, this would mean they receive a better price than if they had waited until all the grass was gone and the animals were in poor condition.

In China, markets need to be developed to accommodate this need. In a good season, it may not be possible to breed or acquire enough animals to reduce the herbage mass to the set critical value. However, that is a good problem as it provides the opportunity for grasslands to recover.

Delaying the start of grazing in summer has been shown to improve both summer growth and total production (Chen, Michalk & Millar 2002). This has now become a standard part of grassland regulations; especially where local government have implemented grassland balance strategies designed to allow grazing and continue livestock production while rehabilitating the degraded grasslands. The research presented in this monograph has helped to define the reduced stocking rates needed. The delay in grazing has, however, been set on calendar dates. The typical and desert steppe experiments have shown that grassland composition has improved when the herbage mass is maintained above 0.5 t DM/ha. That critical threshold could prove to be a better criterion for when to commence grazing than a calendar date, or at least could help set a better average calendar date in different regions.

One of the unresolved dilemmas is how best to manage the reportedly toxic plants in alpine meadows. The limited work done indicated that these plants are grazed, and they increase when not grazed. It may be that they are in a similar category to species in other grasslands, which are considered by herders to be less productive and/or less palatable and not necessarily always toxic. The data obtained so far suggests that these species can be managed by grazing. It may be possible to use heavy grazing at critical times in their development (e.g. when flowering is initiated in early-mid summer or when any known toxins are minimal) to reduce their presence and achieve more productive, higher forage quality meadows. In Australia, as an example, undesirable *Aristida ramosa* grassland can be changed to one dominated by *Rytidosperma linkii* using targeted heavy grazing followed by rest (Lodge & Whalley 1985; Lodge et al. 1999).

Grazing through winter has always been problematic in China, as temperatures are very low. Modelling found that the energy costs of grazing in winter greatly exceeded the energy obtained from eating the dead plant material available (Takahashi, Kemp, Behrendt, unpublished). The one piece of evidence obtained was for the desert steppe (Chapter 8). This showed a considerable reduction in plant growth in the year following heavy grazing pressures in winter. More research is needed to clarify the effects of intensity of grazing through winter on the state of grasslands. It is clear, however, that low temperatures and limited feed supplies will mostly mean that animals will lose considerable weight through winter (Chapter 3). In effect, better design of warm sheds can partly offset the lack of food and achieve better outcomes for animals. The survival of animals through winter will be improved by not grazing, keeping them in better designed warm sheds and increasing the supply of quality food. This will be part of the progress of herders from being focused on simply managing animal survival to managing animals to optimise production and improve incomes.

In China, total grazing bans have been used since 2003 (Xiong et al. 2016) as a prime mechanism for rehabilitating degraded grasslands. However, the research presented here has not found that this always results in the best outcome. Reduced stocking rates have often achieved useful changes in plant species, stored more carbon and CH_4 in soils, and maintained plant cover to reduce erosion risks just as effectively as grazing bans. Under reduced stocking rates, the net financial returns from livestock have increased (Chapter 6; eds Kemp & Michalk 2011) and the level of government payments to achieve reduced stocking rates are significantly less than for a total grazing ban. It is also arguable that when the right stocking rate is used and markets pay premiums for better-quality livestock, as shown in the Siziwang farm demonstrations (Chapter 8), there is no need for a government payment. Furthermore, while these policies are targeted at improving grassland composition, they may have unintended GHG outcomes by displacing production to other less-sustainable areas or intensive feedlot production systems that may have a greater contribution to the production of GHGs (Plevin, Delucchi & Creutzig 2014). The evidence in these experiments (Chen et al. 2015; Zhang et al. 2015) and others (Liu, Zhang et al. 2012; Orgill et al. 2016) indicate that light or moderate grazing can store as much or more carbon than grazing bans due to increased root turnover (Chen et al. 2015). It is clear that grazing is not all bad for the environment. Grazing treatments had similar livestock production with reduced GHG emissions compared to ungrazed treatments (Zhang et al. 2015).

References

Alexandratos, N & Bruinsma, J 2012, 'World agriculture towards 2030/2050: the 2012 revision. *ESA working paper No. 12–03*, Food and Agriculture Organization of the United Nations, Rome, <http://www.fao.org/3/a-ap106e.pdf> accessed 22 December 2017.

Badgery, W, Michalk, DL & Kemp, DR 2015, 'Sustainable management of temperate grasslands in Australia', in PK Ghosh, SK Mahanta, JB Singh & PS Pathak (eds), *Grassland: a global resource*, Rangeland Management Society of India, Jhansi, Uttar Pradesh, India, ch. 7, pp. 141–192.

Badgery, WB 2017, 'Longer rest periods for intensive rotational grazing limit diet quality of sheep without enhancing environmental benefits' *African Journal of Range & Forage Science*, vol. 34, pp. 99–109.

Badgery, W, Millar, G, Broadfoot, K, Martin, J, Pottie, D, Simmons, A & Cranney, P 2017, 'Better management of intensive rotational grazing systems maintains pastures and improves animal performance', *Crop and Pasture Science*, vol. 68(12), pp. 1131–1140, doi: 10.10171/CP16396.

Bai, Y, Han, X, Wu, J, Chen, Z & Li, L 2004, 'Ecosystem stability and compensatory effects in the Inner Mongolia grassland', *Nature*, vol. 431, pp. 181–184.

Briske, DD, Fuhlendorf, SD & Smeins, FE 2005, 'State-and-transition models, thresholds, and rangeland health: a synthesis of ecological concepts and perspectives', *Rangeland Ecology & Management*, vol. 58, pp. 1–10.

Chen, L, Michalk, DL & Millar, GD 2002, 'The ecology and growth patterns of *Cleistogenes* species in degraded grasslands of eastern Inner Mongolia, China', *Journal of Applied Ecology*, vol. 39, pp. 584–594.

Chen, WQ, Huang, D, Liu, N, Zhang, YJ, Badgery, WB, Wang, XY & Shen, Y 2015, 'Improved grazing management may increase soil carbon sequestration in temperate steppe', *Scientific Reports*, 5, 10892, doi: 10.1038/srep10892.

Freer, M, Dove, H & Nolan, JV, (eds) 2007, *Nutrient requirements of domesticated ruminants*, CSIRO Publishing, Collingwood, p. 270.

Friedel, MH 1991, 'Range condition assessment and the concept of thresholds: a viewpoint', *Journal of Range Management*, vol. 44, pp. 422–426.

Gao, YZ, Giese, M, Lin, S, Sattelmacher, B, Zhao, Y & Brueck, H 2008, 'Below ground net primary productivity and biomass allocation of a grassland in Inner Mongolia is affected by grazing intensity', *Plant and Soil*, vol. 307, pp. 41–50.

He, NP, Yu, Q, Wu, L, Wang, YS & Han, XG 2008, 'Carbon and nitrogen store and storage potential as affected by land-use in a *Leymus chinensis* grassland of northern China', *Soil Biology and Biochemistry*, vol. 40, pp. 2952–2959.

Jia, YL & Su, DX 1996, *China's Grassland Resources*, China Sciences Press, Beijing, China.

Kang, L, Han, XG, Zhang, ZB & Sun, OJ 2007, 'Grassland ecosystems in China: review of current knowledge and research advancement', *Philosophical Transactions Royal Society B – Biological Sciences (Series B)*, vol. 362(1482), pp. 997–1008.

Kemp, DR & Dowling, PM 2000, 'Towards sustainable temperate perennial pastures', *Australian Journal of Experimental Agriculture*, vol. 40, pp. 125–132.

Kemp, DR, King, WMcG, Lodge, GM, Murphy, SR, Quigley, P & Sanford, P 2003, 'SGS Biodiversity Theme: the impact of plant biodiversity on the productivity and stability of grazing systems', *Australian Journal of Experimental Agriculture*, vol. 43(8), pp. 962–975, doi: 10.1071/EA02200.

Kemp, DR & Michalk, DL 2007, 'Towards sustainable grassland and livestock management', *The Journal of Agricultural Science*, vol. 145(6), pp. 543–564.

Kemp, DR, Badgery, WB & Michalk, DL 2015, 'Principles for grassland systems research for livelihood and environmental benefits', in PK Ghosh, SK Mahanta, JB Singh & PS Pathak (eds), *Grassland: a global resource*, Rangeland Management Society of India, Jhansi, Uttar Pradesh, India, ch. 13, pp. 283–310.

Kemp, DR & Michalk, DL (eds) 2011, *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings No. 134*, Australian Centre for International Agricultural Research, Canberra, p. 189.

Kemp, DR, Han, GD, Hou, XY, Michalk, DL, Hou, FJ, Wu, JP & Zhang, YJ 2013, 'Innovative grassland management systems for environmental and livelihood benefits', *Proceedings of the National Academy of Sciences of the United States of America*, vol. 110 (21), pp. 8369–8374, doi: 10.1073/pnas.1208063110.

Kemp, DR, Han, GD, Hou, FJ, Hou, XY, Li, ZG, Sun, Y, Wang, ZW, Wu, JP, Zhang, XQ, Zhang, YJ & Gong, XY 2018, 'Sustainable management of Chinese grasslands: issues and knowledge', *Frontiers of Agricultural Science and Engineering*, vol. 5, pp. 9–23, doi: 10.15302/J-FASE-2018204.

Liang, Y, Han, GD, Zhou, H, Zhao, ML, Snyman, HA, Shan, D & Havstad, KA 2009, 'Grazing intensity on vegetation dynamics of a typical steppe in northeast Inner Mongolia', *Rangeland Ecology & Management*, vol. 62, pp. 328–336.

Lin, Y, Han, G, Zhao, M & Chang, SX 2010, 'Spatial vegetation patterns as early signs of desertification: a case study of a desert steppe in Inner Mongolia, China', *Landscape Ecology*, vol. 25, pp. 1519–1527.

Lin, Y, Hong, M, Han, G, Zhao, M, Bai, Y & Chang, SX 2010, 'Grazing intensity affected spatial patterns of vegetation and soil fertility in a desert steppe', *Agriculture, Ecosystems & Environment*, vol. 138, pp. 282–292.

Liu, N, Zhang, YJ, Chang, SJ, Kan, HM & Lin, LJ 2012, 'Impact of grazing on soil carbon and microbial biomass in typical steppe and desert steppe of Inner Mongolia', *PLoS ONE*, vol. 7(5), e36434, doi: 10.1371/journal.pone.0036434

Liu, Y, Sun, Y, Yan, CY, Zhang, T, Yuan, H & Hou FJ 2012, 'Seasonal dynamics of greenhouse gas emission from alpine meadow grazed by Tibetan sheep and effects of sheep dung', *Pratacultural Science*, vol. 29. pp. 1212–1216.

Lodge, GM, Gogel, BJ, Cullis, BR & Archer, KA 1999, 'Effects of grazing, slashing and burning on *Aristida ramosa* and sheep productivity in northern New South Wales', *Australian Journal of Experimental Agriculture*, vol. 39, pp. 685–698.

Lodge, GM & Whalley, RDB 1985, 'The manipulation of species composition of natural pastures by grazing management on the northern slopes of New South Wales', *Australian Rangeland Journal*, vol. 7, pp. 6–16.

Lu, JF, Dong, ZB, Hu, GY, Li, WJ, Luo, WY & Tan, ML 2016, 'Land use and land cover change and its driving forces in Maqu County, China in the past 25 years', *Sciences in Cold and Arid Regions*, vol. 8, pp. 432–440.

Michalk, DL, Kemp, DR, Badgery, WB, Wu, JP, Zhang, YJ & Thomassin, PJ 2015, 'Sustainability, biodiversity and environmental issues: a global perspective for livestock production', in MM Roy, DR Malaviya, VK Yadav, T Singh, RP Sah, D Vijay & A Radhakrishna A (eds), *Sustainable use of grassland resources for forage production, biodiversity and environmental protection*, Souvenir of 23rd International Grassland Congress, 20–24 November 2015, New Delhi, India, Range Management Society of India, Jhansi, Uttar Pradesh, India, pp. 6–23.

Nicol, A (ed.) 1987, *Livestock feeding on pasture*, Occasional Publication 10, New Zealand Society of Animal Production, Hamilton, New Zealand.

Nie, Z, Hua, L, Zollinger, R, Zhang, DG & Shi, S 2013, 'Grazing management of native and naturalised pastures in harsh environments', in P Gorawala & S Mandhatri (eds), *Agricultural Research Updates*, Nova Science Publishers, Inc, New York, pp. 181–203.

Orgill, SE, Condon, JR, Conyers, MK, Morris, SG, Alcock, DJ, Murphy, BW & Greene, RSB 2016, 'Removing grazing pressure from a native pasture decreases soil organic carbon in southern New South Wales, Australia', *Land Degradation & Development*, vol. 29(2), pp. 274–283.

Pei, SF, Fu, H & Wan, CG 2008, 'Changes in soil properties and vegetation following exclosure and grazing in degraded Alxa desert steppe of Inner Mongolia, China', *Agriculture Ecosystems & Environment*, vol. 124, pp. 33–39.

Plevin, RJ, Delucchi, MA & Creutzig, F 2014, 'Using attributional life cycle assessment to estimate climate-change mitigation benefits misleads policy makers', *Journal of Industrial Ecology*, vol. 18, pp. 73–83.

Ren, JZ, Hu, ZZ, Zhao, J, Zhang, DG, Hou, FJ, Lin, HL & Mu, XD 2008, 'A grassland classification system and its application in China', *The Rangeland Journal*, vol. 30(2), pp. 199–209.

Sun, Y 2012, 'Studies on the effects of grazing intensity on vegetation and soil in alpine meadow on the eastern Qinghai-Tibetan Plateau', PhD thesis, Lanzhou University, China.

Sun, Y, Angerer, JP & Hou, FJ 2015, 'Effects of grazing systems on herbage mass and liveweight gain of Tibetan sheep in Eastern Qinghai-Tibetan Plateau, China', *The Rangeland Journal*, vol. 37(2), pp. 181–190.

Thornton, PK 2010, 'Livestock production: recent trends, future prospects', *Philosophical Transactions of the Royal Society B – Biological Sciences*, vol. 365(1554), pp. 2853–2867, doi: 10.1098/rstb.2010.0134

Tong, C, Wu, J, Yong, S, Yang, J & Yong, W 2004, 'A landscape-scale assessment of steppe degradation in the Xilin River Basin, Inner Mongolia, China', *Journal of Arid Environments*, vol. 59, pp. 133–149.

Wang, CJ, Han, GD, Wang, SP, Zhai, XJ, Brown, J, Havstad, KM, Ma, XZ, Wilkes, A, Zhao, ML, Tang, SM, Zhou, P, Jiang, YY, Lu, TT, Wang, ZW & Li, ZG 2014, 'Sound management may sequester methane in grazed rangeland ecosystems', *Science Reports*, vol. 4(4444), doi: 10.1038/srep04444.

Wang, C, Tang, S, Wilkes, A, Jiang, Y, Han, G & Huang, D 2012, 'Effect of stocking rate on soil-atmosphere CH_4 flux during spring freeze-thaw cycles in a northern desert steppe, China', *PLoS ONE*, vol. 7(5), e36794, doi: 10.1371/journal.pone.0036794

Wang, D & Ba L 2008, 'Ecology of meadow steppe in northeast China', *The Rangeland Journal*, vol. 30, pp. 247–254.

Wang, X, Zhang, Y, Huang, D, Li, Z & Zhang, X 2015, 'Methane uptake and emissions in a typical steppe grazing system during the grazing season', *Atmospheric Environment*, vol. 105, pp. 14–21.

Wang, ZW, Jiao, S, Han, GD, Zhao, ML, Willms, WD, Hao, X, Wang J, Din, H & Havstad, KM 2011, 'Impact of stocking rate and rainfall on sheep performance in a desert steppe', *Rangeland Ecology and Management*, vol. 64, pp. 249–256.

Wang, ZW, Hao, XY, Shan, D, Han, GD, Zhao, ML, Willms, WD, Wang, Z & Han, X 2011, 'Influence of increasing temperature and nitrogen input on greenhouse gas emissions from a desert steppe soil in Inner Mongolia', *Soil Science and Plant Nutrition*, vol. 57, pp. 508–518.

Westoby, M, Walker & B, Noy-Meir I 1989, 'Opportunistic management for rangelands not at equilibrium', *Journal of Range Management*, vol. 42, pp. 266–274.

Xiong, DP, Shi, PL, Zhang, XZ & Zou, CB 2016, 'Effects of grazing exclusion on carbon sequestration and plant diversity in grasslands of China: a meta-analysis', *Ecological Engineering*, vol. 94, pp. 647–655.

Zhang, YJ, Huang, D, Badgery, WB, Kemp, DR, Chen, WQ, Wang, XY & Liu, N 2015, 'Reduced grazing pressure delivers production and environmental benefits for the typical steppe of north China', *Scientific Reports*, 5, doi: 10.1038/srep16434.

Zhang, YY & Zhao, WZ 2015, 'Vegetation and soil property response of short-time fencing in temperate desert of the Hexi Corridor, north-western China', *Catena*, vol. 133, pp. 43–51.

11 Capacity building to deliver benefits for sustainable grasslands

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The major imperative of the 21st century is food security and the growing demand for agricultural output while preserving essential ecosystem processes on which both long-term agricultural production and human wellbeing depend (Johnson et al. 2014). For China, the future food issue is essentially a livestock problem. Changing human diet resulting from rising incomes coupled with rapid urbanisation have increased demand for red meat and reduced consumption of staples. In response to these driving forces, supplying animal protein has become more important. Substantial support from government policies and subsidies aim to aid the transition to more efficient production systems (Bai et al. 2018). Traditional herders, officials and researchers have been poorly equipped to achieve more efficient livestock production in grassland regions, as their focus has been on survival. An important part of the program discussed in this monograph has been to build the skills needed to improve grassland management and herder incomes.

By 2025, China's red meat consumption is predicted to exceed 16.7 Mt (Mao et al. 2016). Unless domestic production efficiency and product quality improves significantly, this will require the import of 2.2 Mt by 2025 from global ruminant livestock markets (Table 11.1). At present, much of the increase in red meat output from China's sustainable grassland-based cattle, sheep and goat industries has been achieved simply by increasing livestock numbers (Chapter 2) rather than by improving the production efficiency of existing animals (Chapters 8, 9 and 10). Two factors explain this lag in uptake of market-focused livestock farming practices to produce red meat more efficiently. First, approximately 75% of beef cattle and meat-producing sheep in western China are raised by small household farmers (Yang 2013) who have limited education, management skills and resources (Wang & Xiao 2016) and are reluctant to abandon their familiar traditional subsistence herding practices. Second, Chinese grasslands are complex agro-ecological systems that are in various stages of degradation due to overgrazing (Ren et al. 2001; Kemp et al. 2013). A better appreciation of how system components interact is needed to develop sustainable livestock production solutions (Han et al. 2013; Briske et al. 2015) that will help rehabilitate grasslands and improve herder household incomes at the same time (Kemp et al. 2013; Kemp et al. 2018).

Table 11.1 Red meat production, imports and consumption, China, 2010, 2015 and (predicted) 2025

	Sheep and goat meat			Beef and yak meat		
Year	Domestic production (t)	Imports (t)	Consumption (t)	Domestic production (t)	Imports (t)	Consumption (t)
2010	3,990,000	56,869	4,046,869	6,530,000	25,000	6,555,000
2015	4,280,000	254,335	4,534,335	6,547,000	663,000	7,210,000
2025	5,873,350	450,000	6,323,350	8,653,250	1,746,750	10,400,000

Sources: Mao et al. (2016); FAO (2017)

China's red meat industry is still operating at inherently low efficiency due to low-performance livestock and poor management practices (Wang & Xiao 2016; Li et al. 2018). However, there is clear evidence that efficiency can be improved (Zhou, Zhang & Xu 2012) by adopting new technologies and policies to drive red meat productivity and grassland resilience. Many of these advances in grassland and livestock science which have emerged from two decades of ACIAR-funded farming systems research on China's grasslands (eds Kemp & Michalk 2011; Kemp 2011; Kemp 2018) deliver innovative on-farm practices so small households can significantly increase their income with fewer animals and reduce environmental impacts (Li et al. 2015). This success can be attributed to an integrated approach that identified system solutions, rather than the component approach used with limited success in previous programs that targeted the sustainable use of grasslands (Chapter 1; Kemp et al. 2011).

However, while the farming systems approach hastened the pace of progress in identifying innovative on-farm practices, such research needed to involve overarching interdisciplinary and transdisciplinary studies to be successful (Chapter 1; Kemp et al. 2013). The team involved in this work included plant, animal and social scientists, farm and policy economists, modellers, advisory staff and influential livestock producers. Each participant gained an understanding of disciplines outside their own and contributed to the development of ideas based on their different perspectives. Building this local capacity of skilled, creative, and motivated individuals, and fostering effective networks and teamwork across universities, institutes, government departments and grazing communities located in Gansu, IMAR and Beijing, formed the core responsibility of the capacity-building component of the sustainable livestock grazing systems program. Capacity building was part of all components in the program (Figure 1.3).

Capacity building is not a new concept; however, there is a new urgency and opportunity for capacity building to play a central role in sustainable development (Food Security Collaborative 2012). Building local capacity by empowering individuals and strengthening local institutions has proved pivotal in underpinning economic growth and reducing poverty (Bryant 2006). ACIAR has always placed considerable emphasis on capacity building and training (Gordon & Chadwick 2007) to ensure a continued and replicable legacy of empowered scientists, farmers and policymakers to sustain and further develop food security and poverty alleviation initiatives.

This chapter reports the outputs, outcomes and impacts of the capacity-development program implemented in the 2009–18 program period designed to address three main objectives:

1. Advance the quality and focus of the science in the program's livestock, grasslands and policy themes to underpin the farming systems work needed to identify opportunities to sustainably manage livestock–grassland ecosystems.
2. Create linkages to effectively use the increased capacity developed in researchers, extension agents, farmers and policymakers to craft this new knowledge into sustainable practices that small-scale sheep and cattle households can use to produce red meat more efficiently from Chinese grasslands.
3. Alert government officials of the potential to alleviate poverty and rehabilitate grasslands by developing policies to support adoption of the redesigned livestock production systems by small herder households.

A major aspect of this task is providing hard evidence of how the capacity built was used to generate economic, social and environmental benefits (i.e. impacts) rather than simply considering skills gained (Gordon & Chadwick 2007). Our aim is to identify and report on both formal and informal capacity development delivered within the program in a more systematic way (Mullen, Gray & de Meyer 2015). Using a simple capacity-building framework, we report here the capacity built to reduce poverty, improve grassland condition and enhance sustainable red meat production for each key stakeholder group (partner scientists and students, herders and government officials) in terms of outputs and outcomes. However, it is acknowledged that it is not feasible to delineate total program impacts (e.g. stocking rate reductions, change in lambing time) into discrete contributions for research and capacity-building activity.

Not all the capacity-building activities reported were planned at the program inception. Much additional value was contributed to the ACIAR program by participants using funds and resources provided by their home institutes or from various levels of the Chinese Government, particularly national programs, which opened other opportunities and expanded the influence of the project. The Chinese Government placed importance on the practical application of technologies developed by the program team as a means to improve outcomes for herders and contribute to the resolution of major environmental problems on China's western temperate grasslands.

Capacity building

Each year about a quarter of all international aid ($15–20 billion) is spent on capacity development (Denney 2017). This level of funding support indicates that individual and institutional capacity poses a major constraint to the development process in many countries (Otoo, Agapitova & Behrens 2009) and explains why capacity building is an essential component of most agricultural research for development (AR4D) activities (Gordon & Chadwick 2007). However, while there is general agreement that building local capacity to plan, manage and implement is critical for achieving development objectives, the impacts of capacity-building activities have too frequently fallen short of expectations (OECD 2005, 2006; World Bank 2007).

This gap between expectations and outcomes from capacity-development investments is explained in part by broad and inconsistent definitions of capacity and capacity development, poorly developed and diverse conceptual frameworks and limited understanding of the links between outcomes of capacity-development efforts and development goals. It is challenging to compare results across programs and identify good practices for replication (Otoo, Agapitova & Behrens 2009).

Definitions and concepts

Capacity, as we use the term here, is the ability of individuals, organisations and systems to use skills, knowledge, leadership, relationships and networks, values and attitudes to effectively, efficiently and sustainably perform and progress agricultural development (Morgan 1998; ACIAR 2018). Based on this simple definition, capacity building (also referred to as capacity development) can be broadly defined as evidence-driven activities that build the understanding, skills and knowledge base of individuals, organisations and systems to sustainably improve current socioeconomic and environment conditions (Gordon & Chadwick 2007) and be empowered (especially at the local level) to continue development through effective adaptive problem-solving well beyond the program time frame (Bryant 2006).

For AR4D projects, capacity building is founded on crafting usable knowledge through research to create new, or modify existing, knowledge to solve problems. This means capacity development most often builds on the strengths and opportunities of pre-existing capacity of individuals (Laycock et al. 2011), identified through needs assessment processes (World Bank Institute 2006). Initially this effort was confined to individual training, but today capacity building includes the development of organisations and systems, making it a key pathway for the long-term success of agricultural development (ACIAR 2018). To be effective, all three levels (individual, organisation and system) must be included as part of an integrated capacity-building framework (Figure 11.1) rather than as discrete or loosely connected capacity levels (Bolger 2000).

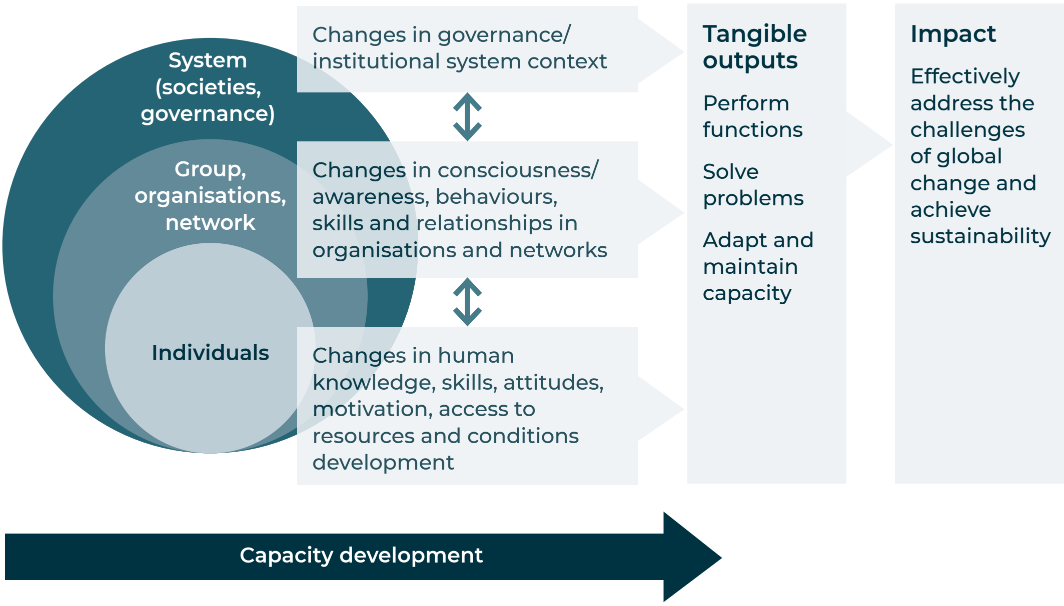

Figure 11.1 Conceptual framework for effective capacity development

Adapted from CAPaBLE, capacity-development program of the Asia Pacific Network for Global Change Research

The individual level, developed through formal, and/or informal on-the-job-training, is fundamental because the benefits of capacity building flow first from trained individuals to other workers in an organisation, then to the organisation as a whole and finally to communities (Gordon & Chadwick 2007; Templeton 2009). Targeted individuals or groups often have greater potential to bring about favourable change (Otoo, Agapitova & Behrens 2009) and were the focus of much of the efforts in the sustainable grasslands program.

Organisational capacity will influence an organisation's performance (JICA 2004). The organisation's capacity includes human resources (total capacities of all individuals), physical resources (facilities, equipment, materials), intellectual resources (organisation strategy, strategic planning, management, business know-how, production technology, program management, process management such as problem-solving skills, decision-making process, communications), inter-institutional linkages (networks, partnerships, incentive and reward systems, organisational culture and leadership of managers (Matachi 2006). Neglecting the capacity building of organisations may not only limit the effectiveness of capacity building of individuals (and vice versa), but limit the host country's capacity to handle the pivotal roles in leading, managing and coordinating agricultural development (Food Security Collaborative 2012). This is why many of our collaborators and the officials we worked with were leaders within their organisations.

Capacity at a system or enabling environment level considers the broad context within which development processes take place (Bolger 2000). This includes systems, frameworks and processes necessary for the formation and implementation of policies and strategies beyond an individual organisation, and includes administrative, legal, technological, political, economic, social and cultural constructs that determine the effectiveness and sustainability of capacity-building efforts (Matachi 2006). Unlike capacity building at the individual level, attempts to effect change at the enabling environment level generally take a considerable length of time. However, as Bolger (2000) pointed out, 'not all capacity development initiatives will seek to effect change in the enabling environment, but they do need to be sensitive to factors at this level which may have an impact (positive or negative) on initiatives which are focused primarily at the organisational or individual levels'. The challenge in designing and implementing an integrated capacity-building program is to ensure that funds and time are appropriately allocated between individual, organisation, and system levels to best deliver on the program objectives. In the sustainable grasslands program, we put less effort into system change, apart from discussing with leaders better ways of delivering information to herders.

Frameworks

The value of capacity building as a critical component of transforming transitional economies is uncontested, but there are ongoing challenges in setting up program-specific frameworks to assess capacity needs, design and sequence capacity building activities and determine impacts of outcomes (World Bank 2005) that may not be fully realised for several years (Bryant 2006). ACIAR has been an active contributor to the development of frameworks and pathways to strategically invest in capacity building activities, through formal training, or informally as learning by doing, across individual, organisation and system levels to achieve the best results. With a growing imperative to gain verifiable value for its $40 million/year capacity investment, ACIAR now requires clearer linking and, where possible, attributing of benefits such as increased agricultural productivity to specific capacity-building activities (Mullen, Gray & de Meyer 2015).

Gordon and Chadwick (2007) identified three main pathways through which human capital is transformed into economic benefit:

1. improved labour productivity of the individuals undertaking training, and the flow-on effects of the training to other individuals
2. capital productivity arising from the complementarity between human capital and physical capital as more-capable workers can better adapt to and utilise equipment, machinery and the latest technology. Higher returns to capital encourage greater investment and enable inward technology transfers
3. total factor productivity arising from better management, intra- and inter-organisational synergies and, over time, higher rates of innovation and improvements in the enabling environment.

Analytical frameworks are required to map these transformational pathways to define benefits and possible attribution (linking back to a specific activity such as a piece of research) to projects. In such frameworks, it is important to distinguish between inputs, activities, outputs, outcomes and impact as intermediary steps in the capacity-development process (Husbands-Fealing 2013) and to identify appropriate indicators to quantify each to substantiate the linkage between capacity built and used and the behavioural and economic changes achieved (Templeton 2009).

Steps in capacity development

Inputs are factors used to implement the capacity-development activities. In broad terms, inputs include expertise, human resource (personnel), funding, facilities, equipment and land, all of which are usually specified for contributing partners at the project inception (Templeton 2009). This combination of inputs leads to planned and, more importantly, non-planned changes that cannot be easily measured.

Activities aim to deliver project goals such as research, mentoring and coaching, training (research workshops, farmer field days), cross visits, study tours and publication of policy briefs, among others (Stephen, Brien & Triraganon 2006). While all have a potentially transformational role, their impact differs with target individuals and groups (Otoo, Agapitova & Behrens 2009), especially for agricultural research for development (Mbabu & Hall 2012).

The capacity-building activities for research in this AR4D context must focus on developing the skills and expertise of local researchers to ensure that the scientific findings are presented in such a way that small households can use the outcomes to improve both their livelihoods and the environment (Leeuwis, Klerkx & Schut 2018). This typically requires considerable time commitments from experts to achieve successful and sustained outcomes (Dinesh et al. 2018).

From a survey across a wide range of livestock projects, Photakoun, Millar and Race (2009) identified training workshops and courses, on-the-job learning, staff meetings, mentoring and attending cross visits and study tours as the main capacity-building methods used to strengthen research and extension staff. Less common methods were on-site training, village learning activities, farmer field schools, formal study and information provided in writing or online. Of these, the methods most effective for capacity building in livestock extension were workshop training, on-the-job learning, staff meetings, mentoring and field trips. All of these were used in the sustainable grasslands program. As expected, farmers place higher value on field-based activities to learn about the major aspects of livestock production and management rather than classroom tuition, in line with good adult education practice. Delivery of information to farmers is best done by project-trained staff with foreign experts acting as catalysts, facilitators and brokers of knowledge and technique (Otoo, Agapitova & Behrens 2009).

Strong policy support is essential for sustainable grassland development to promote public awareness about sustainable development principles, reduce poverty and improve the environment. This means building the capacity of policymakers. Packaging research data into effective policy briefs and presenting these at evidence-to-policy workshops is an effective capacity enhancement initiative that helps policymakers frame and implement evidence-informed policy (Uneke et al. 2015). That was done at the end of the sustainable grasslands program. However, policymakers often assign less value to research findings than prevailing thought or opinion (Sutcliffe & Court 2005) and they have different priorities, agendas, timescales, language and reward systems than researchers (Nutley 2003). The onus is on researchers to ensure all evidence provided to policymakers is accurate, objective, credible, relevant and accessible. These problems increase in developing economies, where policy formulation is often centralised and less open.

Outputs are the first-level, direct, immediate results from a capacity-building activity. Outputs are measurable and include knowledge products (presentations and publications), policies, service delivery (workshops, on-the-job training) and enforcement of regulations (Gordon & Chadwick 2007). Monitoring and recording outputs accurately is central to evaluating capacity-building impacts, because, as Thornton et al. (2017) note, these outputs contribute to behavioural changes and changes in knowledge, attitudes, skills and practices of a wide set of non-research next-users such as development practitioners, extension services, farmers and policymakers. A critical issue here is the need for effective team building across all stakeholder groups. Without ownership from the project inception, research activity outputs may have no impact among partners and intended next-users (Thornton et al. 2017).

Outcomes are the second-level results associated with a project and are the medium-term consequences of a project. Outcomes relate to the project goal, and are identifiable changes that arise from the capacity built in individuals, organisations and systems. In the sustainable grasslands program, one outcome was the reduction in stocking rates for Siziwang, IMAR, after all the background work had been done (Chapter 2). Some outcomes require a long time interval. For example, it took eight years for changes in plant species to become evident in the desert steppe grazing experiment (Chapter 8). This makes attribution a key challenge (Templeton 2009) as project timelines are often short.

Impacts are the long-term changes in producer and consumer economic, social wellbeing and/or environmental conditions that the capacity-development intervention helped bring about (Templeton 2009). In practice, impacts are the long-term or indirect effects of outcomes (Fritz 2018) and they depend upon the quality and reliability of the outcomes (Penfield et al. 2014). Measures work best with quantitative rather than qualitative change (Templeton 2009). For example, a training program may eventually lead to a better quality of life for an individual, but that is difficult to measure (Fritz 2018).

Capacity building for the Chinese sustainable grassland program

The first steps for designing a capacity-development framework for the Chinese sustainable grassland program were to identified what capacity needed to be built, who was the target of the capacity building and what methods would best support a process of transition from subsistence to sustainable grasslands systems in western China.

Building on our previous work on the major grassland types in western China (Gao et al. 2003; Kemp & Michalk 2011), the objectives for our capacity-building program (Kemp 2018) were to:

1. impart new research methods and skills (in modelling, grassland ecology and livestock management) to improve the quality and focus of science being done by researchers and students, and develop a strong collaborative network across our five Chinese groups for advancing sustainable grassland development
2. empower small household herders and local agents with the knowledge, confidence, skills and business thinking to adopt new on-farm practices (in livestock systems) and market opportunities, to increase profitability from their grassland resources, with fewer, better-quality animals
3. provide evidence-based recommendations for better management of grassland–livestock systems (on alpine meadows, meadow, typical and desert steppe) to policymakers for the transition of households to more efficient, profitable and less resource-exploiting livelihood strategies.

These objectives meant we sought to establish contact with relevant people in each of the above categories.

Researchers and students

The sustainable grasslands program involved a large group across six institutions (Table 11.2). The leaders were recognised nationally and internationally and each had a group of keen scientists and other specialists who had a continuous group of postgraduate students. The national roles held by each of the Chinese leaders meant that the skills they acquired were passed onto other staff. The Chinese leaders, despite their other roles, all made substantial time and other commitments to the program. The people listed in Table 11.2 are those who remained through most of the program. In addition, there were many staff who were engaged for a few years. At annual meetings, we usually had 30–40 people present and this led to much cross-discipline discussion.

While the quality of research in China has improved dramatically in recent years, due to better training, mentoring and incentives (Bryant 2006), there is still a significant 'science-action gap' in AR4D for Chinese grasslands. This reflects a lack of capacity to transform research findings into problem-solving practices and vice versa. We used farm demonstrations (Chapter 4), herder surveys (Chapter 5), modelling (Chapters 6 and 7) and grazing experiments (Chapters 8, 9 and 10) as linked components (Chapter 1) to demonstrate how effective systems research and development can be done. In each area, we trained researchers and students in experiment design, methods, data collection, organisation, analyses and interpretation, through to publication (detailed later). Success was evident in the increasingly advanced questions asked by our Chinese colleagues as their experience in each area of research increased. The Australian team provided leadership and mentoring to the core teams at the five partner institutions. This included supporting applications for leadership short courses that resulted in the award of John Dillion Fellowships to four Chinese colleagues.

Table 11.2 Key personnel and general roles within the six main project groups

People	Australians[1]	China Agricultural University	Inner Mongolia Agricultural University	Institute of Grassland Research	Gansu Agricultural University	Lanzhou University
Leader	1	1[2]	1[3]	1[4]	1[5]	1[6]
Scientist	2	3	3	3	3	3
Modeller	2		1	1	1	
Extension	1.5		1		1	
Technical	1					
Students[7]		7	11	1	8	11

Affiliations and roles in national programs run by the Chinese Ministry of Agriculture:

1 Graham Centre for Agricultural Innovation/Charles Sturt University/NSW Department of Primary Industries

2 Head, Grassland Department, national leader of grassland management and forage production

3 Dean, College of Grassland, Resources & Environment, national leader of sustainable grassland management & carbon sequestration

4 Director-General IGR, national leader of forage production

5 President, Gansu Academy of Agricultural Science, national leader for utilising stored fodder

6 Dean, College of Pastoral Agricultural Science and Technology, national leader for forage improvement

7 10 PhDs, 28 MScs

Students from Charles Sturt University and Inner Mongolia Agricultural University discussing areas of common interest, Hohhot. Photo: D.R. Kemp

Herders and officials/extension/county agents

Herders have been directly responsible for managing grasslands in pastoral regions of China from around 1990 (Yin et al. 2018), since the responsibility and market-oriented system was introduced in grassland areas. However, adoption of better livestock and grassland practices by smallholders in China has been less than needed to improve incomes and rehabilitate grasslands. This reflects in part the ineffectiveness of the Chinese top-down extension approach in which farmers are not involved in planning or evaluation, but expected to simply implement what they are told by officials (Wu et al. 2011). Herders are also in transition from a subsistence, survival mode to one focused more on production (Kemp & Michalk 2011), but they do not have the skills to understand, change mindsets and adopt new changes (Wu et al. 2011; Michalk, Kemp et al. 2015; Chen et al. 2016). Low education levels, low income, limited resources (land, labour) and poor access to technical assistance, market information and credit all limit the capacity of most smallholder herders to adapt to climatic, economic and social changes (Vignola et al. 2015).

Local officials in the County Animal Husbandry Bureaux (part of the Provincial Ministries of Agriculture) are charged with managing the grassland, but mainly through regulation of stocking rates or schemes for fodder production. Officials have not acquired the skills for effective extension of improved practices.

While the sustainable grasslands program was primarily one of research, closer links had to be established with both herders and local officials to inform them of the program's progress and to help their understanding of how to transition into production systems that improved household incomes and helped rehabilitate the grasslands.

Grassland management training group in Hohhot, organised by the Institute of Grassland Research, for herders, officials, staff and students. Photo: Xu Zhu

No formal needs assessments of herders and local officials were done, though considerable time was spent from the early 2000s talking with herders and officials to understand how the livestock–grassland system functioned in the various regions studied. This information was used to develop models (Chapter 6) and identify aspects of the system that could be changed. In addition, we developed close relationships with the Gansu-Xinjiang Pastoral Development Project funded by the World Bank (2004–10) (Soderstrom et al. 2003) and the Sustainable Agriculture Development Project (Phase II—2004–09) funded by the Canadian International Development Agency that operated in IMAR and Gansu, among other provinces. These large programs aided our insight into herder needs. From these activities, we built farm demonstrations that included training for herders in simple, basic changes they could make to improve their livelihoods (Chapters 3 and 4) and start rehabilitating their grasslands. We included local agents in the training so they were aware of what we discussed with herders. This also showed we valued them. They could then replicate the training and a manual was prepared to help them. Training was often done by an Australian extension specialist, initially funded by the ACIAR program and then by the Chinese Government, who saw the value of the extension methods used. Over time, the requests for training from herders and local agents continued and the topics have become more appropriate for livestock production as distinct from survival. Herders often request a repeat of some topics (e.g. animal nutrition) to improve their understanding. The topics herders now wish to discuss have gone beyond the issues examined in the sustainable grassland program and have moved, for example, to more sophisticated livestock breeding practices.

Training programs were delivered by NSW Department of Primary Industry and consultants to Chinese delegations visiting Australia specifically to learn about sustainable production and marketing of livestock products, using this program's results. Twenty-nine delegations were supported by the State Administration of Foreign Experts Affairs at no cost to the program. These groups came from 11 provinces (Shangdong, Gansu, IMAR, Tibet, Zhejiang, Beijing, Yunnan, Jiangxi, Guizhou, Henan and Shanxi) and comprised 75% government officials and department technical experts, 20% university staff and students and 5% agribusiness, herders or farmers. The delegation leaders were often the provincial animal husbandry departments' directors-general or their deputies, which provided a good opportunity not just for training but also to discuss policy options.

Rapid pasture assessment training in Orange for visiting Chinese colleagues. Mr Millar (canvas hat) is teaching the use of dry weight ranks to rapidly and non-destructively sample pastures. Mr Langford (straw hat) taught animal condition assessment. These techniques are widely used in Australia and are now increasingly used in China. Photo: D.R. Kemp

Policymakers

China's developing grassland policy is central to the management of 400 Mha of grazing lands that sustain approximately 200 million people and produce 1 Mt of beef, 0.8 Mt mutton, 63% of China's wool and most of its cashmere. Since the 1980s, the Chinese Government has put in place various policy interventions within Grassland Laws aimed at simultaneously balancing grassland rehabilitation and conservation with livestock production and sustainable livelihoods of rural families (Brown, Waldron & Longworth 2008). These policies, of which the grazing ban policy was part, established land user rights and constructed housing and livestock sheds in winter pastures to encourage nomads to settle and to reduce livestock grazing pressure in order to restore degraded rangeland (Gongbuzeren et al. 2015). These policies used different mechanisms to reduce the overgrazing identified as the prime cause of grassland degradation (State Council 2002), but, in practice, despite incentives and subsidies, none were universally successful in stopping increases in livestock numbers (Chapter 2; Michalk 2017a, 2017b; Kemp et al. 2018). Grassland degradation and rural poverty is ongoing in many pastoral areas (Hua & Squires 2015). The program presented in this monograph started in the early 2000s in response to these concerns.

China is emerging from the central planning era, where policies are decided at the highest level (Waldron, Brown & Zhao 2011) and officials down the six layers of government implement them. Officials expected herders to implement what they were told, but it is evident that, in the modern Chinese market economy, compliance is far from ideal. For example, there is much night grazing in areas where total grazing bans have been applied (Gongbuzeren et al. 2015; Li et al. 2017). Today, policies need to consider what can be achieved with the available resources within a market economy, so that the desired outcomes are achieved. The sustainable grasslands project took the approach of seeing what could be done with existing resources in response to markets, before considering the role of government. We had regular discussions with officials involved in developing policy at the provincial and national levels to show them what herders could achieve and where policy changes might be needed. Our aim was not to dictate policy but to provide the background information that policymakers need to develop effective programs. Policy development takes place within a wider context than the large Chinese sustainable grasslands program. We also wanted to encourage more two-way dialogues between herders and officials.

Because there were grassland policies in place for China, and major policy changes only take place with each five-year plan, we did not need to find solutions quickly. We did have annual meetings with national, provincial and county officials in the ministries of agriculture, who are responsible for managing the grasslands. Some years, we met more than once, especially with local officials. Our objective was to keep the officials informed of what we were learning so they could incorporate better ideas into their policies. Initially, to rehabilitate degraded grasslands, a total grazing ban was imposed (often ignored by herders) or a delay in grazing was mandated at start in summer. The latter policy aimed to allow more growth on the grassland. However, during the course of our program, the balance strategy was introduced, where a delay in the start of grazing in summer was combined with lower stocking rates. This was in accord with our results, which showed that incomes could be maintained or increased with lower stocking rates (Chapter 4). As well as these policy changes, officials financially supported the research being done with farm demonstrations, grazing experiments and herder surveys. They appreciated the value of the results coming from this program. At the end of the sustainable grasslands program, a national workshop was held in Hohhot. Many officials were invited and policy briefs based on the work done were presented to them. The policy briefs provided evidence supporting current policy and identified changes that could be made. They also identified what was not known. Using evidence-based examples from the program research, our Chinese partners provided strong advocacy for national government agencies (Ministry of Science & Technology, Ministry of Agriculture) and institutes (universities and academies of agricultural science) to consider local rather than one-size-fits-all policies to address the needs of different grassland types.

Capacity building results

A range of measures for capacity building in AR4D projects (Photakoun, Millar & Race 2009) were used for researchers, students, herders and government officials and policymakers (Table 11.3). Indicators that quantify direct or indirect benefits derived from each capacity-building activity were used to assess whether or not capacity-building efforts were effective in achieving substantive changes, both in terms of implementing the program and providing a lasting legacy of skills and knowledge for future work.

Evaluating capacity building

Capacity building was embedded in all our program activities (Chapter 1), though there is no clear way to differentiate research activities from capacity-building activities (Mullen, Gray & de Meyer 2015). Some of the effects of capacity building are intangible (social and individual transformations) and are not easily accommodated in common evaluation methods. Given this, we first reported the outputs and outcomes for each capacity-building activity, and then provided an aggregated research/capacity-building impact summary. The general experience was that capacity building played a critical role in achieving outcomes for the program that would not have been achieved otherwise. Some of activities were not planned in any detail (e.g. national program linkages, training senior Chinese officials on study tours to Australia) but were built into the program as opportunities arose. This meant capacity building was often not simply a transfer mechanism of knowledge, but rather a process of forming strong partnerships in which we were providers and recipients. This was the best way to achieve scaling-up and scaling-out impacts on smallholders and national development targets.

Table 11.3 Capacity-building activities, target groups and measures of benefits achieved

Capacity-building activities	Target group				Measures of benefits
	Researchers	Students	Herders	Policy officials	
Research projects	✓	✓			number of publications, reads, citations, journal impact
Conferences, workshops, meetings	✓	✓		✓	number of meetings, people
Higher degrees		✓			number of degrees, universities
New skills, technical training	✓	✓			number of technical programs, people days
Mentoring	✓	✓	✓		not recorded but continuous and probably the major activity
Leadership development	✓	✓	✓		number of fellowships, herders leading demonstrations
Herder training			✓		number of training events and herder days of training
Farm demonstrations	✓	✓	✓	✓	number of farms and herders
National programs	✓			✓	number and value of national programs
Study tours to Australia	✓	✓		✓	number of people, training days, origin of delegations

Animal management training session with herders, led by Professor Han, Mr Langford, Ms Junk and Professor Kemp. Photo: D.R. Kemp

Dr Badgery (tall hat) explaining his innovative grazing experiment to Dr Horne (ACIAR, brimmed hat), Prof Zhang (writing), Academician Nan (next to Dr Badgery) and Mr Wang (ACIAR). Photo: D.R. Kemp

Outputs, outcomes and impacts

Genuine capacity building results in a sustainable change in, people's lives, organisation effectiveness and, or in their enabling environment (Simister 2015). This is assessed with various measures:

- **capacity input** includes the number and type of capacity building provided, number of attendees and the quality of the content and delivery of the activity or training
- **capacity outputs** (capacity built) are the tangible and intangible outputs of project activities
- **capacity outcomes** (capacity used) are the benefits from a program, measured by the increase in skills, knowledge and capabilities achieved (number of reads or citations reported for a published paper)
- **impacts** (change in behaviour or economic status) are higher-level strategic results such as herders making more income with fewer animals which, in turn, improves grassland condition; indicators are a practice change at the individual, organisational or community levels.

These measures were evaluated against the seven key questions posed for the sustainable grasslands program (Chapter 1). Because of the overlap between the original questions posed (Table 11.4, notes), the following sections are grouped into three themes:

- identifying the best enterprise/animal management strategies
- management
- contribution to policy development.

Research communications

Communicating the findings from the last nine years of research has been the major communication task (see eds Kemp & Michalk 2011 for earlier work in this program). Refereed journals dominate this output as they are still the most important way to create a public record of original peer reviewed contributions to knowledge and claim intellectual credit for the new ideas they contain (CRABS 2003). Between 2009 and 2018, the program produced 376 publications (Table 11.4), Of these, 273 were refereed papers published in international (186) and Chinese domestic (87) journals. Domestic and international conferences, workshops, significant meetings and book chapters accounted for the balance (103). This research output, of approximately 38 publications per year during the program, has positioned the team as a formidable research consortium with a substantial foundation for farming systems research on which new scientific discoveries and inventions will inevitably be built.

Table 11.4 Research publications grouped by key themes and questions

Key research themes and questions	Type	Number
Identifying improved enterprises and animal management strategies (1, 2, 3, 5)	Journal	109 (40%)
	Conference	40 (39%)
Grazing management (4)	Journal	142 (52%)
	Conference	41 (40%)
Contributions to finance and policy (6)	Journal	22 (8%)
	Conference	22 (21%)

Key questions:

1. Enterprise choice: Which livestock enterprises are the most beneficial for net income and grassland sustainability?
2. Animal management: What changes are needed in the type, numbers and management of animals to achieve this?
3. Animal nutrition: What changes are needed in animal feeding strategies throughout the year?
4. Grassland management: How will these new livestock production systems improve the sustainability of the grassland?
5. Infrastructure: How will changes affect farm infrastructure and management?
6. Finance and policies: What are the additional strategies/policies that could be implemented to achieve greater household incomes and rehabilitate grasslands?

Publications were grouped on topic and content to assess how the three consolidated key research themes were addressed by research activities. Question 7 in the project plan (Driving change: What are the drivers of practice change that will bring about the changes identified?) is addressed in this chapter. These data show that equal emphasis was given to publications addressing livestock and grassland themes, but significantly fewer publications dealing with policy issues, as the latter are more a summary of where the program had got to, rather than research detail.

While number of publications represents a strong, impressive and theme-balanced research output, quantity does not necessary reflect quality. Assessment of the value of information published requires indicators such as reads, citations and the impact factor of the journals publishing our research findings. Citations by other researchers and authors are a partial measure, as this requires other authors to publish in journals listed in the Science Citation Index (Callaham, Weber & Wears 2001). ResearchGate (a social networking site for scientists and researchers to share papers) accumulates statistics on weekly reads as well as citations for members' (currently 15 million) shared papers. This arguably gives a better indication of how information is being used and who is looking at a paper. ResearchGate metrics were used as indicators of research quality. Journal impact factors, which indicate how frequently a journal's recent papers are cited in other journals, were also determined for the 83 rated journals in which the program team published, using the 2016 journal citation report (Sharma 2017). A total of 186 papers were published in these impact-rated journals, and a further 87 papers were published in 29 unrated journals, mostly Chinese. While some of the unrated Chinese journals (*Pratacultural Science*, *Chinese Journal of Grassland*, *Acta Prataculturae Sinica* and *Acta Agrestia Sinica*) do record reads and citations, most do not. This limits quantitative assessment of these papers.

Chinese scholars often prefer to publish in English-language journals as this gives better recognition, prestige and citation tracking for career development (Shen 2017), but others see the important role Chinese agricultural journals play in the bottom-up process of equipping local agents and smallholders with the knowledge that helps them improve their farm system. For example, an analysis of the 109 papers published on aspects of the livestock theme showed that the 51 papers (47%) published in Chinese-language journals focused on practical issues including livestock management and feeding—16 papers; grazing management and stocking rate—15 papers; recommendations from modelling on different grassland types and livestock enterprises—7 papers. Many of these papers were authored by young researchers and graduate students. Often this was their first paper; publishing in their native language was a less threatening experience than writing in English.

For the international publications, the indicators provide a positive picture of the high quality and influence of the published research. There were a total of 12,748 reads and 1,060 citations tracked between 2009 and 2018 (Figure 11.2), averaging 69 and 5.7 respectively per journal paper. The means were skewed, as 62 of the 186 international papers were not cited, generally because they were only recently published (late 2016 onwards). However, in contrast, 42 of these apparently uncited papers were recorded in ResearchGate as being read between 1 and 374 times, depending on date since first published. Only 16 internationally published papers (< 9%) were neither not cited nor read, as far as we could determine.

Journal impact factors (JIF), which ranged from 12.12 (*Nature Communications*) to 0.20 (*Chinese Journal of Ecology*) did influence reads and citation rates. For example, the top seven cited papers (Figure 11.2) that were published in *Nature Communications*, *PNAS*, *Global Environmental Change*, *Ecological Monographs*, *Global Change Biology* and *Land Degradation & Development* (JIFs of 12.12, 9.66, 9.05, 8.76, 8.44 and 7.19 respectively) accounted for 17% of all reads (2,164) and citations (174) and represented < 4% of the papers published. The next 23 papers (12% of published papers) published in 13 journals with JIFs of 3.5–7 accounted for another 18% total reads and 27% citations. Chinese researchers senior-authored all but five of these papers and 114 of the journal papers in total. Papers published in journals with JIFs < 3.5 were generally read and cited less or not at all, though some were read as much as those in higher-ranking journals. This highlights that care must be taken in journal selection to maximum the dissemination of knowledge to the right people, enhance the reputation and career advancement of authors, and improve resource allocations to home organisations.

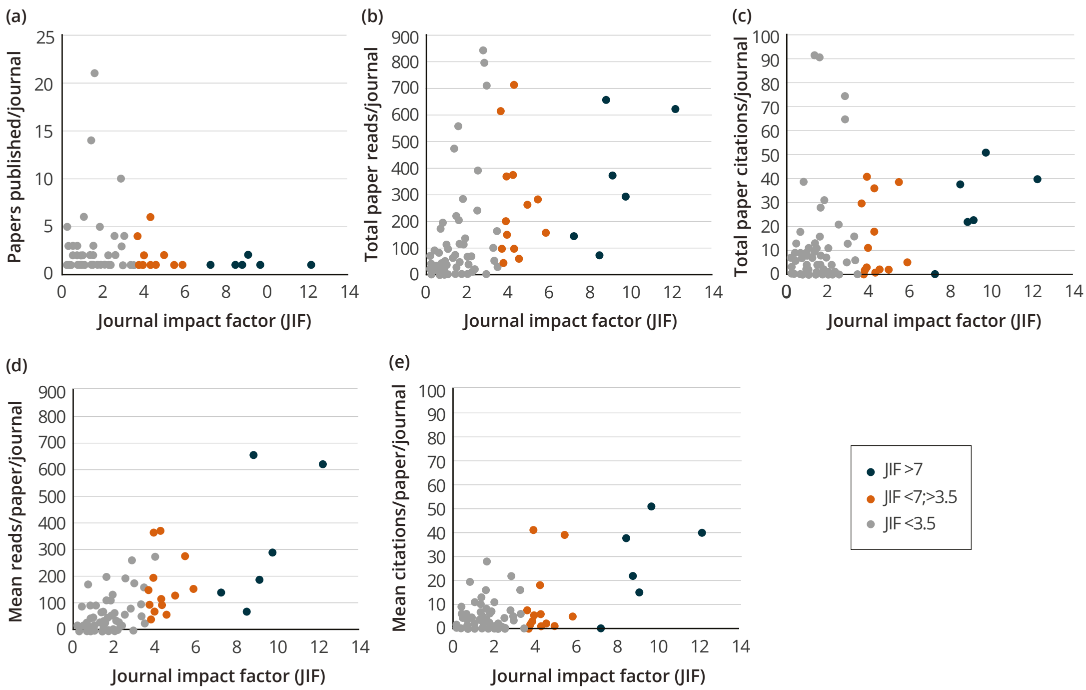

Figure 11.2 Relationship between JIF and (a) the number of papers published/journal, (b) total number of total reads/journal, (c) total number of citations/journal, (d) mean reads/paper/journal and (e) mean citations/paper/journal for 186 program papers published in JIF-rated journals, 2009–18

Contrary to growing scepticism about the usefulness of JIFs as an indicator of research excellence and the value of high-impact journals for attracting attention (Bohannon 2016), we believe that encouraging publication in high-profile journals (i.e. JIFs > 3.5) was a good tactic. It built interest in and visibility for farming system science as a new approach to poverty and grassland degradation (particularly Kemp et al. 2013). The whole publication process also provided important capacity-building opportunities for younger scientists to develop their skills and reputations by publishing in highly-rated journals (e.g. *Scientific Reports*—5 papers, JIF 4.26) than may have been the case without the program.

A major challenge of the research and capacity-building activities was to allocate and manage the program resources (especially time) across the three themes, which required different inputs and approaches. This is reflected in the time log (2009–18) for publications, citations and reads (Figure 11.3). There was considerable activity in the livestock and grassland themes, as these helped frame policy advice. For the livestock theme, initial emphasis was placed on developing skills and practical management solutions for extension workers and herders. These were published primarily in more accessible Chinese. Many of these precision management practices were based on those used in Australia and elsewhere, and were relevant to Chinese journals where such knowledge was limited. At the start of the program, a number of grazing experiments commenced. These results were published in international journals, as they have wider application as similar grasslands occur through Central Asia to eastern Europe. The grassland theme did a lot of research to understand the complex interactions between climate change, grassland condition and livestock grazing. Graduate students did much of that work and they had to publish in international journals as part of their requirement to graduate. The spike in publications in Chinese journals near the end of the program (Figure 11.3) was of more practical papers on various aspects of grassland management to deliver program outcomes. Most of the policy theme focused on clarifying the attitudes of herders to grassland policy and climate change, where capacity was built in developing, analysing and interpreting surveys. During this program, in general, there were an increasing number of Chinese papers appearing in international journals, reflecting the improving quality of Chinese research and development.

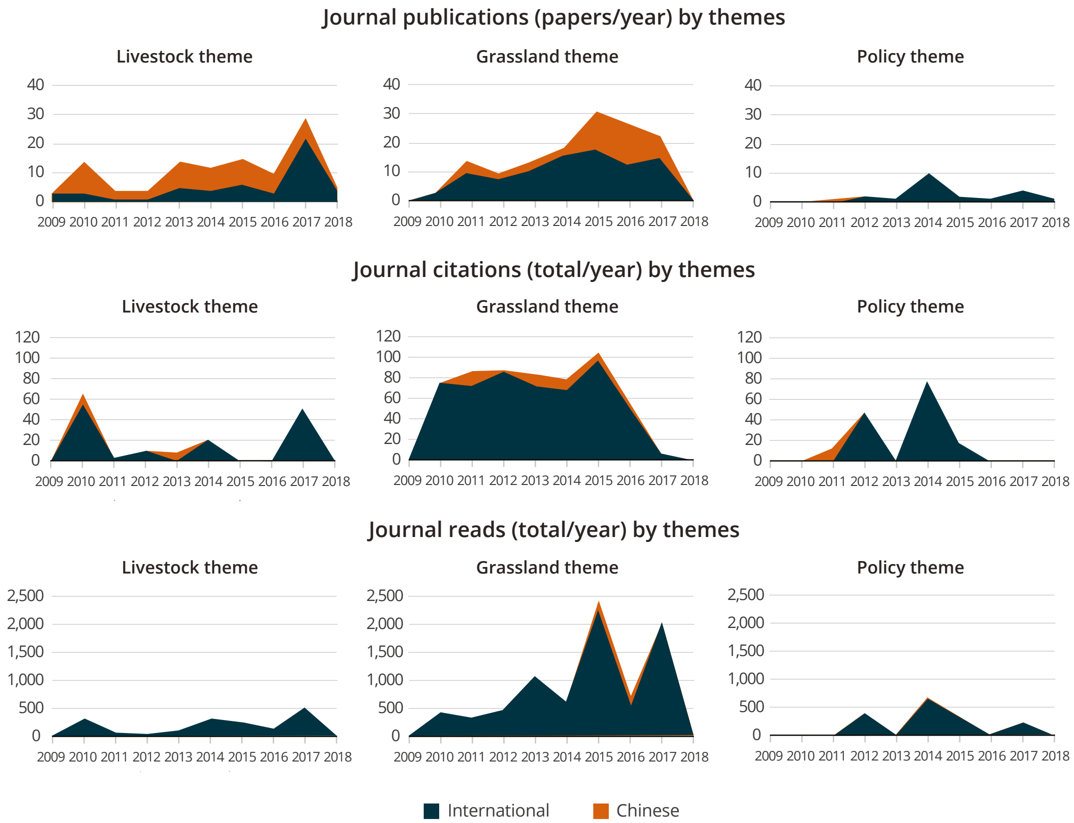

Figure 11.3 Time log showing publications, citations and reads by theme, 2009–18

The grassland theme papers were read and cited more than livestock theme papers, due to the number of international papers. For both themes, locally published papers had low citations and reads, possibly because tracking these metrics is not yet well developed for Chinese publications within the grassland/livestock discipline. Almost all of the policy theme papers were published in overseas journals (*The Rangeland Journal*, *Plos ONE*, *PNAS*) and there is now established capacity to support bottom-up policy development with evidence-based advice on socioeconomic impacts on smallholder herders. Though fewer, policy papers such as Kemp et al. (2013), Briske et al. (2015) and Kemp et al. (2018), which had 5, 8 and 10 Chinese co-authors respectively, were highly read and cited (294 reads, 51 citations; 403 reads, 27 citations; 60 reads, 2 citations).

In parallel with the Chinese work, studies were done in Australia investigating grazing principles (special issue of *Animal Production Science,* Michalk, Badgery & Kemp 2017) and modelling frameworks (Behrendt et al. 2016; Amidy, Behrendt & Badgery 2017; Broadfoot, Badgery & Millar 2017), which complemented the research in China. These were important in continuing to build the skills, capacity and knowledge of the Australian team and their colleagues at Charles Sturt University and NSW DPI. This identified directions for future grassland, livestock research that could then be applied in China.

Conferences, workshops, meetings, book chapters

International and domestic conferences, national workshops, significant meetings (APEC; *One Belt One Road* conferences) and book chapters accounted for 35% (103 papers) of the program's total publication output (376 papers). These contributions were distributed among the livestock, grassland and policy themes in a 40:40:20 ratio respectively, compared to a 40:52:8 ratio for journal publications (Table 11.4). These high-level meetings were attended by policymakers and provided a good opportunity to discuss the program's focus on poverty alleviation and grassland rehabilitation.

International and national conferences, workshops and seminars were used to build communication skills and confidence in delivering presentations to large audiences, establish and nurture networks, test new ideas, promote findings among peers as a pre-publication exercise and meet and seek advice from world experts. Central to the reasons for attending conferences are learning and building relationships. During this program's implementation period, two International Grassland Congresses (IGC Sydney, Australia—2013; ICG New Delhi, India—2015) and two International Rangelands Congresses (IRC Rosario, Argentina—2011; IRC Saskatoon, Canada—2016) were used as key capacity-building opportunities for our program staff to listen to different points of view, learn new ideas, grow from feedback from experts' comments on their research and initiate scientific cooperation by meeting and connecting with researchers from different disciplines, institutes and countries. About 2,300 delegates attended these four international conferences

Of the 43 papers presented at these pivotal grassland conferences by program researchers, 27 were senior-authored by our Chinese researchers and postgraduate students. Another 27 presentations were made to a wide range of international conferences and research forums including the Silk Road Economic Belt 'One Belt One Road', Cultural Roundtable Conference held in 2014 in Gansu (Kemp, Nan & Wu 2014) and the APEC Cooperation on Food Security and Climate Change Forum held in Hanoi in 2017 (Michalk 2017a, 2017b). The program team organised the inaugural meeting of the China-Australian Network for Grassland Farming Systems held in Xinjiang, China in 2011, with help from the China Agricultural University, to foster bilateral collaboration. This network will be further used to foster collaboration between Australian and Chinese grassland–livestock scientists.

The Sydney IGC (800 delegates, 700 papers) provided a tremendous opportunity to add skills and capacity to the whole program team from multiple perspectives. Four of the Australian program team (DR Kemp, DL Michalk, WB Badgery and K Behrendt) were on the organising committee. Chinese site leaders presented papers, including a major plenary address (Zhang et al. 2013), chaired sessions and refereed papers. A major objective of the Sydney IGC was to give presentation opportunities to emerging scientists, which included seven papers from the program's young researchers. Through the program team, ACIAR became the largest sponsor of the Sydney IGC. The team used this capacity to help organise the program for the 2015 New Delhi IGC 2015, where we gave the opening plenary (Michalk, Wu et al. 2015) and several keynote papers.

The national and regional conferences, workshops and meetings (26 presentations) served as a conduit for information updates, designed to provide alternative perspectives of grassland issues for key officials and policymakers from Beijing, provincial departments and county offices. Programs for major workshops on sustainable grasslands held in Lanzhou (2011, 2013), Hohhot (2012, 2016) and selected counties in Gansu (2014, 2015) provided bottom-up understanding about the causes of grassland degradation and possible solutions through alternative livestock management. Over 1500 people from government, research institutes and agribusiness attended these workshops. The wide exposure of the program in China has led to many invitations to meet and talk with officials, other researchers and students from groups not affiliated with the program, including Chinese Grassland Society Annual conferences.

Meetings have been held regularly throughout the course of this program with officials and herders in Beijing, Gansu and IMAR to present program results and provide briefings to help develop government policies. At a workshop held at the Saskatoon IRC (2016), program outcomes were endorsed by a wide representation of the world's most eminent grassland scientists. Their helpful comments were included in the final program report formally presented to Chinese Government and ACIAR representatives in April 2017 at a national workshop sponsored by the Ministry of Science and Technology. This included policy briefs on topics that we believe will be of value in guiding the next steps in policy development for China's grasslands. The policy briefs were also presented to the Ministry of Agriculture in Beijing.

Postgraduate students

Postgraduate programs that integrate industry needs with professional development offer a cost-effective and empowering alternative to traditional research training (Packham & Sriskandarajah 2005; Harman 2010). This was the approach used to embed postgraduate students into the ACIAR program to advance the quality and focus of grassland science, as done in Australian industry-based cooperative research centres (Harman 2010). Across the four universities involved in this program, 38 higher degrees were awarded to students working on aspects of this program (Table 11.5).

Table 11.5 Higher degrees and research publications grouped by key themes and questions

Key research themes	Number	Papers published
Identifying improved enterprises and animal management strategies	18 (6 PhD, 12 MSc) (47%)	42 (64%)
Grazing management	15 (4 PhD, 11 MSc) (40%)	20 (30%)
Contributions to finance and policy	5 (5 MSc) (13%)	4 (6%)

Notes: Lanzhou University – 4 PhD, 8 MSc; China Agricultural University – 3 PhD, 4 MSc; Gansu Agricultural University – 2 PhD, 5 MSc; Inner Mongolia Agricultural University – 1 PhD, 10 MSc.

China follows the US system of coursework requirements for postgraduate degrees (Figure 11.4), which meant research was limited to a small project which connected with other small projects within larger studies. The Australian group provided considerable assistance in experiment design, methods, data analyses, interpretation and writing. In the Chinese system, PhDs are not awarded until a paper is published in a refereed journal. Considerable time was devoted to preparing manuscripts, as Chinese students need significant support in scientific writing (Zhang & Zhu 2016). The 38 students published 18 papers in JIF-rated journals, 25 in unrated Chinese journals and seven in the International Grassland and Rangeland Congresses. Capacity-building activities were across the three program themes but with slightly more emphasis on livestock and less on finance and policy, in both the degrees award and publications (Table 11.5). In cases where work was designed and implemented without help from the team, had design faults or missing information, this required considerably more input to devise ways to resolve issues of logic and missing data. This was a hard task for supervisors and the Australian team, but the outcomes were arguably better research experiences for the students. The next generation of grassland scientists in China have now had considerable exposure to international scientists, which should be reflected in the quality of their future work. An important part of these activities has been the introduction of systems research and thinking into Chinese universities. Prior to this program, we could find no instance of systems thinking being taught in Chinese agricultural courses. The main frustration with the postgraduate program was that students acquired skills, but the staff did not. The students then left and the Australian team taught the new students. This took some time to improve, but staff can now train the coming groups of students.

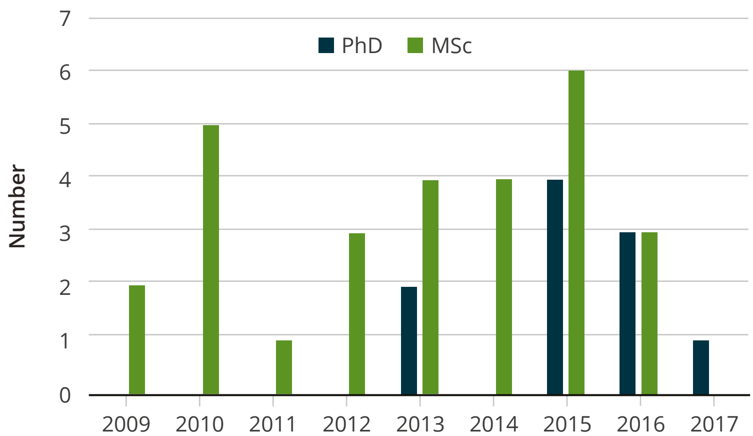

Figure 11.4 Higher degrees awarded to students working on program research, 2009–17

New skills and technical training

Farming systems modelling was the main tool used in this program to identify and test the financial returns of alternative management options relative to those currently practiced by small herder households using farm level socioeconomic and biophysical data. However, the reliable and representative data needed to parameterise the biophysical, farming system and household characteristics within the models developed was not available, especially for some grassland types (alpine meadows in Gannan). To address the issues of generating reliable data for the models, skills and technical training were targeted in three main areas: model use, farm surveys and better data collection methods.

Model-use training

Skills to use and further develop the models were limited but were addressed by dedicated training sessions for training the trainers (in China and Australia) and ongoing one-on-one meetings and email tuition with model users. Specialist modellers (Liu Haibo, Yuan Qing, Qiao Jiang) have emerged from this capacity-building process and now provide competency to use the *StageONE*, *StageTWO* and the complex *StageTHREE* SGM (Chapter 6). A yak submodel was developed by Liu (2017) for the Qinghai–Tibetan Plateau site at Maqu, Gannan, for his PhD. The models are being incorporated into a common framework, 'optimised management models for household pasture livestock farm production', built by Yuan Qing (Kemp 2018) so that they can share a common dataset.

Survey training

Household surveys have been done regularly in China, but they had not previously collected biophysical data that could be used to understand how farms functioned. Often the surveyor simply asked local officials for the required data. We trained staff and students in interview techniques for regular, repeat surveys of herders to obtain biophysical and financial data on how herder households functioned. Initially, staff and students returned to households to clarify the responses previously obtained. That data was then analysed to assess the main drivers of productivity (Chapter 4) and calibrate the models (Chapter 6 and 7) used to investigate alternative management strategies. Putting the data into models often quickly showed staff and students where the data were inconsistent and had to be checked. Additional surveys have been done on herder attitudes to policy (Chapter 5). The data now being obtained is reliable and provides much useful information on herders.

Data collection training

Better-quality grassland data are needed to improve model calibrations, analyse field experiments and for on-farm monitoring. In China, grassland biomass and composition are usually measured by cutting a few randomly placed 1 m^2 quadrats. This sampling method is time-consuming and inadequate due to the small sample size and, because of its destructive nature, cannot be used for repeated measurements over time. Dry weight ranking techniques, first developed in the 1960s (Hargreaves & Kerr 1992), are well-established as non-destructive procedures for sampling grasslands efficiently. Workshops were run with program partners and a highly skilled Australian technician in 2012 and 2014 to train staff and students in these techniques. Pilot training in 2012 at Lanzhou University (12 participants, 72-person days training) was used to develop a course which was then delivered at three workshops (28 participants, 112-person days training) in 2014. Field testing was done in 2014, monitoring grasslands on farms in Siziwang (10 participants, 50-person days training) and assessing biomass and composition at the Hebei grazing experiment (12 participants, 48-person days training). In 2013, workshops were held in Sunan and Maqu (200-person days). These workshops dealt with various technical issues raised by participants and initiated wider use of these techniques. Subsequently, two independent studies were done by workshop participants, assessing biomass and composition of alpine meadows (Li et al. 2015) and typical steppe (Yin et al. 2015). These showed the accuracy, reliability and efficiency of these techniques, relative to traditional methods.

Mentoring and coaching

Mentoring and coaching were used to bridge the gap between the mentee's (researchers, students, herders and policymakers) current skills and knowledge and what was required to produce quality outputs, outcomes and impacts as part of a dynamic, multidisciplinary, multi-institutional development process (Panzer 2016). The Australian team worked closely with staff and students throughout the program. Mentoring and coaching were part of all the interactions, particularly as this became less threatening, especially to students. This often meant that questions arose that probably would not have come up in more formal situations. We emphasised seeing problems and issues within a systems context, as that was more useful for finding workable solutions.

Leadership development

The Australian team comprised senior and junior staff, as did each of the Chinese institutes. We were all conscious of the need to develop the next generation of scientists who could continue the work started in this program. The junior Australian and Chinese staff in 2009 are now leading projects and delivering good results. Four of the program team (Prof Zhang Yingjun, Prof Hu Fujiang, Dr Ren Weibo and Dr Li Ping) were selected for the ACIAR John Dillon Fellowship Program, which includes a formal research management training course and a program of visits to a range of best-practice organisations. Junior staff and students were given the responsibility of managing their project areas and making sure it was done well. Over time they built the confidence to ask how best to solve problems. The benefits are evident in the funds now being obtained and in the number and quality of papers being produced.

Herder training and empowerment

Prior to this program, herders' (and officials') strategy to increase incomes was to increase animal numbers (Chapter 2), which has led to overstocking and ongoing grassland degradation (Kemp et al. 2018). Farm demonstrations were used to show how major improvements could be made in the livestock system, without reducing incomes (Chapter 4). The farm demonstrations were coupled with ongoing herder training, so herders had better knowledge of animal management and could make the transition from a survival to production state (Kemp & Michalk 2011). Total farmer training (with local government officials at some locations) totalled 20,520 person days, of which half (10,280 person days) were delivered by program partners at GAU (23 events), IMAU (16 events) and CAU (8 events), and half by Chinese-funded national programs (10,240 person days, 64 events). In Siziwang, Professor Han Guodong worked with the village leader, Buhechaolu, to train herders in better grassland and livestock management. Various local structures were used. The main one was a farmer association that provided better-quality sheep for breeding, and training in feeding animals and marketing. There are now approximately 2,000 households that have reduced their livestock numbers and are making more money. Other examples are presented in Chapter 3.

Australian livestock grazing extension specialist Colin Langford delivered nine specialised farmer schools on genetics, reproduction, nutrition and grazing management based on the program's *Livestock Production Training Manual*, launched in 2013 (Figure 11.5). This manual was patterned on PROGRAZE©, one of Australia's most successful technology transfers for pasture and livestock management (Bell & Allan 2000). One concept that has been taught, allied to this training, is the need for researchers and herders to have a common language so that knowledge can be transferred more efficiently. That means researchers need to measure plants and animals in terms that are also used by herders. Unfortunately, much research in grassland ecology is not in terms that herders understand (e.g. plant frequency), but herders do understand biomass. Similarly, herders can be taught to measure an animal's condition score (fat to thin), which should also be done in experiments. An animal's condition score is a direct measure of its status. It relates to its liveweight (but is easier to measure) and is a common tool for managing animals and monitoring their nutrition (White & Holst 2006; van Burgel et al. 2011). More staff and students can now measure condition scores.

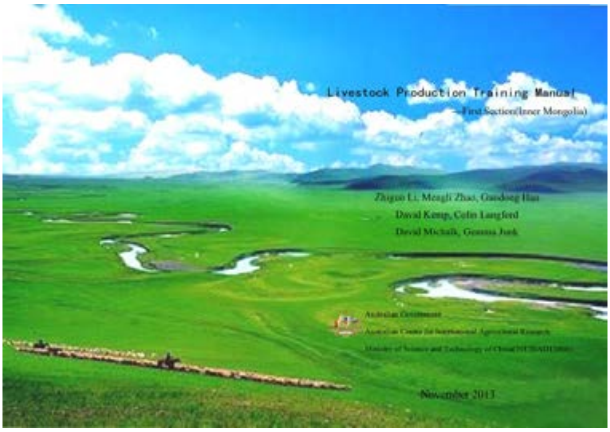

Figure 11.5 ***Livestock Production Training Manual*** **(2013) published in Chinese, Mongolian and English**

The effectiveness of herder training was assessed by considering two questions:

1. How did herder training address the program's three themes?
2. Which themes were of most interest to herders?

In the Gansu training program, 70% of the training sessions focused on the livestock theme (improved enterprises and animal management strategies) and 30% on the grassland theme. There were no sessions on the policy theme (Table 11.6). When herders were asked which themes were of most interest to them, 86% nominated the livestock theme. This arguably reflects a growing perception by herders that optimal solutions are more likely to be found in improving production efficiency by focusing on the number of animals and animal product per hectare (Kemp et al. 2013). The impact of herder training is evident in changes in on-farm practices such as enterprise change, livestock management change and grassland management change (Chapter 4).

Table 11.6 Herder training and preferences for the program's key themes (Gansu Agricultural University workshops)

Key research themes	How did herder training address the program's key themes?	Which themes were of most interest to herders?
	Training events	Person training days
Identifying improved enterprises and animal management strategies	16 (70%)	4,420 (86%)
Grazing management	7 (30%)	740 (14%)
Contributions to finance and policy	0 (0%)	0 (0%)

Farm demonstrations

Farm demonstrations of new practices are one of the most effective teaching tools to achieve on-farm change, as herders can see practices in context. The use of paired farm comparisons with controls was pioneered in the first phase of the sustainable grassland program at four villages in IMAR and Gansu (Kemp et al. 2011; Wang et al. 2013; Kemp et al. 2011, Chapter 4). Previously, in China, no demonstration farms had been established in grassland regions. Monitoring at demonstration farms in Sunan (Chapter 3) has continued throughout the program. The number of demonstration farms was increased to include 14 villages located in all six of the main grassland provinces in northern and western China (Chapter 4) as part of a national program run by staff at IMAU. Each village had six demonstration farms (three households contracted to test new management practices and three to act as controls) operated by the owners to show what results could be obtained by herders under normal conditions. As discussed in Chapter 4, these demonstrations have all shown financial benefits from reduced stocking and other changes.

The demonstration farms and training significantly prepared herders for the transition from subsistence to business thinking. Training covered various topics each year in nine central locations, delivered to groups averaging 40 officials and 120 farmers. Overall, 3,360 and 10,240 person training days were delivered at Siziwang and the other national program locations respectively. Officials now have a greater awareness of how to alleviate poverty and improve grasslands across China, and herders have a greater understanding of how they can increase household income with fewer animals.

The use of demonstration farms introduced the need for ethical practices of researchers commencing this work. Specifically, it was not deemed reasonable for control farms to be constrained over time. We allowed them to change their practices as they observed what the demonstration farms were benefiting from. Over time, the control farms also participated in training workshops. This meant that improvements in the performance of demonstration farms did not show as large a gap with the control farms as might have been the case. Staff were trained to compare demonstration farms as much with their past performance as with the controls.

National programs

Since the sustainable grasslands program started in China, there has been a growing recognition by central agencies of the value of the work done and its importance for improving policy. Advocacy by the program and partners has led to the funding of seven national and six provincial projects (totalling approximately ¥272 million or $A54 million). In addition, leaders have all taken on major roles that aim to improve different aspects of the grassland–livestock system (Table 11.2). The program team are now the leading group of grassland scientists in China.

Study tours

Bilateral engagement built linkages between Australian agricultural providers (government, tertiary institutions, agribusiness and farmers) and their Chinese counterparts. These links facilitate the exchange of ideas, research collaboration and technology transfer, which all provide valuable insights into the current state of agricultural industries in Australia and China. Short-term study tours are one important way to achieve these objectives. They also promote personal growth through the experience of a different culture, which challenges perspectives and stimulates ideas about what can be applied at home.

Between 2009 and 2016, 26 short (1–5 days) training programs (307 people, 911 person training days) were delivered in Australia by NSW DPI and consultants, using this program's results but at no cost to the program. The delegations came from Beijing (6 groups) and 10 provinces (Shangdong (3), Gansu (2), IMAR (5), Tibet (1), Zhejiang (2), Yunnan (1), Jiangxi (1), Guizhou (3), Henan (1), Shanxi (1)). Three of these delegations, all from IMAR, were directly linked with the program. The rest either contacted NSW DPI directly or used a training company approved by the State Administration of Foreign Experts. Most groups were led by officials with director-general or deputy director-general status. Delegation members comprised 75% officials and technical experts from government departments, 20% university staff and students and 5% farmers/herders.

David Michalk arranged the training for all these groups, which included a combination of lectures and site visits showing various aspects of Australia's livestock industries tailored to the interests of each delegation (Table 11.7). Government officials were most interested in policies and government roles in developing market systems, food quality with safety protocols and traceback systems, and funding sources for agricultural research and development. Irrespective of the main focus of individual training programs, the concluding lecture for all groups was based on Kemp et al. (2011) and Michalk et al. (2011) and focused on problems, dilemmas, finding solutions, redesigning livestock strategies to reduce stocking rates and to improve incomes on western China's grasslands. The clear message was that the principles of precision management technology used in Australian livestock systems are being used to change on-farm practices in western China's grasslands. The ongoing requests for repeat visits indicates the value of this program.

Table 11.7 Themes addressed by study tour participants visiting Australia from China

Key research themes	Training events
Identifying improved enterprises and animal management strategies	9 (35%)
Grazing management	6 (23%)
Contributions to finance and policy	11 (42%)

Program impacts

All capacity-building activities produced positive outputs and outcomes, summarised in Table 11.8. Researchers and students received training and gained new skills and knowledge, new approaches to solving serious livelihood and grassland problems were introduced, evidence-based solutions were tested on farms and practical evidence-based management options were developed and adopted by empowered and trained herders. The skills and knowledge of individual researchers and postgraduate students grew significantly as shown by the number and quality of journal papers, participation in international forums and actively and respectful engagement with smallholders. Organisations improved their collaboration in research and research administration (there was little before this program) and developed capacity to work effectively with herders and talk to policymakers. Policymakers' perspectives of the grassland issues were challenged through conferences, workshops, meetings and study tours, with alternatives summarised in a series of policy briefs (Chapter 12).

The capacity of researchers and herders to improve livestock management and grassland condition was greatly strengthened, delivering considerable financial benefits to smallholders (Chapter 4; Li et al. 2015; Yin et al. 2018) and the Chinese economy. It was not possible, though, to estimate the cost-effectiveness of capacity strengthening, as all the capacity-building activities reported here were integrated with research and demonstrations, making it difficult to differentiate between causality and attribution. This is a common challenge for AR4D programs (Templeton 2009). In this program, our capacity-strengthening activities acted as catalysts for outcomes and impacts achieved through other program activities (e.g. research) as evident in our outcomes (Table 11.8). The collective results went well beyond the original program proposals. Of great significance in this was the developed confidence among Chinese partners, who obtained several large projects that greatly extended the work done. Conservatively, more than 8,400 people have been directly influenced by the program outcomes through attending conferences of various types (41%), participating in technical workshops (18%), training programs (2%) and joining herder training sessions, demonstration farm visits (39%) plus another 13,292 reading and 1,124 citing program publications. Capacity-building activities range from a better understanding of doing systems research, through to specific tasks necessary for research, development, extension, training and communications.

While it is not possible to specify impacts for individual capacity activities beyond the outcomes identified, it is possible to report on economic impacts from aggregated activities that specifically address herders' immediate problems of degrading grassland caused by too many animals and resulting in low household profit. Chapter 4 and Li et al. (2015) provide a good example of how capacity built in research, demonstrations and training has contributed to identifying sustainable management strategies to improved herder income for the desert steppes in IMAR. The lead researcher, Li Zhiguo, a student then lecturer at IMAU and a long-term contributor to the ACIAR Chinese sustainable grassland program, has participated in many of the program's capacity-building activities, such as *StageONE* and *StageTWO* models (Takahashi, Jones & Kemp 2011), survey methodology (Kemp et al 2011, Chapter 4), demonstration farms (Kemp et al. 2011), communicating with herders (Wu et al. 2011) and mentoring as a PhD candidate (Li 2015). He now successfully manages the large national project of demonstration farms. The core group in that project are the 2,000 members of the Siziwang Herder Association, who collectively manage about 1.1 Mha of desert steppe in Siziwang. Conservative estimates of additional income for association members generated by adopting new practices indicates their combined net income has increased by ¥43 million/year ($A8.8 million/year). The present value of benefits, calculated over 15 years ($A121 million), is well in excess of the program costs ($A10.8 million of Australian and Chinese funds) giving a benefit–cost ratio for the programs of approximately 11:1. This highlights the value of capacity building for economic outcomes, as they could not do this without a clearer understanding of how the system works. In addition, there was an environmental impact from a 34% reduction in CH_4 emissions under the new strategy (Li et al. 2015) that is yet to be costed. There are examples in the technical chapters of this monograph that demonstrate the same pattern of capacity building from the program.

The Chinese sustainable grassland program began with the recognition that smallholder herders were neither profitable nor sustainable, but it had the vision that these small smallholders can play a central role in improving household incomes, rehabilitating their grasslands and closing China's red meat supply gap when empowered with skills, knowledge and market incentives (eds Kemp & Michalk 2011; Michalk, Wu et al. 2015). Ways of achieving this have been demonstrated in practice, based on a much better understanding of the grassland–livestock system. People from herders to national officials now have that better understanding of how the system functions, what can be changed and what are the most effective pathways to follow to achieve profitable and sustainable livestock enterprises. Across China, approximately 23,000 people are estimated to have had some contact with the program. This enhanced knowledge now lies with the Chinese personnel involved, though they still express a desire for continued collaboration with the Australian scientists to help them to continually develop their skills and knowledge to improve the livelihoods of smallholder herders and the grasslands on which they depend.

Table 11.8 Outputs and outcomes from capacity-building activities implemented between 2009 and 2018

Capacity building activities	Targets of capacity building: Researchers	Students	Herders	Policy makers, officials	Outputs	Outcomes
Research projects	✓	✓			Total publications 376 including: Journals 273 (186 international JIF-rated, 87 Chinese unrated); Conferences 103 (see below). Students publications: 50 (included in totals). Journal impact factor range 12.12 to 0.20; 30 papers published in journals with JIF>3.5.	Published with influence: 12,748 reads and 1060 citations tracked (2009 and 2017) in 83 JIF rated journals; Only 16 papers not cited internationally. Chinese papers promote on-farm practices (bottom-up influence). Stage 3 Sustainability Model developed and calibrated. Enhanced reputations of individuals and partner institutes. Improved the core production relationships used in the models.
Conferences, workshops and meetings	✓	✓		✓	Total conferences, workshops, significant meetings, book chapter 103. 43 papers in IGC & IRC congresses (27 senior authored by Chinese); 27 papers in other international conferences; 26 papers at Chinese conferences, workshops and meetings; 7 book chapters published. Sydney IGC (800 delegates, 700 papers) success dependent on project team for organisation, program and proceedings production. Keynote papers at 6 major national workshops attended by ~1500 government, researchers and agribusiness people.	Effectively promoted project approach and results to eminent scientists at major grassland conferences (2011-2015). Informed policy makers through high level meetings (APEC and 'One Belt One Road' conferences) and national workshops of evidence-based alternative solutions to rural poverty and grassland degradation. Developed and nurtured international networks with leading scientists. Built skills in staging an international conferences and confidence in younger researchers in presentation delivery to large audiences.

Capacity building activities	Targets of capacity building: Researchers	Students	Herders	Policy makers, officials	Outputs	Outcomes
Higher degrees		✓			38 higher degrees (10 PhD, 28 Masters) awarded. Partner universities shared contribution: LU – 4 PhD, 8 MSc; CAU – 3 PhD, 4 MSc; GAU – 2 PhD, 5 MSc; and IMAU – 1 PhD, 10 MSc. Development of yak sub-model to facilitate modelling in alpine grasslands.	Expertise development in key areas to support farming systems research including training modelling specialists. Industry-ready graduates with a broader educational experience linked to the needs of research users. Use of models has identified better on-farm practices.
New skills and technical training	✓	✓			Capacity built to use all models developed by project. Survey methodology developed and used with ~1400 households. Training in new methods to analyse and graph survey results. DWR training (40 participants, 184 person days training) and field testing (22 participants, 98 person days) demonstrated value of DWR.	Competency to use all models in desert steppe and alpine meadow and to calibrate sustainability model for other grassland types. Statistically reliable data generated by household survey methodology to identify sustainable and profitable farm management strategies. Independent studies confirm DWR an accurate and cost effective alternative method to monitor biomass and botanical composition in Chinese grasslands. DWR now used in grassland research.
Mentoring and coaching	✓	✓	✓		Researchers and students bridged gap between existing skills and knowledge and that required for system research. Herders changed mindset and built skills to implement new on-farm practices.	Researchers and students built competency (skills and knowledge) to continue producing good science. Some herders now at lead their districts by demonstrating better grassland and livestock management practices to others.

Capacity building activities	Targets of capacity building: Researchers	Students	Herders	Policy makers, officials	Outputs	Outcomes
Leadership development	✓	✓	✓		Four project team members completed ACIAR John Dillon Fellowship Program. Demonstration household herders transitioned into effective group leaders	Established strong bilateral collaboration networks, e.g. China-Australian Network for Grassland Farming Systems. Formation of Herder Associations; Siziwang Herder Association, now 2000 members with own training programs, elite ram breeding facilities, branded product and marketing in eastern China cities.
Herder training			✓		20,520 person days delivered by project (10,280 person days, 56 events) and National Programs (10,240 person days, 63 events). Herder Training Manual published 2013. Herders trained in Fat Scoring Method for monitoring livestock performance.	Many herders transitioned from subsistence to market-oriented livestock production. Precision livestock production identified by herders as key to maintaining farm product output with less livestock. Achieved on-farm practice change (enterprise, management) that reduced stocking rate, increase household profitability and improved grassland.
Farm demonstrations	✓	✓	✓	✓	Project demonstration farms (102) in paired farm comparisons with ‘controls’ monitored in 21 villages in Gansu & IMAR. National Demonstration Farms Program monitored another 84 farms in 14 villages located in grassland provinces. Core target for farms: 1110 herders & 380 government officers visited demonstration farms and training each year. Demonstration households surveyed to monitored benefits of practices tested using methodology and analyses developed by project.	Use of project survey and demonstration farm methodologies validated by publication in high impact journals. Demonstration farms convinced herders that lower stocking rates resulted in higher nett incomes. Value of demonstrations farms confirmed as a key driver of on-farm change and justify their inclusion in AR4D projects focuses on alleviating smallholder poverty and grassland degradation.

Capacity building activities	Targets of capacity building: Researchers	Students	Herders	Policy makers, officials	Outputs	Outcomes
National programs	✓			✓	Substantial capacity building and technical support provided to 13 national and provincial funded projects (total $A54 million). National Grazing Management Program used project's experimental layout, data collection methods and analyses to investigate sustainable stocking rates in 14 experiments across northern and western China. National Demonstration Farms Program used project's survey methodology and demonstration farm design.	National Programs scaled up the evaluation of the outcomes of core project research to grassland provinces beyond the project footprint. Project senior scientists entrusted with the responsibility to implement these National Programs. Substantial co-investment in knowledge and capacity building demonstrated clear 'win-win' outcome in ACIAR-China partnership.
Study tours to Australia	✓	✓		✓	Study tours delivered in Australia – 26 short (1 to 5 days) training programs (307 people, 911-person training days) from Beijing and 10 provinces. 3 directly linked with project, others indirect. Most groups included 75% government officials and technicians and led by senior officials (DG or DDG level) with strong interest in policies and government roles.	Key senior leaders (230 people) responsible for grassland issues but outside the project footprint provided with clear demonstration (using project outcomes) that principles of precision management used in Australian livestock systems are being used to change on-farm practices in western and norther China's grasslands.

References

Australian Centre for International Agricultural Research (ACIAR) 2018, *Capacity Building Policy*, ACIAR Canberra, Australia, <https://www.aciar.gov.au/capacity-building> accessed 10 December 2018.

Bai, Z, Ma, W, Ma, L, Velthof, GL, Wei, Z, Havlík, P, Oenema, O & Lee, MR 2018, 'China's livestock transition: driving forces, impacts, and consequences', *Science Advances*, vol. 4(07), eaar8534, doi: 10.1126/sciadv.aar8534.

Bolger, 2000, *Capacity development: why, what and how*, Canadian International Development Agency, Gatineau, Quebec, Canada. <http://www.hiproweb.org/fileadmin/cdroms/Biblio_Renforcement/documents/Chapter-1/Chap1Doc1.pdf>

Behrendt, K, Cacho, OJ, Scott, JM & Jones, R 2016, 'Using seasonal stochastic dynamic programming to identify optimal management decisions that achieve maximum economic sustainable yields from grasslands under climate risk', *Agricultural Systems*, vol. 145, pp. 13–23.

Bell, AK & CJ Allan 2000, 'PROGRAZE: an extension package in grazing and pasture management', *Australian Journal of Experimental Agriculture*, vol. 40(2), pp. 325–330, doi: 10.1071/EA98017.

Bohannon J 2016, 'Hate journal impact factors? New study gives you one more reason', *Science*, 6 July 2016, doi: 10.1126/science.aag0643.

Briske, DD, Zhao, M, Han, G, Xiu, C, Kemp, DR, Willms, W, Havstad, K, Kang, L, Wang, Z, Wu, J, Han, X & Bai, Y 2015, 'Strategies to alleviate poverty and grassland degradation in Inner Mongolia: intensification vs production efficiency of livestock systems', *Journal of Environmental Management*, vol. 152c, pp. 177–182.

Broadfoot, KM, Badgery, WB & Millar, GD 2017, 'Post-experimental modelling of grazing systems to improve profit and environmental outcomes using AusFarm', *Animal Production Science*, vol. 57(9). pp. 1849–1858.

Brown CG, Waldron, SA & Longworth, JW 2008, *Sustainable development in western China: managing people, livestock and grasslands in pastoral areas*, Edward Elgar Publishing, Cheltenham, pp. 320.

Bryant, E 2006, 'Building local skills and knowledge for food security', International Food Policy Research Institute, 13 February 2006, <www.ifpri.org/blog/building-local-skills-and-knowledge-food-security>

Callaham, M, Weber, E & Wears, R 2001, 'Citation characteristics of research published in Emergency Medicine versus other scientific journals', *Annals of Emergency Medicine*, vol. 38, pp. 513–517.

Chen, H, L He, Tang, H, Zhao, M, Shao, L 2016, 'A two-step strategy for developing cultivated pastures in China that offer the advantages of ecosystem services', *Sustainability*, vol. 8(4), pp. 392, doi: 10.3390/su8040392.

Committee of Responsibilities of Authorship in the Biological Sciences (CRABS) 2003, 'The purpose of publication and responsibilities for sharing the tradition of scientific publication', in *Sharing publication-related data and materials: responsibilities of authorship in the life sciences*, National Academy of Sciences, Ch.2, pp. 27–34.

Denney. L 2017, '$15bn is spent every year on training, with disappointing results. Why the aid industry needs to rethink "capacity building"', in *From poverty to power*, 6 July 2017, <https://oxfamblogs.org/fp2p/15bn-is-spent-every-year-on-aid-for-training-with-disappointing-results-why-the-aid-industry-needs-to-rethink-its-approach-to-capacity-building/>

Dinesh, D, Zougmore, RB, Vervoort, J, Totin, E, Thornton, PK, Solomon, D, Shirsath, PB, Pede, VO, Lopez Noriega, I Läderach, P, Körner, J, Hegger, D, Girvetz, EH, Friis, AE, Driessen, PPJ & Campbell, BM 2018, 'Facilitating change for Climate-Smart Agriculture through science-policy engagement', *Sustainability*, vol. 10(8), p. 2616, doi: 10.3390/su10082616.

Food and Agriculture Organization of the United Nations (FAO), Statistics Division 2017, *FAOSTAT*, Rome, Italy, <http://www.fao.org/faostat>

Food Security Collaborative 2012, 'Building institutional capacity to increase food security in Africa', Food Security Collaborative, Michigan State University, Department of Agricultural, Food, and Resource, East Lansing, MI, USA <http://www.msiworldwide.com/wpcontent/uploads/Capacity_Building_for_Food_Security.pdf> accessed 10 December 2018.

Fritz, J 2018, 'How to talk about non-profit impact from inputs to outcomes', *The balance small business*, 12 February 2018, <https://www.thebalancesmb.com/inputs-outputs-outcomes-impact-what-s-the-difference-2502227> accessed 15 December 2018.

Gao, XF, Achi, F, Jin, S, Michalk, DL & Zho, WG 2003, 'Using disaster recovery funding to change livestock management practices in Inner Mongolia, PRC', *VII International Rangeland Congress*, Durban, South Africa.

Gongbuzeren, YL & Li, WJ 2015, 'China's rangeland management policy debates: what have we learned?', *Rangeland Ecology & Management*, vol. 68, pp. 305–314.

Gordon, J & Chadwick, K 2007, 'Impact assessment of capacity building and training: assessment framework and two case studies', *Impact Assessment Series*, No. 44, Australian Centre for International Agricultural Research, Canberra.

Han, GD, Liu, T, Wang, ZW, Li, ZG, Zhao, ML, Havstad, KM, Wu, JG & Kemp, D. 2013, 'Adaptive management of grazing lands', in *Dryland East Asia, Land Dynamics Amid Social and Climate Change*, Higher Education Press, Beijing, China, pp. 447–464.

Hargreaves, JNG & Kerr, JD 1992, 'BOTANAL: A comprehensive sampling and computing procedure for estimating pasture yield and composition. II. Computational package. CSIRO Aust. Division of Tropical Crops and Pastures', *Tropical Agronomy Technical Memorandum No. 79*.

Harman, KM 2010, 'Producing "industry-ready" doctorates: Australian Cooperative Research Centre approaches to doctoral education', *Studies in Continuing Education*, vol. 26(3), pp. 387–404.

Hua, LM & Squires, VR 2015, 'Managing China's pastoral lands: current problems and future prospects', *Land Use Policy*, vol. 43, pp.129–137, doi: 10.1016/j.landusepol.2014.11.004.

Husbands-Fealing K 2013, 'Assessing impacts of higher education systems', in A Dean, M Wykes & H Stevens (eds), 7 Essays on Impact, DESCRIBE project report for Joint Information Systems Committee, University of Exeter, pp. 44–61.

Japan International Cooperation Agency (JICA) 2004, *Capacity development handbook for JICA staff*, Task Force on Aid Approaches, Japan International Cooperation Agency, Tokyo, Japan, <https://www.jica.go.jp/jica-ri/IFIC_and_JBICI-Studies/english/publications/reports/study/capacity/200403/pdf/200403.pdf>

Johnson, JA, Runge, CF, Senauer, B, Foley, J & Polasky, S 2014, 'Global agriculture and carbon trade-offs', *Proceedings of the National Academy of Sciences of the United States of America*, vol. 111 pp. 12342–12347.

Kemp, DR 2011, *Sustainable livestock grazing systems on Chinese temperate grasslands*, Project proposal (LPS/2008/048), Australian Centre for International Agricultural Research, Canberra, p. 38.

—— 2018, *Sustainable livestock grazing systems on Chinese temperate grasslands*, Final report (LPS/2008/048), Australian Centre for International Agricultural Research, Canberra, p. 89.

Kemp, DR & Michalk, DL (eds) 2011, *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, p. 189.

—— 'Livestock production styles and managing grassland ecosystems' in G Lemaire, J Hodgson, A Chabbi (eds), *Grassland ecosystems: productivity and environmental issues*, CABI Publishing, Wallingford, Ch. 1.6, pp. 53–62.

Kemp, DR, Han, GD, Junk, G, Langford, C, Michalk, DL, Millar, GD, Takahashi, T, Xu, Z, and Zhao, ML 2011, 'Demonstration farms to improve grasslands and household incomes in western China – what can be done, what are we learning?', in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China*. ACIAR Proceedings 134, pp. 152–161.

Kemp, DR, Han, GD, Hou, XY, Michalk, DL, Hou, FJ, Wu, JP & Zhang, YJ 2013, 'Innovative grassland management systems for environmental and livelihood benefits', *Proceedings of the National Academy of Sciences of the United States of America*, vol. 110 (21), pp. 8369–8374, doi: 10.1073/pnas.1208063110.

Kemp, DR, Han, GD, Hou, FJ, Hou, XY, Li, ZG, Sun, Y, Wang, ZW, Wu, JP, Zhang, XQ, Zhang, YJ & Gong, XY 2018, 'Sustainable management of Chinese grasslands: issues and knowledge', *Frontiers of Agricultural Science and Engineering*, vol. 5, pp. 9–23, doi: 10.15302/J-FASE-2018204.

Kemp, DR, Nan, ZB & Wu, JP 2014, 'Livestock production and environmental improvement, economic pillars along the Silk Road', *Proceedings of the Silk Road Economic Belt 'one belt one road' cultural roundtable conference,* Lanzhou University, China, 23–29 August 2014, pp. 1–11.

Laycock, A, Walker, A, Harrison, N & Brands, J 2011, 'Chapter 6: Building capacity through research', in *Researching Indigenous health: a practical guide for researchers*, The Lowitja Institute, Melbourne, pp. 131–153.

Leeuwis, C, Klerkx, L & Schut, M 2018, 'Reforming the research policy and impact culture in the CGIAR: integrating science and systemic capacity development', *Global Food Security*, vol. 16, pp. 17–21.

Li, P, Hadrich, JC, Robinson, BE, Hou, YL, Dai, YT & Hou, XY 2018, 'How do herders do well? Profitability potential of livestock grazing in Inner Mongolia, China, across ecosystem types', *The Rangeland Journal*, vol. 40, pp. 77–90.

Li, S, Hua, LM, Nie, Z & Zheng, Y 2015, 'Application of Dry Weight Rank rapid monitoring of grassland in alpine meadow' *Chinese Journal of Ecology*, vol. 34(12), pp. 3575–3580

Li, XL, Ding, Y, Yin, YT, Yang, TT, Liu, ZY, Ren, WB, Zhang, JL, Sarula, Li, YH & Hou XY 2017, 'Patterns of herders' adaptation to changes in social-ecological systems across northern China's grasslands over the past three decades', *The Rangeland Journal*, vol. 39, pp. 317–328.

Li, ZG 2015, 'Simulation study of the resources optimizing allocation and adaptive management in household farm, Inner Mongolia: a case in Siziwang Banner', PhD thesis, Inner Mongolia Agricultural University, Hohhot.

Li, ZG, Han, GD, Zhao, ML, Wang, J, Wang, ZW & Kemp, DR 2015, 'Identifying management strategies to improve sustainability and household income for herders on the desert steppe in Inner Mongolia, China', *Agricultural Systems*, vol. 132, pp. 62–72, doi: 10.1016/j.agsy.2014.08.011.

Liu, HB 2017, 'Simulation and application of the Sustainable Grasslands Model in the meadow area of Qinghai-Tibetan Plateau', PhD thesis, Gansu Agricultural University, Lanzhou, China, p. 188.

Mao, YW, Hopkins, DL, Zhang, YM & Luo, X 2016, 'Consumption patterns and consumer attitudes to beef and sheep meat in China' *American Journal of Food and Nutrition*, vol. 4(2), pp. 30–39.

Matachi, A 2006, *Capacity building framework*, UNESCO – International Institute for Capacity Building in Africa, <http://www.iicba.unesco.org/sites/default/files/Capacity%20Building%20framework.pdf> accessed 18 December 2018.

Mbabu, AN & Hall, A 2012, 'Introduction', in AN Mbabu & A Hall, *Capacity building for agricultural research for development: lessons from practices in Papua New Guinea*, Maastricht Economic and Social Research Institute on Innovation and Technology (UNU-MERIT), Maastricht, The Netherlands.

Michalk, DL 2017a, 'Policies, practices, technology and capacity building on livestock: lessons learnt', *Workshop on Strengthening APEC Cooperation on Food Security and Climate Change*, Ha Noi, Viet Nam 19–21 April 2017, 2017/PPFS/WKSP1/005, p. 12.

——b 'Policy development, coordination and coherence on the livestock sector', *Workshop on Strengthening APEC Cooperation on Food Security and Climate Change*, Ha Noi, Viet Nam 19–21 April 2017, 2017/PPFS/WKSP1/017, p. 11.

Michalk, DL, Badgery, WB & Kemp, DR 2017, 'Balancing animal, pasture and environmental outcomes in grazing management experiments', *Animal Production Science*, vol. 57(9), pp. 1775–1784.

Michalk, DL, Wu, JP, Badgery, WB & Kemp, DR 2015, 'Impact of market forces on product quality and grassland condition', in D Vijay, MK Srivastava, CK Gupta, DR Malaviya, MM Roy, SK Mahanta, JB Singh, A Maity & PK Ghosh (eds), *Sustainable use of grassland resources for forage production, biodiversity and environmental protection,* Proceedings of 23rd International Grassland Congress, New Delhi, India, Keynote Lectures, Range Management Society of India, Jhansi, Uttar Pradesh, India, pp. 184–197.

Michalk, DL, Kemp, DR, Badgery, WB, Wu, JP, Zhang, YJ & Thomassin, PJ 2015, 'Sustainability, biodiversity and environmental issues: a global perspective for livestock production', in MM Roy, DR Malaviya, VK Yadav, T Singh, RP Sah, D Vijay & A Radhakrishna (eds), *Sustainable use of grassland resources for forage production, biodiversity and environmental protection*, Souvenir of 23rd International Grassland Congress, 20–24 November 2015, New Delhi, India, Range Management Society of India, Jhansi, Uttar Pradesh, India, pp. 6–23.

Morgan, P 1998, *Capacity and capacity development – some strategies*, Policy Branch, Canadian International Development Agency, Hull, Quebec, Canada, p. 6.

Mullen, J, Gray, D & de Meyer, J 2015, 'Evaluating the impact of capacity building by ACIAR' *59th conference, Australian Agricultural and Resource Economics Society*, 10–13 February 2015, Rotorua, New Zealand.

Nutley, S 2003, 'Bridging the policy/research divide: reflections and lessons from the UK', Keynote paper at National Institute of Governance Conference, *Facing the future: engaging stakeholders and citizens in developing public policy*, Canberra, Australia, 23–24 April 2003.

Organisation for Economic Co-operation and Development (OEDC) 2005, *Paris declaration on aid effectiveness 2005*, OECD, Paris, <http://www.oecd.org/dataoecd/11/41/34428351.pdf>

—— 2006, *Survey on monitoring the Paris Declaration: overview of the results*, OECD, Paris. <http://www.oecd.org/document/20/0,3343,en_2649_33721_38521876_1_1_1_1,00.html>

Otoo, SKE, Agapitova, N & Behrens, J 2009, *The capacity development results framework: a strategic and results-oriented approach to learning for capacity development*, World Bank Institute, World Bank Group Washington DC.

Panzer, B 2016, 'The need for mentoring in agriculture', Columnist, *Fond du Lac Reporter*, Fond Du Lac, Wisconsin, published 23 August 2016, <https://www.fdlreporter.com/story/news/2016/08/23/columnist-need-mentoring-agriculture/89198440/> accessed 8 January 2019.

Packham, R & Sriskandarajah, N 2005, 'Systemic action research for postgraduate education in agriculture and rural development', *Systems Research & Behavioural Science*, vol. 22(2), pp. 119–130.

Penfield, T, Baker, MJ, Scoble, R & Wykes, MC 2014, 'Assessment, evaluations, and definitions of research impact: a review', *Research Evaluation*, vol. 23, pp. 21–32.

Photakoun, V, Millar, J & Race, D 2009, 'Evaluating capacity building methods to strengthen livestock extension outcomes in Laos', *Extension Farming Systems Journal*, vol. 5(2), pp. 91–100.

Ren, JZ, Hu, Z, Zhang, Z, Hou, FJ & Chen Q 2001, 'Zonation of grassland industry for sustainable ecological and economic development in China', in F Hong F & J Ren (eds), *Prospects of Grassland Science and Industry for the 21st Century*, Chinese Grassland Society/China Association of Agricultural Societies, Beijing.

Sharma, A 2017, 'Latest impact factors 2016', *Journal Citation Reports*, Thomson Reuters.

Shen, C 2017, 'Open access scholarly journal publishing in Chinese', *Publications*, vol. 5(4), p. 22, doi: 10.3390/publications5040022.

Simister, N 2015, 'Outputs, outcomes and impact', International Non-Governmental Organisation Training and Research Centre (INTRAC), Oxford, UK, <https://www.intrac.org/wpcms/wp-content/uploads/2016/06/Monitoring-and-Evaluation-Series-Outcomes-Outputs-and-Impact-7.pdf>

State Council, 2002, 'Some opinions of State Council on enhance rangeland conservation and construction', in GW Yuan, G Yu, J Qiang, C Yuan, B Hu, Y JianShe, DR Gan & Y Jian (eds), *Chinese animal husbandry yearbook*, Chinese Agricultural Publication, Beijing, China.

Stephen, P, Brien, N & Triraganon, R 2006, 'Capacity Building for CBNRM in Asia: a regional review', in Regional Community Forestry Training Centre for Asia and the Pacific, <http://www.recoftc.org/site/fileadmin/docs/CABS/idrc review.pdf> accessed 29 October 2007.

Soderstrom, SK, Baker, D, Banks, T, Bete, N, Brandenburg, A, Broadfield, R, Brown, M, Dadgari, F, de Haan, C, Eliste, P, Fock, A, Guldin, G, Karaky, R, Xiao-Ping, L, Mackinnon, K, Mangum, M, Michalk, DL, Miller, D, Nguyen, HC, O'Leary, R, Ping, M, Reyes, A, Sheehy, D, Watson, R, Wu, JP, Zhou, WG, Zhao, Y 2003, 'Project appraisal document on a proposed loan in the amount of $US66.27 million and a grant from the global environment facility trust fund in the amount of $US10.5 million to the People's Republic of China for a Gansu and Xinjiang Pastoral Development Project', World Bank Rural Development and Natural Resources Sector Unit, East Asia and Pacific Region, 13 August 2003, <http://documents.worldbank.org/curated/en/270051468746659697/pdf/257030CN0PAD.pdf> p. 165.

Sutcliffe, S & Court, J 2005, 'Evidence-based policymaking: what is it? How does it work? What relevance for developing countries?' *Overseas Development Institute*, <https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/3683.pdf> p. 45.

Takahashi, T, Jones, R & Kemp, DR 2011, 'Steady-state modelling for better understanding of current livestock production systems and for exploration of optimal short-term strategies', in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, pp. 26–35.

Templeton, DJ 2009, 'A framework for assessing of the impact of capacity building', *International Association of Agricultural Economists' 2009 Conference*, Beijing, China, 16–22 August 2009.

Thornton, PK, Schuetz, T, Förcha, W, Cramer, L, Abreu, D, Vermeulen, S & Campbell, BM 2017, 'Responding to global change: a theory of change approach to making agricultural research for development outcome-based', *Agricultural Systems*, vol. 152, pp. 145–153.

Uneke, CJ, Ezeoha, AE, Uro-Chukwu, H, Ezeonu, CT, Ogbu, O, Onwe, F & Edoga, C 2015, 'Enhancing the capacity of policy-makers to develop evidence-informed policy brief on infectious diseases of poverty in Nigeria', *International Journal of Health Policy and Management*, vol. 4(9), pp. 599–610, doi: 10.15171/ijhpm.2015.100.

van Burgel, AJ, Oldham, CM, Behrendt, R, Curnow, M, Gordon, DJ & Thompson, AN 2011, 'The merit of condition score and fat score as alternatives to liveweight for managing the nutrition of ewes', *Animal Production Science,* vol. 51(9), pp. 834–841, doi: 10.1071/AN09146.

Vignola, R, Harvey, CA, Bautista-Solisa, P, Avelinoa, J, Rapidela, B, Donatti, C & Martinez, R 2015, 'Ecosystem-based adaptation for smallholder farmers: definitions, opportunities and constraints', *Agriculture, Ecosystems and Environment*, vol. 211, pp. 126–132.

Waldron, S, Brown, C & Zhao, YT 2011, 'Developing the right institutional environment to deal with grassland degradation in China', in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China ACIAR Proceedings No. 134*, Australian Centre for International Agricultural Research, Canberra, pp. 98–104.

Wang, J, Zhao, M, Kemp, DR & Turnbull, G 2013, 'Demonstration farms to improve grassland and household incomes in western China', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress, September 2013, Sydney, Australia, pp. 1846–1848.

Wang, X & Xiao, H 2016, 'Technical efficiency and its influencing factors of farmers' meat sheep production in China: based on the survey data of farmers', *International Journal of Agricultural Economics*, vol. 1(1), pp. 10–15, doi: 10.11648/j.ijae.20160101.12.

White, A & Holst, P 2006, 'Fat scoring sheep and lambs', *Primefact 302*, NSW Department of Primary Industries, Orange, NSW.

World Bank Operations Evaluations Department (OED) 2005, 'Capacity building in Africa: an OED evaluation of World Bank support', The World Bank Group, Washington, DC, <http://www.oecd.org/countries/mozambique/35280349.pdf>

World Bank Independent Evaluation Group 2007, 'Evaluation of World Bank support for client training', Independent Evaluation Group, The World Bank Group, Washington, DC, <http://www.worldbank.org>

World Bank Institute 2006, 'Developing Capacities in Countries', *WBI Annual Report 2006*, The World Bank Group, Washington, DC.

Wu JP, Michalk, DL, Kemp, DR, Yang, L & Gong, XY 2011, 'Talking with China's livestock herders: what was learnt about their attitudes to new practices', in DR Kemp & DL Michalk (eds), *Development of Sustainable Livestock Systems on Grasslands in North-Western China ACIAR Proceedings No. 134*, Australian Centre for International Agricultural Research, Canberra, pp. 162–176.

Yang, H 2013, 'Editorial – livestock development in China: animal production, consumption and genetic resources', *Journal of Animal Breeding and Genetics*, vol. 130, pp. 249–251.

Yin, Q, Gao, TT, Liu, HF, Wei, CX & Wang, HC 2015, 'Application of Dry Weight Rank method in estimating biomass of natural grassland', *Pratacultural Science*, vol. 32(3), pp. 464–469.

Yin, YT, Wang, Z, Li, XL, Langford, C, Yun, XJ, Mu, HB & Hou, XY 2018, 'Factors affecting herder adoption of winter lambing practices in the desert steppe region of Inner Mongolia, China', *The Rangeland Journal*, vol. 40, pp. 65–75, doi: 10.1071/RJ17068.

Zhang, CJ, Zhu, Y 2016, 'China's graduate students need better education in scientific writing and publishing', *Journal of Zhejiang University – Science B (Biomedicine & Biotechnology)*, vol. 15(12), pp. 1088–1092.

Zhang, YJ, Zhang, LZ, Wang, ML, Li, XL, Yang, QC, Hanson, J & Jorge, MA 2013, 'Drivers of change for grassland and forage systems: A case study of China', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 80–89.

Zhou, G, Zhang, W & Xu X 2012, 'China's meat industry revolution: challenges and opportunities for the future', *Meat Science*, vol. 92(3), pp. 188–96, doi: 10.1016/j.meatsci.2012.04.016.

12 Future-proof sustainable Chinese grasslands

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The scale of China's degraded grasslands and the number of people who depend upon them and their low incomes is one of the world's largest socioenvironmental problems. These problems are widespread, as the issues discussed in this monograph are common throughout large areas of China, Mongolia, Russia, Central Asia, India, Pakistan and Africa. Grassland/grazing lands are 40% of the world's land area and there is common concern about the state of these lands and the need to find sustainable solutions that maintain these lands in a resilient, stable state, while sustaining the livelihoods of the millions of people who depend upon them. What are the options and pathways whereby the vast natural resource of grasslands can be utilised sustainably by future generations? In this monograph, we have focused on the grasslands of northern and western China, and devised a range of options and pathways for rehabilitating degraded grasslands and improving the livelihoods of herders. In this chapter, the aim is to first review the lessons learned from working for herders, assess the impact of this program and provide conclusions and general policy recommendations. We outline the lessons learned that, if maintained, will help future-proof the development of sustainable grassland livestock industries across China.

The program's aim has been to rehabilitate the vast grasslands of China and improve herder incomes. Methods to achieve this are detailed through this monograph. Photo: D.R. Kemp

Working for herders

What are the general lessons from this large program that has been in place for 15 years? A lot of detail has emerged and is ongoing that helps to understand how the livestock-grazing system functions in these tough environments. The work can be distilled into general issues that help focus this and other similar research.

Use common language

To understand a system, researchers often use measurements, techniques and terminology that are inaccessible to farmers and herders. A common problem is that ecologists measure terms like frequency or basal cover, yet livestock eat biomass, not frequency, and the primary competition among grassland plants is best understood through biomass interactions. It is difficult to make much practical use of a lot of the ecological work. This does not mean that scientists should not use specialised techniques, rather that they should always include measures that are directly relevant to the herders and their advisers. Similarly, the relationship between an animal's liveweight and condition score can be well understood, yet grazing experiments have not always measured the grazing animals. In the Chinese literature, there are grazing studies that did not monitor the animals in a useful way that could then provide direct information of relevance to grassland management, so those studies could not be used. For grassland management, the common measure that directly related to several aspects of grassland and animal productivity is grassland herbage mass (Chapter 10). This can also be monitored by governments through remote sensing techniques. Throughout this program, we have sought to use techniques that directly help quantify and understand grassland and livestock interactions.

Work within system limits

Work with what you have. The grasslands are vast and it would never be feasible to completely replant them to achieve a more productive state, as has been proposed in various publications and forums. Seed is not available for most of the useful species, vegetative propagation is not feasible and past practices mean that the botanical composition of most grasslands has changed from what would be considered a preferable state. Similarly, it is not feasible or even beneficial to simply replace all the animals with another breed. Thus, the current task in most areas is to work with the current system components and aim to optimise them. The work on managing the desert and typical steppe (Chapters 8 and 9) showed how different objectives had to be set. The analyses of options for livestock production (Chapter 3) showed that, within existing flocks, culling of the least-productive animals could quickly result in more animal product and higher household incomes from fewer animals. This then created the opportunity for grassland recovery.

Minimise management criteria

Decision-making becomes increasingly problematic as the number of criteria that need to be optimised increases. In biological systems, it is effectively impossible to optimise several criteria at once. Grassland livestock managers may focus on a few items that may or may not help improve the system. A typical problem is focusing on improving animal genetics without improving the feed supply. Research needs to identify criteria that will relate directly to grassland condition and improved incomes from livestock. That process applied throughout the work discussed in this monograph and was distilled to a primary focus on herbage mass. This was the measure that researchers could use to analyse system performance and herders could learn to identify (Chapter 10). Herders do not need to be perfect at estimating all possible values of herbage mass, just critical values like minimum values (Chapters 8 and 9) below which grasslands should not be grazed. This approach is central in the models, where the objective is to test different management strategies and understand the risks of different options (Chapters 6 and 7).

Work at all levels of government

In many countries, including China, land management depends upon both government policies, laws, regulations and programs, and herder practices. Good grassland management requires the development of practices that everyone agrees on and that research has shown will deliver the desired social and economic outcomes. It is essential to communicate with all relevant authorities, as well as herders, to understand how the system functions, devise investigations that aim to identify sustainable solutions and work through how solutions can be implemented in practice by all those involved. In the program discussed in this monograph, our aim was to maintain regular contact across the six layers of government in China, as well as with herder groups in the study villages. We met regularly with these groups to discuss our findings and plan the work (Chapter 11). With government officials, our aim was to keep them informed of key results so that, as they developed policies, there would be more chance of compliance to deliver the desired benefits. When this program started, the solution to grassland degradation was to ban grazing for five years. This did not always result in grasslands returning to a desirable state (Chapter 5) and carried with it a large socioeconomic cost. The experiments showed that reduced stocking rates could achieve similar results to a grazing ban, while also improving the profitability of livestock production (Chapters 3, 6, 7, 8, 9 and 10). Current policies allow for a reduced stocking rate option instead of a grazing ban, which results in higher herder household incomes. This program helped to establish the policy of achieving a balance in feed supply and demand.

Develop markets

Where major grassland improvements and household incomes occurred (Chapters 2, 3, 4 and 8), we used a combination of surveys, experiments and farm demonstrations to show the benefits from reducing animal numbers and improving the genetics of the retained animals. However, we want to acknowledge that the impetus for these changes often came as much from markets increasing payments for better-quality, more-productive animals. Where markets shift to paying for animal products, rather than a common price per animal, there is the incentive to optimise the amount of meat, milk, fibre etc. produced per animal. This leads to reducing stocking rates on grasslands (Chapter 1). While this program was not involved with detailed work on improving markets, program members at Siziwang and Sunan worked with local herders to enable price premiums for better-quality animals. Herders are unlikely to change practices that would improve grasslands unless those changes also improve their incomes. The value of improving market efficiencies in developing economies cannot be understated.

Farmers need to focus more on consumer wants. These examples are from a feedlot producer and processor who is selling to the middle class with (left) special packages and (right) well-marbled meat. The meat is now exported to Japan. Photos: D.R. Kemp

Use farm demonstrations

One of the program successes was the introduction of demonstration farms to grassland regions, a program that expanded significantly over the years (Chapters 3 and 4). In these demonstrations, we were conscious of the need to trial practice changes that were within the capabilities of herders. This included culling unproductive animals and improved feeding in winter, typically with local fodder or grain. We did not use expensive alternative animals or fodder. The efficiencies of these changes were often lower than theoretically possible. However, even with these limitations, financial benefits were clear (Chapter 4). Herders were then in a position to see the benefits, learn from the experience and work out how to continue to make further improvements.

Use a range of investigative techniques

Research work often involves analysing a problem and then devising studies designed to identify solutions. However, when that is done in isolation, the solutions devised may not be feasible, nor applied. For this reason, we first surveyed herder households to understand how the grassland–livestock system worked, then used that information to construct simple models of how livestock production functioned (Chapter 6; eds Kemp & Michalk 2011). That process helped identify the main issue of reorganising livestock production as the pathway to grassland improvement. In contrast, there had been ecological research in China to identify a range of practices that could rehabilitate grasslands, although the practices recommended may not have been relevant to herders. The grassland research done in this program was designed to provide information that was directly related to herder incomes. In addition, farms demonstrations were used to test the model predictions. The combination of farm surveys, field experiments and farm demonstrations built confidence that the conclusions drawn would be real and achievable for herders, making them more likely to be adopted.

Consider the systems context

As emphasised through this monograph, it is important to do research for development work in context (Chapter 1). The original plans for this program were to do some field experiments, backed by modelling. But the more that was initially learned, the more we needed a greater understanding of the grassland–livestock system. Some modelling was needed to bring the information together with field experiments that tested ideas for improving grasslands and herder incomes. Modelling was the tool that helped check various data sources to see if they made sense in a systems context. Often individual pieces of information (e.g. animal weights) made no sense when lined up against grassland measures, which indicated very low quantities and quality of forage, well below animal maintenance levels. The data required was then remeasured. Systems modelling also suggested that lambing times could be changed from mid winter to late spring or early summer, a prediction that was then substantiated in farm demonstrations (Chapters 3 and 4). *StageONE*, *StageTWO* and *StageTHREE* models (Chapter 6; eds Kemp & Michalk 2011), based on the energy feed balance of livestock, all indicated reduced stocking rates should improve the grasslands, incomes and system resilience. The PhaseONE model (Chapter 3; eds Kemp & Michalk 2011) took a completely different precision livestock management approach of estimating the gross margin for each individual animal, but came up with the same conclusion that reduced stocking rates would improve household incomes. Analysing different parts of the system using different tools, and comparing results at a whole-system level, built confidence in the program outcomes.

Build capacity of all

To create effective, long-lasting change requires not only devising sustainable grassland–livestock management techniques, but also lasting changes in the knowledge and skill base of all the personnel involved in finding sustainable solutions. Throughout this program, we were conscious of the need to build the capacity of all the people involved (Chapter 11). That commitment paid significant dividends in the capacity of the people involved to research system problems, in herders to take on and devise better practices and in officials to modify policies so that better outcomes resulted. The impressive list of papers produced by this program (Appendix 2) gives some insight into how the capacity of everyone involved in this program developed.

Dr Horne (ACIAR), Dr Austin (CEO, ACIAR) and Professor Kemp at a meeting with local officials and project members in China to discuss progress in the program. Photo: Han G.D.

Impacts

Scientific

This research has introduced a new approach to solving problems that is now accepted and is in use among the Chinese groups involved, and others who followed the work. Much of the work done has been published (Appendix 2). The sequence of studies involved:

1. surveying herders to understand how their grassland–livestock system works
2. modelling choices to identify improved tactics and strategies
3. evaluating better choices in farm demonstrations and on-farm experiments
4. undertaking further surveys to identify benefits on demonstration farms vs controls
5. running experiments in parallel to the above studies to resolve the details that cannot be done on farms
6. modelling aspects of the system that cannot easily be tested on farms or in experiments
7. building theoretical knowledge about how the system works and using that to enhance the predictability of the results obtained.

This systems analysis sequence has considerably increased the skills toolkit of Chinese grassland and grazing livestock researchers. Each of the seven components require different knowledge and skills, but all those engaged in this work should now have a better idea of what others are doing and why. Our Chinese colleagues had very few of these diverse skills when the program started. They are now confident about collaborating in multidisciplinary teams and using these techniques effectively. Typically, in China, collaboration among groups has been very limited. Collectively, the groups involved in this program are viewed as the leading grassland scientists in China. The success of this work means that they will continue a systems approach into the future.

The ability to do systems research means that more appropriate solutions to real problems are likely to be found. In this program, considerable knowledge was advanced about the intensity of grazing and how that related to grassland condition and animal production, through surveys, experiments and modelling. From that knowledge, management rules were developed about the level of herbage mass and other criteria that could be used to determine sustainable stocking rates. But, as shown in the farm surveys, to achieve the benefits of reduced stocking rates for households and for grasslands, it was important to ensure that markets were developed to properly reflect the quantities and qualities of livestock products that consumers wanted, and for herders to receive training in better management practices. When all system components are in place, stocking rates were significantly reduced and herder incomes increased.

This program has shown that stocking rates across the grasslands of northern and western China can be reduced by up to 50% while maintaining or increasing herder household incomes. This has real benefits for maintaining a desirable botanical composition and reducing the risk of soil erosion. A 50% reduction in stocking rates was further justified by an analysis of historical livestock numbers from farm surveys and farm demonstrations.

A key concept coming from this work is the benefit of focusing on livestock productivity per head rather than on livestock productivity per hectare. These two criteria are linked, but as shown in the farm data, they were not linked in practice to stocking rates (Chapter 4). In many countries, land is a more limiting resource and therefore productivity per hectare is commonly used to evaluate practice changes. However, herders have not traditionally thought of land as a constraint, nor about optimising stocking rates, though they have been conscious of productivity per head and can be trained to relate condition scoring to animal growth. We have shown how the optimum productivity per head and per hectare are linked. When productivity per head is about 75% of the potential possible for a grassland system, it will be close to maximising net incomes from livestock on the available land. Experiments and demonstrations need to be done in many regions to identify when animals over summer are about that optimum point. Around that point, the grassland herbage mass has to be higher than normally applies to enable high animal growth rates. This leads to better management of the grassland and reduced erosion risks, as the ground cover is higher. In addition, rather than using stocking rates to define the sustainable position, the analyses show that criteria can be set for the minimum average herbage mass that needs to be maintained over summer (e.g. > 0.5 t DM/ha for both the desert and typical steppes). Animals need to be moved before all the herbage is eaten. This is an easier criterion for herders to use. Managing optimum stocking rates is more difficult, as these continue to be a moving target within and between seasons, and this has not been traditionally done. In addition, a start has been made on defining sustainable levels of grassland consumption by livestock. The sustainable consumption level was 10% for the desert steppe and 20% for the typical steppe. Defining those limits enables researchers and officials to better estimate the sustainable stocking rates. Current methods used for those calculations result in overgrazing. These low values for consumption rates are different to what is often called utilisation, as that is determined by a different technique. All these criteria need to be defined for the major grasslands of China.

The methods devised to analyse the datasets obtained and identify optimal management practices are new and not common in the literature (e.g. decision trees to classify farms from survey data and various graphical methods to show interactions clearly). Wider use of these techniques makes it easier to understand how the system functions. The list of publications in Appendix 2 details the many studies done.

Environmental

A central focus of this program has been to rehabilitate grasslands to reduce adverse environmental impacts. Dust storms across northern China, Korea and Japan are common in spring and their frequency is much higher than in previous centuries. Beijing and many other large cities are affected by these dust storms. Dust storms cannot be completely eliminated, as the grassland areas include the Gobi and other deserts where annual precipitation is only 50 mm and areas such as the desert steppe can never achieve 100% ground cover. However, by reducing grazing pressures and allowing the grasslands to regrow, the frequency and intensity of dust storms can be reduced, as shown with the modelling (Chapter 6). Our research has shown that the average herbage mass on the grasslands needs to be higher to improve animal production, maintain a desirable species composition and reduce the risk of soil erosion (Chapter 10). Associated benefits with extensive application of the practices developed in this program would also mean that silt in the Yellow River would be reduced. The Yellow River is the mother river of China. Civilisation and the first development of agriculture is considered to have occurred along its course, initially in Gansu. The Yellow River starts on the Qinghai–Tibetan Plateau and nearly half the water in the river comes from the Gannan in Gansu, where we have been working with the Tibetan communities to better manage the grasslands.

Economic

The changes in practice that have come out of this program are enabling improved incomes for herder households. Most herders are interested in meat production. Net incomes increase as stocking rates decline through higher growth rates of individual animals, faster turn-off to markets and nil or limited carryover of livestock destined for meat markets between years. As productivity per animal increases, there is less wastage and a higher price paid by traders. In Siziwang, herders have established a very effective system where lambs are better fed, weaned early and go to feedlots then to abattoirs and hot-pot restaurants in Beijing, resulting in higher incomes (Chapter 4). Previously, there were many traders in the system and no one made much money. In Siziwang, herders with 200 sheep have better incomes than those in neighbouring areas or in nearby Mongolia, where practices are still traditional, prices are less and herders believe they need 800 sheep to be viable.

An indication of the financial benefits from the work reported in this monograph can be estimated from a 2010 survey of approximately 1,200 herder households across the six main grassland types (Chapter 5). Decision trees were used to classify the households within each grassland type, using net income/SE as the dependent variable. An average of five groups were formed in each case. The median group had an average net income from livestock of approximately A$5,000 per household (A$2.74 per capita per day). The next highest group were starting to employ the recommended practices of lower stocking rates, better selection of animals, better feeding practices, more warm sheds, better marketing etc., and their net income more than doubled to approximately A$11,400 per household (A$6.24 per capita per day). There are 16 million herders across China who are dependent upon grasslands. If 1 million of them (6%) achieved this increased income, the total net benefit would be A$1,277,500,000 (2010 prices). Given recent market developments, we would anticipate returns and higher adoption rates.

Community

In 2004, when this program formally started after three years of planning, the concern was that herders could no longer exist on the grassland as their incomes were too low, the grasslands were in a degraded state and their children saw no future in the grasslands. With the changes in practice that have come out of our program, along with the additional details resolved by herders, officials, researchers and others involved in the value-chain for livestock, we have shown that herder household incomes can be improved while restoring the grasslands and that the next generation of herders will have a future. Older herders are now retiring and renting their land to others, which results in more viable farms. We showed there is a strong relationship between farm size and stocking rate, so as farms get larger the stocking rate is likely to naturally decline, in line with national goals. Those herders who are now getting higher incomes are able to ensure their children get a better education.

Across the various study villages, the largest impact has been at Siziwang on the desert steppe in IMAR. In this village, some 2,000 households have reduced their flock numbers to 40% of previous levels (Chapter 2) are now focused on production. They have changed the way animals are produced, use feedlots to finish lambs and have a more efficient market system where they now obtain much higher prices than those in neighbouring districts. The local grasslands are also now in better condition and household incomes have increased. These results arose from a combination of a willingness to try new ideas, many discussions about options, backed by modelled results of those options and farm scale demonstrations of benefits, and visits to Australia by herders and local officials to better understand the ideas we talked about. A dynamic village leader, keen local officials, energetic university staff and a commercial company evolved system improvements including targeted government funds, feedlots and streamlined higher-value markets so that benefits could be delivered. System studies are the best approach for solving these problems.

Capacity building

Our 'learning while doing' capacity building and training had three objectives:

- advance the quality and focus of grassland science done by researchers and students
- achieve adoption of improved management practices by small herder households
- show officials better methods of managing grasslands while improving herder household incomes.

Across the five Chinese groups involved in this program, we have had a major impact on the way grassland research is done in China. Previously, most grassland scientists worked within a narrow field, as did animal scientists, ecologists, economists and policy advisers. They mainly aimed to describe their results, not evaluate principles or mechanisms. This created many problems, as data was often incompatible between disciplines (e.g. ecologists collected detailed data on species frequency and not on biomass, which is what animals eat). Similar problems occur in Australia. We have taken a systems approach, as outlined earlier, and helped various groups to appreciate how components interact. Each of our university partners now incorporate systems thinking into their teaching. This integrated approach meant that collaborators were more successful at convincing authorities to fund programs (China has provided A$54 million for 13 projects associated with this program). There is now a clearer understanding of pathways for improving grasslands by reducing livestock numbers while improving household incomes.

Many Chinese staff members involved in this project have continually sought our assistance in design, developing methodologies, analyses and writing their research. That has meant we improved the results from their research, got more data of value for understanding the grassland–livestock system, developed the functions needed for the models and published more papers in international journals (Appendix 2).

We planned to work closely with Chinese postgraduate students and that has happened to a reasonable extent. China follows the US system of coursework and a small research project for a PhD program. The Australian group has been involved in student programs. In China, PhDs are not awarded until a paper is published in a refereed journal and this is where students realised how much help they required. Unfortunately, in several cases, the research was designed or implemented locally, without help from the team. This meant much of the work done was helping the students find the useful pieces of information in their data and writing papers that would be accepted by journals. That is a harder task, but the outcome is arguably better research experiences for the student. The next generation of grassland scientists in China have now had considerable exposure to international scientists and the quality of their future work should be better. Details of the work done with students and their publications are presented in Chapter 11.

In the case study villages in Gansu and IMAR, we aimed to help herders shift from their traditional survival practices to a mode of production. More households were involved in this work in IMAR, where we held regular training sessions on animal nutrition during winter, use of warm sheds and monitoring animal condition, which they implemented on their farms. We have produced a 'train the trainer' manual on livestock management for use by officials. Farm surveys are showing that herder incomes have risen considerably above what they were a decade ago, indicating that these training sessions have helped. A lot of the training included presenting results from this program to herders and local officials (Chapter 11). There are now more herders thinking about livestock as a production business than when this program started.

Social

The herders on the grassland are among the poorest groups in China. As a result of this program and the related activities, they consider they have a future. The Chinese Government puts A$2 billion a year into their grassland programs, much of which is concerned with poverty alleviation. This includes some of the funds that support projects associated with this program. Previously some officials considered the only solution might be to abandon all grazing. There is now an appreciation that better management of the grassland–livestock system can achieve improved household incomes and improve the grasslands. Instead of grazing bans, we have shown that reduced stocking rates can sustain incomes and help rehabilitate the grasslands. The government is spending significant funds in grassland areas on improving roads, communications and services, indicating that they see these regions have a future. Where we have been working, the local communities are more viable. Some herders now rent their land to others, which improves the efficiency of livestock production. They stay in their houses and earn rent alongside other income, and remain part of the community. However, it is likely that the rural-based populations on grasslands will decline over time if alternative employment opportunities do not evolve.

Policy

Through this project we have maintained contact with officials across the six layers of government in China, aiming to keep them informed of our results. During 2017, we made formal presentations to the national, Gansu and IMAR governments on the major outcomes from our work. We know from the earlier project that they have incorporated some early general ideas into their policies and programs, notably the emphasis on maintaining a balance between feed supply and animal demand. We have been discussing the results that show that grazing bans do not always work. Grazing bans are a central part of their grassland program and compensation is paid. Grazing bans can be a complete ban for five years or a partial ban in early summer, designed to increase early pasture growth and total growth over summer. We have found that on the desert steppe (250 mm precipitation), light grazing achieves as good an outcome for the grassland plant community as a grazing ban, but it takes eight years before useful effects appear. The typical grazing bans of five years, achieved little of value. In addition, heavy grazing in winter may be needed once every five years to pressure the less-desirable species and give more desirable plants a chance to become dominant. Current policies need some reconsideration. A series of policy briefs (Appendix 1) were prepared and presented to national, provincial and county officials at national workshops and meetings in IMAR and Beijing in 2017 and in Tibet in 2018.

Summary

Key outcomes from the program reported in this monograph are the need for a stronger focus on livestock production per head as the primary criteria for managing livestock, using critical values for the herbage mass to manage grasslands, and identifying targets for production that align with better environmental and financial outcomes, using modelling tools that are simpler to calibrate to investigate contrasting management options.

Main conclusions and policy recommendations

There is a clear need to redefine and reorganise the livestock enterprises within each district to identify the sustainable stocking rates that improve and then maintain the grasslands. A 50% reduction in stocking rates from the levels of the early 2000s is realistic in many of the regions studied. Even lower reductions could be more profitable, as shown by modelling. Precision livestock management should be used to select and retain the better animals and improve their productivity, instead of allowing traders to take the best animals. This is the preferable way to reduce stocking rates, as the remaining livestock will be more productive and the sale of culled livestock provides cash to finance fodder purchases and better livestock genetics. To achieve the full benefits of stock reductions, there is a need to improve the fodder supply for livestock, especially through winter, to make better use of warm sheds and improve the genetics of livestock. The new *StageTHREE* model enables much better evaluation of the options available to herders and better defines the outcomes for grasslands.

Grazing of grasslands is best restricted to summer, as severe damage can be done by grazing in winter, affecting growth in the next year and accentuating weight loss from animals. Emphasis needs to be on monitoring, and improving the efficiency of livestock production per head rather than per hectare, as herders more readily understand the former. Over summer, aiming for production per head levels around 75% of the potential will get close to the economic optimum and increase herder household incomes, while also enabling higher levels of herbage mass and lower grassland consumption rates. Ongoing work is needed to define sustainable consumption rates for the grasslands as well as the average minimum critical values for herbage mass that should apply to each grassland type. Stocking rates derived from these perspectives are better defined as SE grazing days over summer, as that enables more flexibility in management. Current methods of calculating stocking rates overestimate what is sustainable and are more relevant to livestock survival than production.

Livestock lose less weight over winter if they are kept in sheds. A program of continuing improvement in shed design and management is needed. Typical feeding regimes in winter mean that animals start to lose weight at temperatures below 5 °C, higher than would apply to well-fed livestock. Weight loss in sheds is less than occurs when animals are taken out to graze through winter.

Critical for the success of reorganised livestock systems is the need to develop markets where herders receive prices that better reflect demand from the end consumer. Marketing chains can be very long, with many traders involved. Farmer associations are one mechanism being promoted by the government that can improve marketing and prices.

Herders are very skilful at managing survival of their animals through very tough seasons, but their skills in production are less well developed. As a consequence, they receive low prices for animals and their products. Training programs need to focus on how best to move from survival to production, and how to develop a business approach to their livestock enterprise. Training should include ways of financing change. At present, herders rely annually on bank loans, which means they are in perpetual debt. Culling unproductive animals can provide cash for improving productivity.

Farm surveys showed large differences between herders in all regions, in terms of the profitability of their livestock. This was a clear indication that within the present livestock production system there are opportunities for herders to improve their incomes. This supports the argument that the existing system can be reorganised, rather than requiring a set of completely new conditions. Net profit per head from livestock was not related to stocking rates, supporting the view that productivity per head should be the focus of management.

Models were developed that enable a staged analysis of options for improving grasslands and livestock, then for investigating longer-term sustainability issues. Calibrated models have been confirmed by comparisons with data from experiments and farm surveys. The sustainable stocking rates estimated by models confirm the benefits of a 50% reduction, which was confirmed in farm demonstrations.

Government reforms of agriculture and grasslands are continuing. There are clear needs to revise land tenure arrangements, as the evidence from surveys is that land rented from neighbours is used for summer grazing and is overgrazed. Herders do reduce stocking rates if they have more land, but they need incentives to manage rented land better.

Payments to herders for short-term or complete grazing bans are not working as desired. Grazing experiments showed that grazing at sustainable stocking rates helps manage the botanical composition and herbage mass just as well as no grazing, while sustaining net incomes. Light grazing is a better strategy.

References

Kemp, DR & Michalk DL (eds) 2011, *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra.

Professor Kemp being congratulated on receiving the Friendship Award by Chinese Premier Li Keqiang in the Great Hall of the People in Beijing. This award is the highest given to foreign experts working in China. The award was for the program's contribution to development in pastoral areas and followed other awards in IMAR and Gansu.

International workshop held in Hohhot to bring together the people working on the problems of the Mongolian Plateau. This workshop is now an annual event, carrying on much of the work started in the ACIAR Chinese Sustainable Grasslands Program. Photo: Han G.D.

Appendix 1: Policy advisory briefs

Policy Advisory Brief: ACIAR Sustainable Chinese Grasslands Program

Sustainable Chinese Grasslands Program

ACIAR has funded a program with other Australian and Chinese agencies since 2004 to investigate ways of improving the degraded grasslands of northern and western China and improving herder household incomes. ACIAR projects have had the core roles of system analysis, modelling and connecting other work being done by Chinese collaborators. The Chinese governments, at national and provincial levels, have funded an extensive series of national and local research projects designed to investigate various aspects of grassland improvement and herder livelihoods.

This document brings together in convenient summaries, information and the key outcomes of this large program that we consider are relevant to policymakers as they develop their plans, with recommendations for system improvements. In these topics, we have summarised the current state of knowledge. The main understanding and recommendations are highlighted in boxed text. Because there have been regular discussions with officials and herders, many of the recommendations in these policy briefs are already being adopted in some districts, while others still work in traditional ways. There are many other results from this program that have vastly improved our understanding of grassland livestock farming systems. Those results can be found in the many publications our team members have produced, many of which are listed in a separate document.

The policy advisory briefs presented in this document are part of an integrated package. The policy briefs need to be considered as a group, and then strategies developed to deliver them in ways that maximise benefits to herders, the grasslands and China.

The broad policy goal is to:

Improve and maintain the grassland environment while improving herder livelihoods to deliver the best social outcomes.

The policy briefs to deliver this goal outline the key issues to:

- better define sustainable stocking rates to rehabilitate degraded grasslands, improve incomes and improve environmental outcomes
- use precision livestock management to improve herder household incomes and reduce stocking rates
- train herders to move from a survival to a production focus and to benefit from the market economy.

For further information, please contact the key personnel listed in this document.

David Kemp
Project Leader
June 2018

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If you require more detailed information, please contact the leaders listed below.

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Further information

Briske, DD, Zhao, M, Han, G, Xiu, C, Kemp, DR, Willms, W, Havstad, K, Kang, L, Wang, Z, Wu, J, Han, X & Bai, Y 2015, 'Strategies to alleviate poverty and grassland degradation in Inner Mongolia: intensification vs production efficiency of livestock systems', *Journal of Environmental Management*, vol. 152c, pp. 177–182.

Jones, RJ & Sandland, RL 1974, 'The relation between animal gain and stocking rate: derivation of the relation from the results of grazing trials', *The Journal of Agricultural Science*, vol. 83(2), pp. 335–342.

Kemp, DR & Michalk DL (eds) 2011, *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, p. 189.

Kemp, DR, Han, GD, Hou, XY, Michalk, DL, Hou, FJ, Wu, JP & Zhang, YJ 2013, 'Innovative grassland management systems for environmental and livelihood benefits', *Proceedings of the National Academy of Sciences of the United States of America*, vol. 110 (21), pp. 8369–8374, doi: 10.1073/pnas.1208063110.

Kemp, DR, Han, GD, Hou, FJ, Hou, XY, Li, ZG, Sun, Y, Wang, ZW, Wu, JP, Zhang, XQ, Zhang, YJ & Gong, XY 2018, 'Sustainable management of Chinese grasslands: issues and knowledge', *Frontiers of Agricultural Science and Engineering*, vol. 5, pp. 9–23, doi: 10.15302/J-FASE-2018204.

Li, ZG, Han, GD, Zhao, ML, Wang, J, Wang, ZW & Kemp, DR 2015, 'Identifying management strategies to improve sustainability and household income for herders on the desert steppe in Inner Mongolia, China', *Agricultural Systems*, vol. 132, pp. 62–72, doi: 10.1016/j.agsy.2014.08.011.

Neidhardt, R, Grell, H, Schrecke, W & Jakob, H 1996, 'Sustainable livestock farming in east Africa', *Animal Research and Development*, vol. 43/44, pp. 45–53.

Yang, B, Wu, JP, Yang, L, Gong, XY, Kemp, DR, Feng, MT & Sun, L 2012, 'Establishing precision management techniques for sheep and feed balance research in pastoral areas', *Acta Agrestia Sinica*, vol. 20(3), pp. 589–596.

Zhang, YJ, Huang, D, Badgery, WB, Kemp, DR, Chen, WQ, Wang, XY & Liu, N 2015, 'Reduced grazing pressure delivers production and environmental benefits for the typical steppe of north China', *Scientific Reports*, 5, doi: 10.1038/srep16434.

Policy Advisory Brief: ACIAR Sustainable Chinese Grasslands Program

Sustainable stocking rates for grasslands and incomes

Livestock numbers across China have increased fourfold since 1950 and are widely acknowledged by authorities to be the main cause of grassland degradation.

- Sustainable stocking rates (SSRs) are often half that currently used by herders in China. SSRs are more profitable than current stocking rates, do not reduce animal production or household incomes and can maintain grasslands as well as a grazing ban.
  - Calculations using estimated utilisation rates can seriously overestimate SSR.
  - SSRs, managed flexibly, rehabilitate grasslands as effectively as grazing bans.
- Best grassland management is not to graze below the critical amounts of herbage mass that retain desirable species and ground cover.
  - ASRs can be flexible when managing to the critical herbage mass.
  - Herbage mass can be monitored by herders, officials and remote sensing.
- Best practice is to only graze grasslands in summer, when they are green.
  - Winter grazing can reduce grassland growth by 50% in the next summer.
  - Animal production is better in winter when animals are in a warm shed and not grazed.
  - Desirable species benefit from grazing rests.
  - Less-desirable species are suppressed by heavier grazing.
- It will not be possible to restore the best plant species to all grasslands. In most cases, herders need to work with what they have got and optimise those species.

* This policy advisory brief was produced by the Sustainable Chinese Grasslands Program team. The views expressed are their own and are based on their research and knowledge at the time. Please discuss this further with them and acknowledge their work.

Chinese livestock numbers

Total livestock numbers in China grazing grasslands have risen dramatically since 1950 (Figure A1.1).

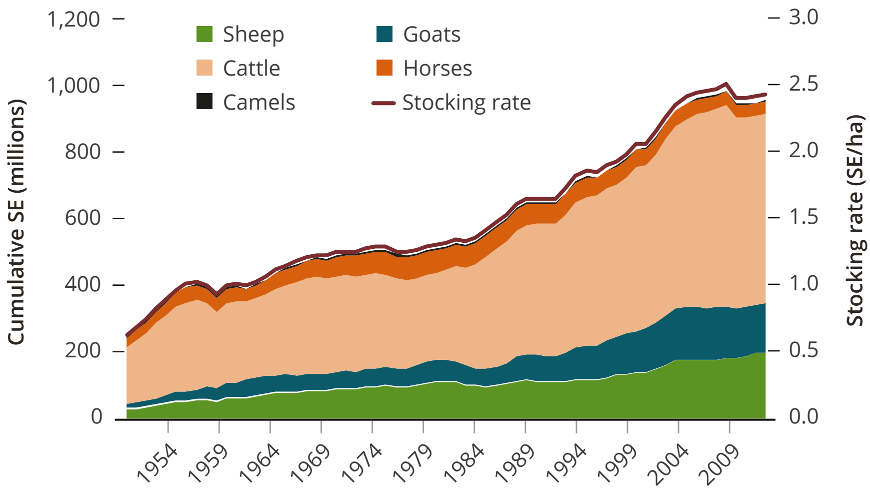

Figure A1.1 Cumulative SE and standardised stocking rate (SE/ha), China, 1950–2014
Source: FAOSTAT

The average stocking rate has risen fourfold from 0.6 SE/ha in 1950 to 2.4 SE/ha in 2014. China now has about 1 billion SE.

These changes had four general phases. From 1950 to 1957, there was a steep increase as the country recovered, then a slower rate of change from 1958 to 1984, followed by a rapid increase when the responsibility system was introduced. Since 2008, there has been a slight decrease in numbers. In some regions the increase in SE has been sixfold. Opinions often consider the period 1958–84 as being sustainable, suggesting that current stocking rates are on average twice what is the long-term capacity of the grasslands.

Herders will typically consider their ideal number of animals to be the maximum they can manage and keep alive through winter. This is rarely the number of animals that produce the highest household net income. The period after 1984, when herders started to be allocated individual areas of grassland and believed they could manage more animals, led to the current level of overgrazing.

Animal production and stocking rates

Animal growth rates (meat, fibre, milk) often have a linear decline with increasing stocking rates (Figure A1.2). This linear decline was evident over summer in grazing experiments done in IMAR and Gansu. Animal production per hectare is calculated from production per head and this shows a curved relationship. Typically, in China, many flocks and herds are around point B, but economic analyses show that maximum net income per hectare would apply at point A. Point B has the same animal production per hectare as point A, but the stocking rate is three times larger and the growth rate per head is one third that of point A. The consequence of this slower animal production is that lambs and calves would take three times longer to reach marketable weights, resulting in more animals on the grassland for much longer.

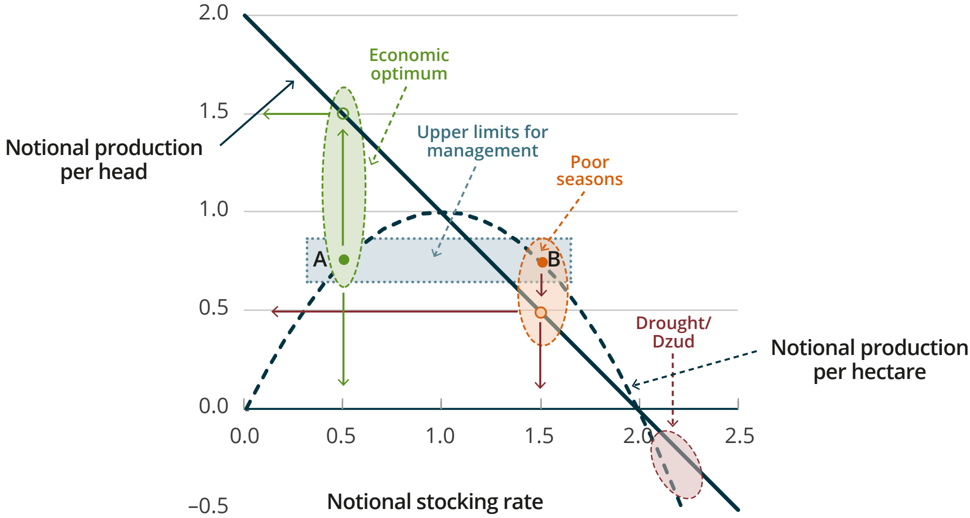

Figure A1.2 Basic animal production relationships between stocking rate, production per head and production per hectare

These curves are relative to the current seasonal conditions, but the general patterns remain the same. The general rule that emerges is that if animal production per head is about 75% of the maximum that could be expected for the grassland at that time, the stocking rate is close to the economic optimum.

Farm demonstrations in IMAR showed that reduced stocking rates on farms that then fed the animals better resulted in higher net incomes (Figure A1.3). Only when the stocking rate reductions of demonstration farms declined to 50% of the control farms were the net incomes per farm similar. When ecological considerations indicate a 50% reduction is needed, this can be done within the present systems in ways that do not affect herder incomes.

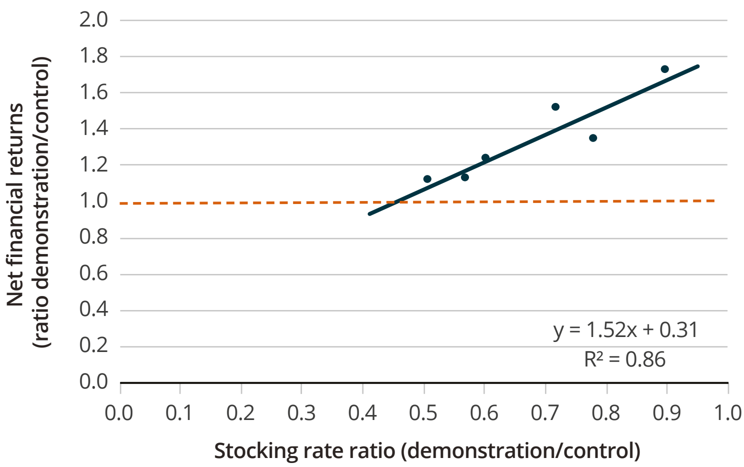

Figure A1.3 Net financial returns and stocking rate ration for demonstration/control farms in six regions in IMAR, 2013

Note: The dashed horizontal line shows where the net income of demonstration and control farms were equal.

Stocking rate impacts are affected by the livestock enterprise. Breeding animals require more food than non-breeding and the effect of this on grasslands depends upon breeding cycles. In some districts, the effective stocking rate can be reduced by changing the type of livestock enterprise, the annual livestock management calendar and how young animals are managed.

Herbage mass

Animal production growth rates around 75% of the potential requires green grassland with herbage mass above 1 t DM/ha. If the grassland is short, animal growth rates are much lower.

The first sign of grassland degradation is a shift in species to less-desirable species. Reducing grazing pressure gives desirable species a chance of recovering within the grassland.

The herbage mass of the grassland is correlated with the plant species composition. In a grazing experiment on the typical steppe in Hebei, the herbage mass had to be maintained above 0.5 t DM/ha to maintain a high proportion of the desirable grass (*Leymus chinensis*) and a low proportion of the less-desirable shrub (*Artemisia frigida*). On the degraded grassland of the desert steppe in IMAR, a herbage mass above 0.5 t DM/ha maintained a balance between the more-desirable shrub (*Artemisia frigida*) and the less-desirable grass (*Stipa breviflora*). For the higher rainfall meadow steppe, it is proposed that the minimum herbage mass that should be maintained over summer is 1.5 t DM/ha.

The level of herbage mass that sustains a desirable grassland condition, and cover to reduce soil erosion, is similar to that required to optimise animal production and herder incomes. Defining critical values for herbage mass over summer gives herders a better management guideline than a rigid stocking rate. Herbage mass measures the balance between grassland supply and animal demand. Stocking rates can be flexible using this approach. Herders can be trained to estimate the critical herbage mass values.

Flexible stocking rates can be defined in ways that help herders adjust to changing circumstances. SE grazing days/ha over summer gives a better measure than SE/ha. Experiments on the desert steppe found that the sustainable SE grazing days/ha was 100, while on the typical steppe the critical level was 400. Experiments showed that grasslands managed with a sustainable stocking rate had a similar plant composition to those where a grazing ban had applied. However, the grazed plots did provide an income for herders.

Critical herbage mass values can also be used to define when grazing can commence in summer. At present this is defined by a calendar date, but that does not work in dry years.

Livestock consumption estimates

Grazing experiments are the best way to define SSRs, though these have also been estimated using a common formula that requires an estimate of the percentage of grassland that animals can sustainably utilise.

An analysis of this formula found that using the standard rates of grassland utilisation resulted in stocking rates that were up to twice that which experiments found sustainable. Utilisation rates are typically derived from a comparison of grazed and ungrazed areas in a field, when often 50% of that difference is due to losses not due to livestock consumption. Better results are obtained if utilisation is defined as the actual direct consumption rates of forage by livestock at the experimentally derived sustainable stocking rate. This can be estimated from models.

Experiments found that, on the desert steppe, the sustainable summer consumption rate was 10% of the forage grown over summer. On the typical steppe the rate was 20% and estimates for the meadow steppe were 30%.

Winter grazing

In winter, animals typically lose 20–30% of their liveweight, with an increasing linear decline as stocking rates increase. An analysis of a grazing experiment in eastern Gansu found that the grassland herbage mass in autumn was, at best, only half of that required for animals to maintain their liveweight. Heavy stocking rates in winter on the desert steppe in IMAR reduced grassland growth in the next summer by more than 50%. Animal lose less weight if they are kept in sheds through winter.

In an experiment in IMAR, ewes fed a better ration than normal lost weight when the temperatures declined below 5 °C. Weight loss increased as temperatures declined further. Growth rates in lambs reduced as the weight loss in their mothers increased. Warm sheds reduced weight loss compared to traditional sheds.

Herders should aim to minimise the number of animals they have to manage in winter, keep their animals in well-designed warm sheds and provide better-quality fodder.

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Precision livestock management for incomes and grasslands

- Selection and improved management of the better animals on a farm will increase herder incomes while reducing the number of animals on grasslands:
  - select which animals to keep based on net income for each animal
  - sell the least-profitable animals (reducing stocking rates) and use the money obtained to purchase better-quality animals and higher-quality fodder to feed all animals in winter.
- Herders need training in precision livestock management:
  - use objective measurement, not appearance, to improve birth rates and meat, milk and fibre production
  - manage and feed all animals better through winter
  - design, build, modify and manage warm sheds to maintain warmth and minimise disease
  - improve feeding practices and understand the energy value of fodder.

Select better animals

Surveys of herder flocks have found some animals with no teeth and no functioning udders. Traders buy the best animals and, over time, the productivity of the remaining animals declines. Lambing and calving rates are well below what is possible, as are the growth rates of all livestock. Flocks and herds are only renewed after disasters such as a snow emergency. These patterns are similar to wild animal populations, rather than well-managed flocks. Increasing animal numbers is not the best way to improve herder incomes. The focus should be on improving the net income from animal products.

A model was developed using age, body, teeth and udder condition as well as liveweight to predict the productivity (as net income) of each animal. All animals were ranked from best to worst net income against the cumulative net income from livestock (Figure A1.4). The total net income from livestock on the farm is shown at point A.

* This policy advisory brief was produced by the Sustainable Chinese Grasslands Program team. The views expressed are their own and are based on their research and knowledge at the time. Please discuss this further with them and acknowledge their work.

The decline in net income from livestock over the 50 or so least-productive animals is clearly evident. These low-performing animals cost more than they earn in income. Point B has the same net income from livestock as the whole farm, but this is achieved with fewer animals.

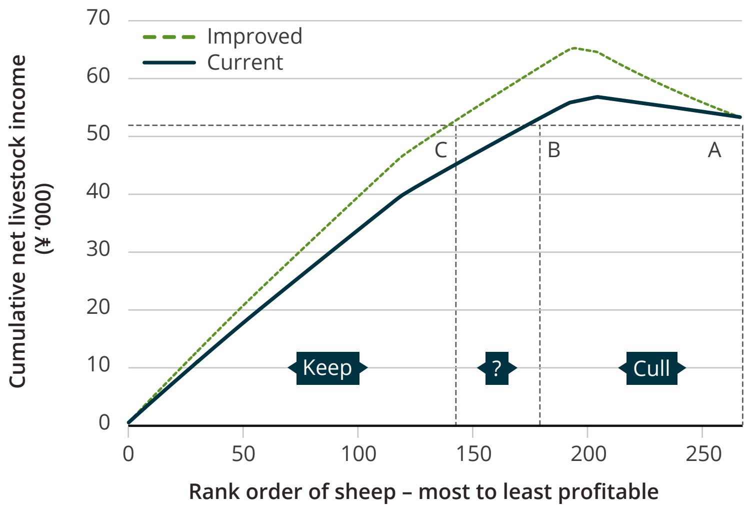

Figure A1.4 Ranking of net income (gross margin) per sheep on a demonstration fine-wool sheep farm, Gansu

The animals between points A and B are the first group to cull. Fewer animals means more grassland and more fodder per head for the remaining animals. The dashed line estimates the effect of that extra food on animal productivity. Point C generates the same net income as points A and B, so the animals below point C are the main group to keep. Between points B and C is a group of animals that may or may not be kept, depending upon their age and condition.

These relationships show another mechanism whereby animal numbers can be reduced without affecting herder net incomes that would add further benefits to those obtained by reducing stocking rates (see policy advisory note on SSRs).

This modelling is based on an analysis of typical flocks, or herds, but additional gains could be made by more objective selection of animals for meat, fibre or milk production, introduction of better genetics and improved feeding practices. The aim is to produce more of the quality animal products wanted by markets.

Herders have a limited number of animals that they can physically manage, so it is important that they maximise the net income from those animals. They need training in the skills required to achieve this, including business skills.

Manage animals better

Herders have great skills for surviving in a difficult climate. Their animals survive through long periods with limited food and very low temperatures. But to obtain the income they need for education, health care, household goods, vehicles, etc., herders need to learn the skills of managing animals for production within a business framework. There are many aspects of animal production that need improvement.

The primary issue is to select for and control the breeding of better-quality animals, as discussed above. Those animals then need to be better fed and managed to minimise weight loss. Herders often have a poor understanding of the relative merits of quantity and quality of alternative supplementary food sources. None are used to calculating the cost per unit of energy.

Research is needed to develop the relationships between the condition score for animals and other measures of animal performance. While the international literature has useful information for sheep and cattle, there is no information for fat-tailed sheep, yaks or camels in China.

Animals can lose 5–10% of their body weight without that being obvious visually. This loss can only be identified by regular weighing of animals or monitoring of their condition score. Any weight loss means extra time to regain condition before animals can be marketed, and there are additional consequences for lambs and calves.

Traditional management calendars (when to mate, lamb, calve, market, etc.) have evolved over centuries as solutions to survival, within the limits of climate and other natural constraints. To improve the efficiencies of production where supplementary fodder, sheds, transport and more regular markets are available, traditional practices can change. Research is needed to assess those practices that can be usefully changed.

One example is lambing time, which in northern China has often been in mid winter. Modelling showed that lambing closer to the start of summer would better align the feed demand from animals with the feed supply. Farm demonstrations have shown that it is beneficial to change lambing times.

There is a clear need to focus on productivity per head, rather than assuming that maximising animal numbers will maximise net income. Modelling has shown that when animal production is around 75% of the maximum possible for the system at the time, net income per hectare and per farm is also maximised.

Warm sheds

Across northern and western China there is no grassland growth for 8–9 months and winter temperatures are severe. The impact of winter temperatures is often poorly understood. Herders often think that sheep, goats and cattle do not suffer. Herders are focused on the survival of animals, rather than production. Much work has been done over recent years on improving the shelters used for livestock in winter, but many herders still need training in how to build, modify and use sheds effectively.

Common problems with sheds are having too many animals with poor ventilation, making respiratory diseases common. Sheds are not adequately insulated to create a warmer environment and where supplementary heating is available, that is not used until temperatures are significantly below zero.

Animals that are very well fed and in a well-designed greenhouse or warm shed are less affected by the cold, but those practices are rare. More commonly, a modified old shed is used. One experiment compared a conventional shed with one modified to be warmer (Figure A1.5). The results showed that ewe and lamb growth rates started to decline when temperatures were below about 5 °C. In this experiment, the animals were fed a ration that provided more energy and protein than normal, but not enough to stop weight loss. The shed modifications did not improve ventilation and respiratory problems were common. The overlap of points between the warm and traditional sheds show the warm shed only had small benefits. Increasing weight loss by the ewes then resulted in reduced lamb growth rates.

Herders often argue that animals want to go outside. There is no evidence that this results in better animal production.

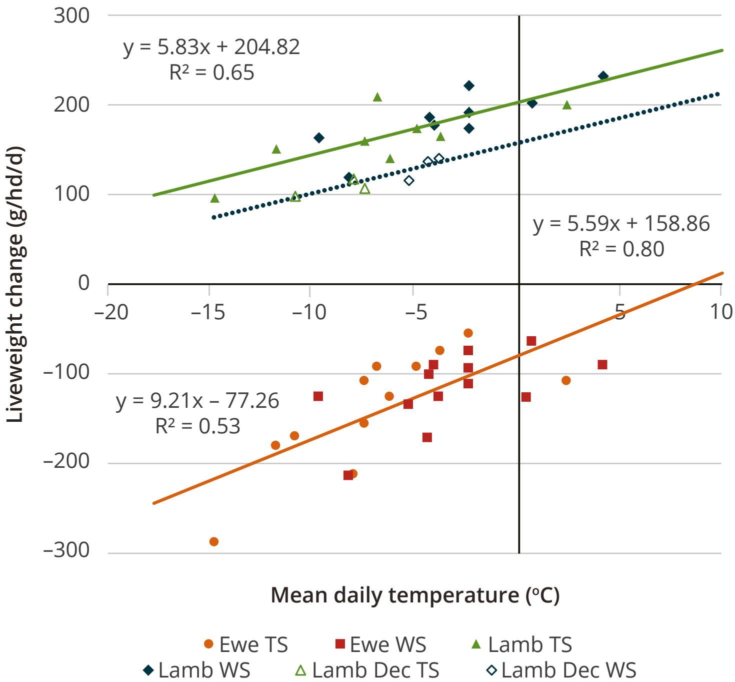

Figure A1.5 Relationship between daily lamb growth rates and ewe weight and mean daily temperatures in a traditional (TS) or warm (WS) shed

Note: The dotted line designates lambs in the first month after birth.

Source: Kemp et al. (2018)

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Herders from survival to production and benefiting from the market economy

- Herders need training to:
  - manage their farms as a business
  - use markets more effectively
  - change from managing their animals for survival to being efficient producers.
- Grassland improvements can occur when herders improve net income per head, rather than increasing animal numbers. Increased production per head requires lower stocking rates.
- Government assistance is required to improve markets by:
  - increasing market power of herders
  - streamlining the value-chain from herder to consumer
  - improving transparency in prices
  - ensuring that payments reflect both the quantity and quality of animal products.
- Finance to herders needs to be suitable for livestock production:
  - Loans should be structured to be paid back over the life of an animal, not within a year.
  - Loans should aim to increase livestock incomes, not be mainly for household survival.
  - Herders can initially self-finance some livestock improvements by selling unproductive animals.
- Land user rights need to be transferable to other herders for longer periods, not just rented annually. Herders should be responsible for managing the extra land sustainably. Land user rights should be an asset to help herders finance their livestock business.

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Herder development pathway

Traditional Chinese herders have an impressive amount of knowledge about how to survive in their tough environment. However, they are mostly in the early stages of a common development pathway (Figure A1.6).

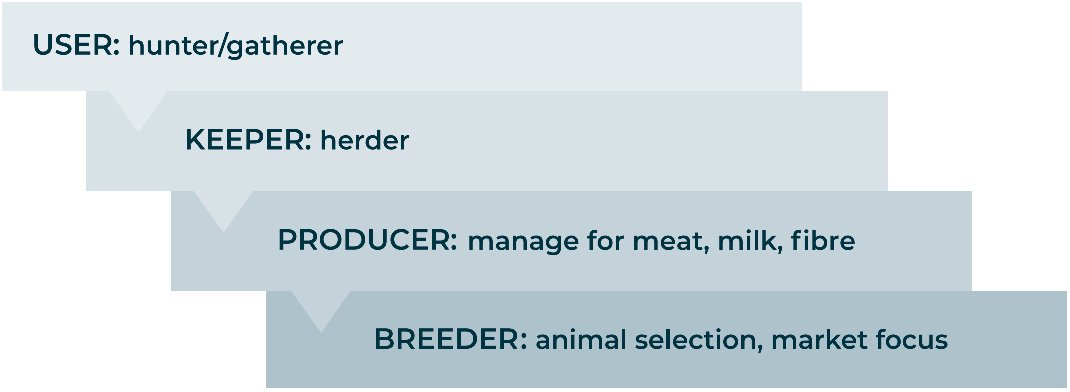


Figure A1.6 Herder development pathway

Traditional herders are keepers. Their management of livestock is minimal, supplementary feeding is usually only for animals that are not well and only a small surplus is sold each year. Animals are the household's 'bank' (assets) and the main measure of their status.

Today, many herders are becoming producers. They are engaging more in the developing markets of China and wish to increase their household incomes so they can acquire goods and services (e.g. education, health, phones, vehicles). To do this they need new skills.

Markets are developing in China that pay premiums for the quantity and quality of animal products. Animals are no longer all worth a similar price. Unfortunately, many herders are still price-takers, rather than price-makers.

To satisfy Chinese markets, herders need to learn more about optimising the quantities and qualities of what they produce with their animal. Simply increasing animal numbers on limited land is unlikely to increase net household incomes.

Herders need to be better trained in feed management, including the conservation and use of crop residues, the use of feedlots and the need to take advantage of government policies to improve sheds so they can deliver the quantity and quality of products that markets want.

A production focus is better for the grasslands. Optimising production of meat, milk, and fibre requires larger amounts of better-quality forage through the growing season and over the life of the animal. This is not possible with overgrazing.

Stocking rates can often be reduced by half across the degraded grasslands of China without reducing net household incomes. The system is feed-limited. Any reduction in stocking rates means more food per animal, leading to increased production per head.

There is a need to identify optimal systems (considering natural, social, human, production and financial factors) that improve outcomes for grasslands, herders and industries within different regions of China's grasslands and integrate them into modern markets. Herders will need to specialise more, producing what is best for them and their region (e.g. wool, cashmere, meat, milk, breeding young livestock, or specialised finishing). More herders will then become breeders.

Markets for grassland improvement

Markets are part of the grassland–livestock system, but traditional practices mean the markets have encouraged overgrazing and kept herder incomes low. What is a better strategy to rehabilitate degraded grasslands?

Much research has investigated the ecology of grasslands and provided recommendations for improvement, but those recommendations do not always consider costs, the likelihood that herders will accept them, or the benefits for animal production.

Markets need to be efficient and regular—but not daily. There should be fewer traders between herders and the ultimate consumers, improved transport systems, and payments need to account for the differences in quality and quantity of livestock and their products. Prices do not yet always reflect these aims.

Efficient markets that pay a premium for the quantity and quality of livestock products encourage herders to improve productivity per head and sell products that consumers want. Traditional practices encourage maximising the number of animals per hectare, producing low quality product and selling when the market is oversupplied.

Research has shown that an emphasis on production per head means that stocking rates need to be reduced to achieve improvements. This starts the process of grassland rehabilitation by enabling better growth of the grassland and reduced pressure on desirable species.

Efficient markets occur where many buyers and sellers meet and prices are known to all. This enables the best prices to be determined.

Market information services need to be improved so that herders can know the specifications for different animal products, and the time of the year and market locations where they will get the best prices.

Well-constructed farmer's associations, which local governments are encouraging, can train and empower herders in trading and marketing skills and develop recognisable branding in city markets.

Tourism markets can also play a part in grassland rehabilitation. Most tourists want to see extensive areas of grassland, rather than shrubs or bare ground. This can only be achieved by reducing stocking rates.

When urban residents know that dust storms can be reduced by lower stocking rates, they can be encouraged to pay premiums for livestock products from certified areas where district management plans are in place. Promotion of eco-labelling can help educate consumers.

Enabling markets to help support the process of grassland rehabilitation means that government payments can be better targeted to areas where problems are more severe, and herders can achieve the same or higher incomes while grassland improvement occurs.

Financing change

Herders on the grasslands of China are among the poorest people in China and they have very limited resources to improve their situation. The Chinese Government has several programs to help support the herders. These programs are evolving to develop sustainable outcomes.

Many herders borrow money from banks to support their households, but the terms of these loans rarely consider the economics or timeframes of livestock production. Loans are short-term (less than one year) and have high interest rates.

Loans for herders are similar to those for crops, where it is easier to repay the loan once the crop is harvested and sold. In contrast, the timeline for redesigning livestock production systems and obtaining a profit is several years, as the cost of an animal is not easily repaid within a year.

Grassland recovery can take 5–20 years depending upon the state of the grassland and the district. The full benefits of reduced stocking rates and improved animal production per head cannot be achieved within the term of normal bank loans.

Herders now appear to be perpetually in debt, having to borrow money each year to survive. Many are unable to develop their livestock enterprise and improve their household incomes. Finance needs to be for a business plan over the medium to longer-term with the ultimate goal of improving grasslands and household incomes.

Surveys indicate there are broadly two main groups of herders: those who wish to leave herding and move into a town or city, and those who would like to remain in herding and improve their household incomes. Herders who leave often rent their land to other herders, which provides some income. The herders who remain can use the principles outlined in these briefs to improve both their incomes and their grasslands.

In addition to more appropriate terms for loans for improving livestock production, there are opportunities for some self-financing of the changes needed.

Research has shown that when all the unproductive animals are sold (this is often half the flock or herd), the production from the remaining animals (mostly females) increases substantially and household incomes remain the same or increase. The variability of herder household incomes declines, increasing household security and resilience.

The money received from selling the least-productive animals can be used to purchase better-quality rams, bucks, bulls etc., and/or better-quality fodder for winter. This reduces the need to borrow money, improves production from the remaining animals, and increases household incomes.

Land tenure

The land in China is owned by the people, but various regulations and user rights have been developed so that herders are able to improve their livelihoods.

Herders have been moving from traditional survival practices based around providing food and shelter for their families where only a small amount of their livestock products were traded or sold, to being producers who manage their livestock enterprise as a business and increase the proportion of animal products for sale.

Some herders now prefer to rent their land to neighbours and seek work in cities or towns. In some districts, up to half of herders have done this, particularly where local authorities have assisted with housing and small areas of land to grow vegetables.

Herders who rent land from others typically use the rented land for summer grazing, but there is evidence that these lands tend to be overgrazed. Summer is the time of maximum animal numbers and the land is not theirs. Herders graze their own land more in winter, which aids grassland recovery. The incentive to manage rented land better is low as rent agreements are often only for a year.

Surveys are showing that as farm size increases, average stocking rate decreases (Figure A1.7). There is now less labour on farms and as farm size increases it is not as easy to utilise all the land as intensively as on a small farm. Lower stocking rates are important for grassland rehabilitation.

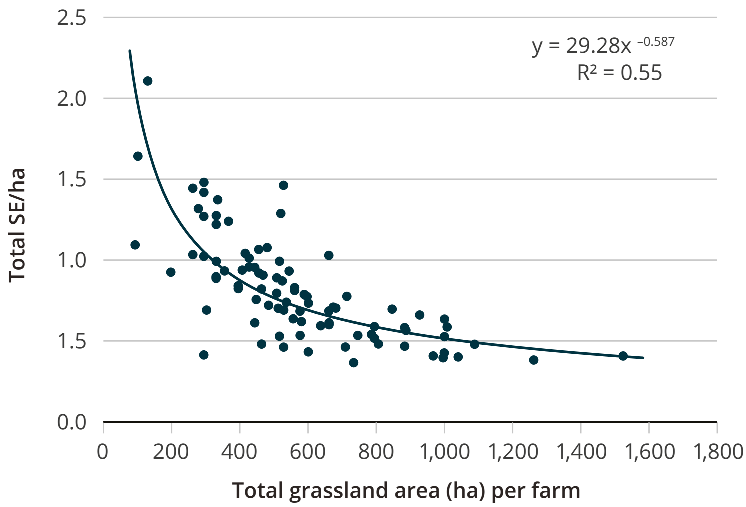


Figure A1.7 Grassland area and standardised stocking rate for 92 desert steppe farms, Siziwang, IMAR, 2012

These surveys may indicate that herders have the goal of owning an ideal number of animals more than having access to an ideal area of land. The ideal number of animals reflects their current needs to improve household incomes and the number of animals they consider they can manage effectively. Herders are defining stocking rates as the number of animals they would like to have, not as a stock density.

However, experience around the world shows that as herders become more efficient their ideal number of animals will increase (this also depends on the prices they receive for animal products). Policies need to allow for a continuing increase in farm size.

These trends all show that policies need to be developed so that herders who wish to remain in livestock production can expand their livestock enterprises in ways that are both profitable and sustainable. Initially this means that the herders who remain in livestock production need more land.

Changes in land use arrangements also need to allow herders to use that land as an asset to guarantee loans. The asset value could be the guaranteed rental value of the land. This would build the confidence of herders to improve their livestock enterprise, but not at the expense of the grassland.

Appendix 2:

Communications from the ACIAR Sustainable Chinese Grasslands Program 2010–18

David Kemp, David Michalk

This appendix lists the publications in books, journals, conferences, workshop and other communications that have come from the program and sorts them into four main categories. The 405 publications listed are those produced by the group that are relevant to the objectives of this program. Funding for all this work came from a variety of sources as noted earlier, hence the diversity of topics. Information from all these sources were used to understand the system and especially for developing the models. Some of the conference papers only exist as a presentation. This list is from 2010–18; earlier papers are in Kemp, DR & Michalk, DL 2011, *Development of Sustainable Livestock Systems on Grasslands in North-Western China, ACIAR Proceedings 134*, Australian Centre for International Agricultural Research, Canberra, p. 189.

Identifying improved enterprises/animal management strategies (147)

Amidy, MR, Behrendt, K & Badgery, WB 2017, 'Assessing the profitability of native pasture grazing systems: a stochastic whole-farm modelling approach', *Animal Production Science*, vol. 57(9), pp. 1859–1868.

Avery, A, Sargeant, K, Friend, M, Behrendt, R, Sanford, P, Beverly, C, Allan, C & Michalk, DL 2013, 'The role modelling and farming systems research can play in redesigning grazing systems for improved productivity and environmental sustainability', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 1846–1848.

Badgery, WB & Brown, W 2017, 'Foreword: Orange EverGraze proof site', *Animal Production Science*, vol. 57(9), pp. i–ii.

Badgery, WB, Cranney, P, Millar, GD, Mitchell, D & Behrendt, K 2012, 'Intensive rotational grazing can improve profitability and environmental outcomes', in Grassland Society of NSW, *Driving your landscape to success: managing a grazing business for profit in the agricultural landscape*, Proceedings of the 27th Annual Conference of the Grassland Society of NSW, 24–26 July 2012, Wagga Wagga, NSW.

Badgery, WB & Michalk DL 2017, 'Synthesis of system outcomes for a grazing-management experiment in temperate native pastures', *Animal Production Science*, vol. 57(9), pp. 1869–1876.

Badgery, WB, Millar, G, Broadfoot, K, Pottie, D, Simmons, AT & Cranney, P 2015, 'Grazing management options to boost productivity and secure healthy landscapes', in Grassland Society of NSW, *Making pastures pay*, Proceedings of the 29th Annual Conference of The Grassland Society of NSW, Goulburn, Australia.

Badgery, W, Millar, G, Broadfoot, K, Martin, J, Pottie, D, Simmons, A & Cranney, P 2017, 'Better management of intensive rotational grazing systems maintains pastures and improves animal performance', *Crop and Pasture Science*, vol. 68(12), pp. 1131–1140, doi: 10.10171/CP16396.

Badgery, WB, Millar, GD, Broadfoot, K, Michalk, DL, Cranney, P, Mitchell, D & van de Ven, R 2017, 'Increased production and cover in a variable native pasture following intensive grazing management', *Animal Production Science*, vol. 57(9), pp. 1812–1823.

Badgery, WB, Millar, GD, Michalk, DL, Cranney, P & Broadfoot, K 2017, 'The intensity of grazing management influences lamb production from native grassland', *Animal Production Science*, vol. 57(9), pp. 1837–1848.

Badgery, WB, Mitchell, D, Millar, GD, Broadfoot, K, Michalk, DL, Cranney, P & Brown, W 2017, 'Designing a grazing-system experiment for variable native pastures and flexible lamb-production systems', *Animal Production Science*, vol. 57(9), pp. 1785–1798.

Badgery, WB 2017, 'Longer rest periods for intensive rotational grazing limit diet quality of sheep without enhancing environmental benefits' *African Journal of Range & Forage Science*, vol. 34, pp. 99–109.

Bai, HH, Hou, XY, Bao, YL 2016, 'Analysis of the condition of snow disaster in the eastern margin of pastoral areas of Eurasian Temperate Grassland: a case study of typical areas in the eastern margin of Eurasian temperate grassland' [Chinese], *Chinese Journal of Grassland*, vol. 38(3), pp. 63–70.

Bai, WJ, Zhao, ML, Han, GD, Li, ZG & Chaoketu, W 2010, 'Effect on lactation ewe body condition to reproducing performance of household ranch in desert steppe', *Journal of Inner Mongolia Agricultural University (Natural Science Edition)*, vol. 1, pp. 47–50.

Behrendt, K, Cacho, O, Scott, JM & Jones, R 2013, 'Optimising pasture and grazing management decisions on the Cicerone Project farmlets over variable time horizons', *Animal Production Science*, vol. 53, pp. 796–805.

Behrendt, K, Scott, JM, Cacho, O & Jones, RE 2013, 'Simulating the impact of fertiliser strategies and prices on the economics of developing and managing the Cicerone Project farmlets under climatic uncertainty', *Animal Production Science*, vol. 53, pp. 806–816.

Behrendt, K & Weeks, P 2014, 'How are global and Australian beef and sheepmeat producers performing?', *Global agri benchmark network results 2014*, Meat & Livestock Australia Limited, Sydney, Australia.

—— 2017, 'How are global and Australian beef producers performing? *Global agri benchmark network results 2016*, Meat & Livestock Australia Limited, Sydney, Australia.

—— 2018, 'How are global and Australian sheepmeat producers performing? *Global agri benchmark network results 2017*, Meat & Livestock Australia Limited, Sydney, Australia.

Behrendt, K 2011, 'Integrating the management of pasture resource condition with production, profit and supplementary feeding to improve the sustainability of extensive grasslands under climatic uncertainty', *Proceedings of the First Meeting of China-Australia Network for Grassland Farming Systems*, Xinjiang, China, 16–19 August 2011.

—— 2013, 'Optimising management to achieve sustainable economic yields from grasslands', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 883–884.

Broadfoot, KM, Badgery, WB & Millar, GD 2017, 'Post-experimental modelling of grazing systems to improve profit and environmental outcomes using AusFarm', *Animal Production Science*, vol. 57(9). pp. 1849–1858.

Cahi, LR, Ma, QQ, Cheng, YX, Shen, B & Hou, FJ 2017, 'Effects of different grazing patterns on yak economic benefit', *China Science and Technology*, 2017–05.

Chen, A, Wu, JP, Zhou, CH & Tan, ZL 2015, 'Effects of C3 and C4 plants of roughage and concentrate to roughage ratio of substrate on in vitro ruminal fermentation characteristics of goats' [Chinese], *Journal of Animal Nutrition*, vol. 27(1), pp. 112–123.

Chen, JS, Zhu, RF, Xu, RX, Zhang, WJ, Yue, S & Zhang, YJ 2015, 'Evaluation of *Leymus chinensis* quality using near-infrared reflectance spectroscopy with three different statistical analyses', *Peer J*, vol. 3, e1416, doi: 10.7717/peerj.1416.

Chen, WQ, Huang, D, Liu, N, Zhang, YJ, Badgery, WB, Wang, XY & Shen, Y 2015, 'Improved grazing management may increase soil carbon sequestration in temperate steppe', *Scientific Reports*, 5, 10892, doi: 10.1038/srep10892.

Chen, WQ, Wang, XY, Zhang, YJ & Huang, D 2015, 'Effects of the vertical and horizontal availability of food resources: the diet selection of sheep grazing on natural grassland', *Journal of Agricultural Science*, vol. 153(2), pp. 322–334.

Chen, XJ, Hou, FJ, Matthew, C & He, XZ 2010, 'Stocking rate effects on metabolizable energy intake and grazing behaviour of Tan sheep in steppe grassland on the Loess Plateau of north-west China', *The Journal of Agricultural Science*, vol. 148, pp. 709–721.

Chen, ZF, Jia, PY, Yang, Y, Zhang, J, Xi, JL, Zhu, SS, Zhao, ML, Han, GD & Wang, CJ. 2012, 'Effects of grazing intensity on ecosystem gas exchange of different grassland types in Inner Mongolia' [Chinese], *Acta Agrestia Sinica*, 2012–03.

Cheng, SR, Pan, JF, Wang, JF & Wu, JP 2014, 'Polymorphism analysis of aemoglobin beta gene in yak' [Chinese], *Chinese Agricultural Science Bulletin*, vol. 30(32), pp. 1–5.

Cheng, YX, Sun, Y, Tsubo, M, Ito, TY & Hou, FJ 2013, 'Plant species diversity along a precipitation gradient in temperate grasslands of China and Mongolia', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 1697–1698.

Cox, F, Badgery, WB, Kemp, DR, Krebs, GL 2013, 'The development of a grazing rating index to identify the biomass removed and the plant species and parts eaten by grazing sheep', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia pp. 1101–1102.

—— 2017, 'Seasonal diet selection by ewes grazing within contrasting grazing systems', *Animal Production Science*, vol. 57(9), pp. 1824–1836.

Derner, JD, Hunt, L, Fiho, KE, Ritten, J & Han, GD 2017, 'Livestock production systems', in D Briske (ed.), *Rangeland systems: processes, management and challenges*, Springer Series on Environmental Management, Springer International Publishing, Cham, pp. 347–372.

Ding, WQ, Li, P, Yin, YT & Hou, XY 2015, 'Vulnerability of herder households under the framework of sustainable livelihoods in the grassland of Northern China' [Chinese], *Acta Prataculturae Sinica*, vol. 26(8), pp. 1–11.

Ding, Y, Niu, JM, Hou, XY, Zhang, Q, Wang, H & Yin, YT 2010, 'Differentiation in households' production in the view of sustainable development evaluation' [Chinese], *Pratacultural Science*, 2010–11.

Du, WC, Yan, T, Chang, SH, Wang, ZF & Hou, FJ 2017, 'Seasonal hogget grazing as a potential alternative grazing system for the Qinghai-Tibetan plateau: weight gain and animal behaviour under continuous or rotational grazing at high or low stocking rates', *The Rangeland Journal*, vol. 39, pp. 329–339.

Gao, P, Wang, WF, Chang, SH & Hou, FJ 2014, 'Livestock production features and development strategy in main ecological regions of north-west of China' [Chinese], *Pratacultural Science*, vol. 31, pp. 2316–2322.

Gao, XY & Hou, FJ 2011, 'Preliminary discussion of agricultural structure and economy from Qinghai Tibet to Loess Plateau: a case study of the transitional region of Xiahe-Weiyuan-Tongwei County' [Chinese], *Pratacultural Science*, vol. 28, pp. 1556–1560.

Guo, WJ, Zhang, Y, Li, XM, Zhang, LP, Zhang, CJ & Cheng, SR 2017, 'Impact of cold-season grazing and supplementary feeding on growth performance and biochemical indexes of Gansu alpine fine-wool sheep' [Chinese], *Journal of Gansu Agricultural University*, 2017–03.

Han, GD, Wang, ZW, Li, ZG, Zhao, ML, Kemp, DR, Michalk, DL & Havstad, KM 2013, 'Grassland rehabilitation through re-designing livestock management systems', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 1637–1642.

Han, GD, Zhao, ML, Li, ZG, Wang, ZW, Kemp, DR, Wilkes, A, Han, CW, Willms, WD & Havstad, K 2016, 'New way to manage grazing livestock system in degraded grassland based on system economics', in A Iwaasa, HA Lardner, W Willms, M Schellenberg & K Larson (eds), *The future management of grazing and wild lands in a high-tech world*, Proceedings of the 10th International Rangeland Congress, Saskatoon, Canada, pp. 502–505.

Han, Y & Hou, XY 2011, 'Perceptions and adaptation strategies of herders in desert steppe of Inner Mongolia to climate change' [Chinese], *Ying Yong Shengtai Xuebao*, vol. 22(4), pp. 913–922.

He, XL, Liu, T, Zhao, ML & Wang J 2013, 'Analysis on adaptive practices to climate change in desert steppe' [Chinese], *Animal Husbandry & Feed Science*, 2013–05.

Hou, FJ, Jiao, N & Feng QS 2016, 'The type and productivity of grassland grazing system' [Chinese], *Pratacultural Science*, vol. 33(3), pp. 353–367.

Hou, FJ 2011, 'Role of grazing in an integrated crop-livestock production system', *Proceedings of the First Meeting of China-Australia Network for Grassland Farming Systems*, Xinjiang, China, 16–19 August 2011.

—— 2014, 'Adaptation of mixed crop livestock systems in Asia', in J Fuhrer & P Gregory (eds), *Climate change impact and adaptation in agricultural systems*, CABI Publishing, Wallingford, pp. 153–166.

Hou, XY, Yin, YT & Wang, TT 2015, 'Herders' desirable stocking rates and methods for implementing a sustainable grass-animal balance in the rangeland regions of northern China' [Chinese], *Acta Ecologica Sinica* vol. 35(24), pp. 8036–8045.

Hou, XY, Yin, YT, Yun, XJ, Li, XL & Ding, Y 2013, 'Herders' stocking rates and shift of grass-animal balance model in northern grassland of China' [Chinese], *Grasslands in China*, 2013–01.

Hua, LM & Michalk, DL 2010, 'Herders' income and expenditure: perceptions and expectations', in V Squires, L Hua, G Li & D Zhang (eds), *Towards sustainable use of rangelands in North-West China*, Springer, Dordrecht, Netherlands, pp. 233–254.

Kemp, DR & Michalk, DL 2011, 'Livestock production styles and managing grassland ecosystems' in G Lemaire, J Hodgson, A Chabbi (eds), *Grassland ecosystems: productivity and environmental issues*, CABI Publishing, Wallingford, Ch. 1.6, pp. 53–62.

Kemp, DR 2011, *Proceedings of the First Meeting of China-Australia Network for Grassland Farming Systems*, Xinjiang, China, 16–19 August 2011.

Kobayashi, N, Hou, FJ, Tsunekawa, A, Chen, WJ, Yan, TH & Ichinohe, T 2017, 'Effects of substituting alfalfa hay for concentrate on energy utilization and feeding cost of crossbred Simmental male calves in Gansu Province, China', *Grassland Science*, vol. 63(4), pp. 245–254.

Le, J, Zhao, ML, Han, GD, Dong, T & Amula 2011, 'Effects of different stocking rate on plant community in desert steppe' [Chinese], *Chinese Journal of Grassland*, 2011–04.

Li, JW, Li, ZG, Wang, J, Li, YH & Han, GD 2015, 'Daily weight gain of Hulunbuir Short Tail Sheep in response to greenhouse precision feeding after weaning in Inner Mongolia' [Chinese], *Acta Agrestia Sinica*, vol. 23(05), pp. 1101–1105.

Li, JW, Li, ZG, Wang, J, Wang, RZ, Zhao, YF, Qin, J & Han, GD 2016, 'Analysis and application of forage and animal balance model on the meadow steppe in Inner Mongolia' [Chinese], *Chinese Journal of Grassland*, vol. 38(2), pp. 79–85.

Li, JW, Li, ZG, Wang, RZ, Wu, Q, Liu, F, Jin, YX & Han, GD 2016, 'Difference analysis of nutritive element content of common natural grass in Ewenki meadow steppe' [Chinese], *Chinese Journal of Grassland*, vol. 38(6), pp. 66–70.

Li, L & Hou, FJ 2016, 'Economic analysis of animal production in China' [Chinese], *Pratacultural Science* vol. 25(1), pp. 230–239.

Li, P, Hadrich, JC, Robinson, BE, Hou, YL, Dai, YT & Hou, XY 2018, 'How do herders do well? Profitability potential of livestock grazing in Inner Mongolia, China, across ecosystem types', *The Rangeland Journal*, vol. 40, pp. 77–90.

Li, SG, Zhao, SG, Wang, WR, Li, YD, Zhang, CQ, Sun, GH & Wu, JP 2014, 'Analysis of the correlations between milk performance and body weight in various blood lines of dairy cows' [Chinese], *Chinese Agricultural Science Bulletin*, vol. 30(14), pp. 6–9.

Li, YQ, Li, ZG, Ding, Z, Wang, ZW, Qi, ZQ & Han, GD 2016, 'Effects of grazing intensity on windblown sediment mass flux and particle size distribution in the desert steppe of Nei Mongol, China' [Chinese], *Chinese Journal of Plant Ecology*, vol. 40(10), pp. 1003–1014.

Li, ZG, Hang, GD, Zhao, ML, Yuan, Q, Qiao, J & Wang, J 2014, 'Review of household ranch models' [Chinese], *Chinese Journal of Eco-Agriculture*, vol. 22(12), pp. 1385–1396.

Li, ZG, Zhang, FG, Yao, M & Han, GD 2017, 'Effect of management strategy change on vegetation characteristics in household ranch of desert steppe' [Chinese], *Chinese Journal of Grassland*, vol. 39(1), pp. 105–110.

Liang, Y, Han, GD, Zhou, H, Zhao, ML, Snyman, HA, Shan, D & Havstad, KA 2009, 'Grazing intensity on vegetation dynamics of a typical steppe in northeast Inner Mongolia', *Rangeland Ecology & Management*, vol. 62, pp. 328–336.

Liang, JY, Jiao, T, Wu, JP & Xiao, YM 2015, 'Degradation dynamic of forage dry matter of alpine rangeland in sheep rumen' [Chinese], *Grassland & Turf*, 2015–05, pp. 32–36.

Lin, LJ, Zhu, XY, Jiang, C, Luo, HL, Wang, H, Zhang, YJ &Hong, FZ 2012, 'The potential use of n-alkanes, long-chain alcohols and long-chain fatty acids as diet composition markers: Indoor validation with sheep and herbage species from the rangeland of Inner Mongolia of China', *Animal*, vol. 6(3), pp. 449–458.

Lin, Y, Han, G, Zhao, M & Chang, SX 2010, 'Grazing intensity affected spatial patterns of vegetation and soil fertility in a desert steppe', *Agriculture, Ecosystems & Environment*, vol. 138, pp. 282–292.

Liu, GH, Zhang, YJ, Wang, SH & Han, JG 2013, 'Estimation of diet composition and herbage intake of grazing sheep at different stocking rates in Inner Mongolia typical steppe by using n-alkanes technique' [Chinese], *Acta Prataculturae Sinica*, vol. 22 (2), pp. 71–71.

Liu, T, Li, ZG, Han, GD, Zhao, ML, He, XL & Wang, J 2013. 'Simulating research on energy balance between forage supply and animal demand under different grazing patterns on household farms on desert steppe' [Chinese], *Inner Mongolia Prataculture*, vol. 25(2), pp. 14–18.

Liu, Y, Yan, CY, Matthew, C, Wood, B & Hou, FJ 2017, 'Key sources and seasonal dynamics of greenhouse gas fluxes from yak grazing systems on the Qinghai-Tibetan Plateau', *Scientific Reports*, 7, 40857.

McAuliffe, GA, Takahashi, T, Orr, RJ, Harris. P, Richardson, RJ & Lee, MRF 2017, 'Developing novel environmental metrics for beef production systems to account for differences in meat quality', *Sustainable intensification conference,* The Association of Applied Biologists and the Sustainable Intensification Research Platform, 28–30 November, Harpenden, UK.

Michalk, DL, Badgery, WB & Kemp, DR 2017, 'Balancing animal, pasture and environmental outcomes in grazing management experiments', *Animal Production Science*, vol. 57(9), pp. 1775–1784.

Michalk, DL, Hua, LM, Kemp, DR, Jones, R, Wu, JP, Nan, ZB & Han, GD 2011, 'Redesigning livestock systems to better match feed supply and improve livelihoods: experience from China', in S Bazarov & V Squires (eds), *Pastures of Tajikistan: challenges and perspectives* [Russian & English], 28–30 June, Dushanbe, Tajikistan.

Michalk, DL, Kemp, DR, Badgery, WB, Wu, JP, Zhang, YJ & Thomassin, PJ 2015, 'Sustainability, biodiversity and environmental issues: a global perspective for livestock production', in MM Roy, DR Malaviya, VK Yadav, T Singh, RP Sah, D Vijay & A Radhakrishna (eds), *Sustainable use of grassland resources for forage production, biodiversity and environmental protection*, Souvenir of 23rd International Grassland Congress, 20–24 November 2015, New Delhi, India, Range Management Society of India, Jhansi, Uttar Pradesh, India, pp. 6–23.

Michalk, DL, Wu, JP, Badgery, WB & Kemp, DR 2015, 'Impact of market forces on product quality and grassland condition' in D Vijay, MK Srivastava, CK Gupta, DR Malaviya, MM Roy, SK Mahanta, JB Singh, A Maity & PK Ghosh (eds), *Sustainable use of grassland resources for forage production, biodiversity and environmental protection*, Proceedings of 23rd International Grassland Congress, New Delhi, India, Keynote Lectures, Range Management Society of India, Jhansi, Uttar Pradesh, India, pp. 184–197.

Michalk, DL 2011, 'Achieving high quality livestock products through application of precision management principles', Gansu Natural Livestock Products sustainability of production systems workshop, June 2011.

—— 'Redesigning livestock systems to better match the feed supply and improve livelihoods: experience from Gansu and Inner Mongolia', *Proceedings of the First Meeting of China-Australia Network for Grassland Farming Systems*, Xinjiang, China, 16–19 August 2011.

Millar, GD, Jones, R, Michalk, DL & Brady, S 2009, 'An exploratory tool for analysis of forage and livestock production options', *Animal Production Science*, vol. 49, pp. 788–796.

Mitchell, DC, Badgery, WB, Cranney, P, Broadfoot, K, Priest, S & Pickering, D 2017, 'In a native pasture, landscape properties influence soil moisture more than grazing management', *Animal Production Science*, vol. 57(9), pp. 1799–1811.

Na, S, Han GD, Zhao, ML, Li, ZG, Chao, K & Wu, R 2010, 'The influence of different feeding mode on performance of Simmental cattle and grassland production' [Chinese], *Animal Husbandry & Feed Science*, vol. 31(2), pp. 57–59.

Peng, LX, Gao, XY & Hou, FJ 2018, 'The economic benefits of integrated farming system in the transitional region from Loess Plateau to Qinghai-Tibetan Plateau — a case study of Tongwei-Weiyuan-Xiahe transect' [Chinese], *Chinese Science Bulletin*, vol. 63(2), pp. 201–213.

Pu, XJ, Du, WH, Wu, JP & Mao, HX 2017, 'The growth and development of Oula type Tibetan sheep in an alpine meadow are at the eastern margin of the Qinghai-Tibetan Plateau'[Chinese], *Pratacultural Science*, vol. 34(2), pp. 396–406.

Qin, J, Han, GD, Wang, ZW, Hu, LX & Zhang, J 2017, 'Early warning indicators of grassland degradation in Inner Mongolia', *PeerJ*, 2915v1.

Qiu, Q, Wang, LZ, Wang, K, Yang, YZ, Ma, T, Wang, ZF, Zhang, X, Ni, ZQ, Hou, FJ, Long, RJ, Abbott, RJ, Lenstra, J & Liu, JQ 2015, 'Yak whole-genome resequencing reveals domestication signatures and prehistoric population expansions', *Nature Communications*, 6: 10283.

Ren, HY, Han, GD, Lan, ZC, Wan, HW, Schönbach, P, Gierus, M & Taube, F 2016, 'Grazing effects on herbage nutritive values depend on precipitation and growing season in Inner Mongolian grassland', *Journal of Plant Ecology*, vol. 9(6), pp. 712–723.

Ren, HY, Taude, F, Zhang, YJ, Bai, YF & Hu, SJ 2017, 'Transitions and coexistence along a grazing gradient in the Eurasian steppe', *Geophysical Research Abstracts*, 19, EGU2017–1789–4, 2017 EGU General Assembly 2017.

Ren, WB, Hou, XY, Wang, YQ, Badgery, WB, Li, XL, Ding, Y, Guo, HQ, Wu, ZN, Hu, NN, Kong, LQ, Chang, C, Jiang, C & Zhang, JZ 2017, 'Overgrazing induces alterations in the hepatic proteome of sheep (Ovis aries): an iTRAQ-based quantitative proteomic analysis', *Proteome Science*, 15, 2, doi: 10.1186/s12953–016–0111-z.

Scott, JM, Behrendt, K, Colvin, A, Scott, F, Shakhane, LM, Guppy, C, Hoad, J, Gaden, CA, Edwards, C, Hinch, GN, Cacho, OJ, Donald, GE, Cottle, D, Coventry, T, Williams, G & Mackay, DF 2013, 'Integrated overview of results from a farmlet experiment which compared the effects of pasture inputs and grazing management on profitability and sustainability' *Animal Production Science*, vol. 53(8), pp. 841–855.

Shu, B, Zhang, YJ, Lin, LJ, Luo, HL & Wang, H 2009, 'Fecal near-infrared reflectance spectroscopy to predict *Leymus chinensis* of diets from penned sheep in north China, *Rangeland Ecology & Management*, vol. 62, pp. 193–197.

Sun, XL, Liu, PT & Li, P 2014, 'The dynamic state of the NDVI index in Xilingol grassland during 1981–2010' [Chinese], *Chinese Journal of Grassland*, vol. 36(6), pp. 23–28.

Sun, Y, Angerer, JP & Hou, FJ 2015, 'Effects of grazing systems on herbage mass and liveweight gain of Tibetan sheep in Eastern Qinghai-Tibetan Plateau, China', *The Rangeland Journal*, vol. 37(2), pp. 181–190.

Sun, Y, Liu, Y, Zhang, Y, Chang, SH, Wang, ZF, Chen, XJ & Hou FJ 2013, 'Relationship between live weight gain of Tibetan sheep and available pasture in Qinghai-Tibetan Plateau', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 1668–1669.

Takahashi, T, Zheng, Y, Xu, Z & Kemp, DR 2012, 'Energy and economic values of greenhouse sheds in Taipusi, Inner Mongolia', in The Japanese Society of Grassland Science (ed.) *Evolution and future challenges of grasslands and grassland agriculture in East Asia*, (based on proceedings of the 4th Japan-China-Korea Grassland Conference, 30 March – 1 April 2012, Aichi, Japan), pp. 98–99.

Takahashi, T 2015, 'Quantifying the economic value of evidence-based animal selection on the Inner Mongolian desert steppe', oral paper available on web.

Tang, HJ, Zhao, SG, Lei, ZM, Wang, XR, Wang, JF, Cai, Y & Wu, JP 2014, 'Single nucleotide polymorphisms in A-FABP associated with carcass quality and meat quality Traits in Five Zaosheng Cattle Groups' [Chinese], *Biotechnology Bulletin*, 2014–05.

Wan, D, Wan, Y, Hou, XY, Ren, W, Ding, Y & Sa, R 2015, 'De novo assembly and transcriptomic profiling of the grazing response in *Stipa grandis*', *PLoS ONE*, vol. 10(4), e0122641.

Wang, H, Zhang, YJ, Lin, LJ, Shu, B, Na, RS, Wang, N & Qin, Y 2010, 'Evaluation of complex diet dry matter digestibility of sheep using spectral difference', *Spectroscopy & Spectral Analysis*, vol. 30, pp. 1575–1578.

Wang, HM, Li, ZH & Han, GD 2016, 'Influence of climate and grazing on NDVI in a typical steppe region in Inner Mongolia, China', *Frontiers in Environmental Engineering*, 5: 230–239.

Wang, HY, Dong, Z, Guo, JY, Li, HL, Han, GD & Chen, XC 2017, 'Effects of grazing intensity on organic carbon stock characteristics in *Stipa breviflora* desert steppe vegetation soil systems', *The Rangeland Journal*, vol. 39(2), pp. 169–177.

Wang, J, Zhao, M, Kemp, DR & Turnbull, G 2013, 'Demonstration farms to improve grassland and household incomes in western China', in DL Michalk, GD Millar, WB Badgery and KM Broadfoot (eds), *Revitalising grasslands to sustain our communities,* Proceedings of the 22nd International Grassland Congress, September 2013, Sydney, Australia, pp. 1846–1848.

Wang, M, Han, G, Cui, G & Zhao, M 2010, 'Effects of grazing intensity on the biodiversity and productivity of meadow steppe' [Chinese], *Chinese Journal of Ecology*, 2010–05.

Wang, MJ, Zhao, ML, Cui, GW & Han, GD 2010, 'Effect of grazing intensities on vegetation and soil in meadow steppe' [Chinese], *Acta Agrestia Sinica*, 2010–06.

Wang, S, Han, GD, Bao, YH & Wu, L 2015, 'The influence of stocking rates on vegetation coverage in *Stipa breviflora* desert steppe' [Chinese], *Chinese Journal of Grassland*, vol. 37(6), pp. 67–72.

Wang, S, Hang, GD, Zhang, SW, Bao, YH, Wu, L Wang, ZW & Wu, CY 2015, 'Analysis of sheep grazing behavior and interaction with grassland environment in desert steppes using 3S' [Chinese], *Chinese Journal of Eco-Agriculture*, vol. 23(7), pp. 860–867.

Wang, XR, Liu, T, Su, DW, Cheng, SR & Wu, JP 2017, 'Effect of parity, calves' gender, birth weight and calving season on reproductive traits of Holstein cows' [Chinese], *Journal of Domestic Animal Ecology* 2017–03.

Wang, ZF, Hu, A, Chen, XJ & Hou, FJ 2016, 'Effects of Tan sheep grazing on productivity of typical steppe on the Loess Plateau', in A Iwaasa, HA Lardner, W Willms, M Schellenberg & K Larson (eds), *The future management of grazing and wild lands in a high-tech world*, Proceedings of the 10th International Rangeland Congress, Saskatoon, Canada, p. 261.

Wang, ZW, Jiao, S, Han, GD, Zhao, ML, Willms, WD, Hao, X, Wang J, Din, H & Havstad, KM 2011, 'Impact of stocking rate and rainfall on sheep performance in a desert steppe', *Rangeland Ecology and Management*, vol. 64, pp. 249–256.

Wang, ZW, Jiao, SY, Han, GD, Zhao, ML, Wang, J & Willms, WD 2013, 'Effects of stocking rate on the variability of ecosystem productivity in desert steppe', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 914–916.

Wu, JP, Squires, V, Yang, L 2010, 'Improved animal husbandry practices as a basis for profitability' in V Squires, L Hua, G Li & D Zhang (eds), *Towards sustainable use of rangelands in North-West China*, Springer, Dordrecht, Netherlands, pp. 207–232.

Wu, JP 2011, 'Animal breeding theory of sustainable production systems', Gansu Natural Livestock Products sustainability of production systems workshop, June 2011.

Wu, JP 2011, 'The strategies in balancing animal genotypes to the sustainable grazing production system', *Proceedings of the First Meeting of China-Australia Network for Grassland Farming Systems*, Xinjiang, China, 16–19 August 2011.

Xie, J, Li, ZG, Aotegen, W, Wulumushan, B, Han, GD & Wang CJ 2013, 'Application of forage and livestock energy balance model in typical steppe family ranches' [Chinese], *Animal Husbandry & Feed Science*, vol. 34(4), pp. 13–16, 60.

Xu, L, Wang, XY, Hou, FJ & Nan, ZB 2010, 'Energy balance of integrated crop-rangeland-livestock production systems in eastern Gansu, China', in H Dove & RA Culvenor (eds), *Food security from sustainable agriculture*, Proceedings of 15th Agronomy Conference, 15–18 November 2010, Lincoln, New Zealand.

Xu, L, Wang, XY, Hou, FJ & Nan, ZB 2010, 'System analysis of integrated crop-livestock production in the Loess Plateau, eastern Gansu Province', *Proceedings of the 14th AAAP Animal Science Congress*, Pinttung, 23–27 August, p. 132.

Yan, RR, Wei, ZJ, Yang, GX, Han, GD, Xin, XP & Lu, ZH 2013, 'Influences of family ranches management mode on plant community characteristic in Hulunber Meadow Steppe', *Agricultural Science & Technology*, vol. 14, pp. 1664–1669.

Yang, B, Wu, JP, Yang, L, Gong, XY, Kemp, DR, Feng, MT & Sun, L 2012, 'Establishing precision management techniques for sheep and feed balance research in pastoral areas', *Acta Agrestia Sinica*, vol. 20(3), pp. 589–596.

Yang, B, Wu, JP, Yang, L, Kemp, DR, Gong, XY, Takahashi, T & Feng, MT 2012, 'Metabolic energy balance and countermeasures study in the north grassland of China' [Chinese], *Acta Prataculturae Sinica*, vol. 21(2), pp. 187–195

Yang, CT, Gao, P, Hou, FJ, Yan, TH, Chang, SH, Chen, XJ & Wang, ZF 2018, 'Relationship between chemical composition of native forage and nutrient digestibility by Tibetan sheep on the Qinghai-Tibetan Plateau', *Journal of Animal Science*, vol. 96, pp. 1140–1149.

Yang, L 2011, 'Changing livestock and grassland management to improve the sustainability and profitability of Alpine grasslands in Sunan County, Gansu', *Proceedings of the First Meeting of China-Australia Network for Grassland Farming Systems*, Xinjiang, China, 16–19 August 2011.

Yin, GM, Zhang, YJ, Liu, Y, Wei, Z & Zhao, H 2013, 'Nutrition diet of grazing sheep and forage supply on natural grassland', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 653–654.

Yin, YT, Hou, XY, Yun, XJ, Ding & Y, Li, XL 2013, 'Plant community convergence of herders' pasture in desert steppe' [Chinese], *Grasslands in China*, 2013–01.

Yin, YT, Hou, ZY, Yun, XJ, Ding, Y, Li, XL 2013, 'Vegetation characteristics comparison of herders' pastures at different economic levels in desert steppe, Inner Mongolia' [Chinese], *Journal of Desert Research*, 2013–04.

Yin, YT, Wang, Z, Li, XL, Langford, C, Yun, XJ, Mu, HB & Hou, XY 2018, 'Factors affecting herder adoption of winter lambing practices in the desert steppe region of Inner Mongolia, China', *The Rangeland Journal*, vol. 40, pp. 65–75, doi: 10.1071/RJ17068.

Yin, YT 2015, 'Framing effect and pastoralist decision making behaviour regarding lambing time – an analysis from Inner Mongolia, China', Proceedings of 23rd International Grassland Congress, 20–24 November 2015, New Delhi, India, oral paper available on web.

Zhang, CJ, Zhang, Y, Gu, WJ, Zhang, LP & Guo, SB 2017, 'Effects of supplementary feeding in late pregnancy on Gansu Alpine Fine-Wool ewes' [Chinese], *Acta Prataculturae Sinica* vol. 26(7), pp. 106–115.

Zhang, CX, Wu, JP, Zhao, SG, Cai, Y, Li, TK, Zhang & J, Lei, ZM 2014, 'Analysis on polymorphism of CAPN1 gene in local cattle and its relationships with meat quality trait' [Chinese], *Acta Agriculturae Boreali-Occidentalia Sinica*, 2014–03, pp. 14–19.

Zhang, RR, Li, XX, Yan, R, Yu, YD, Jiang, C, Zhang, YJ & Han, JG 2011, 'The evaluation of nutritive value in alfalfa silage through near infrared reflectance spectroscopy', *International conference on remote sensing, environment and transportation engineering*, 24–26 June 2011, Nanjing, China.

Zhang, RY, Han, GD, Li, ZG, Li, JW, Pan, ZL & Wang, RZ 2015, 'Effects of different stocking rates on the economy and forage-animal balance on the meadow steppe in Inner Mongolia – taking Bayanhushuo, Ewenke Banner, as an example' [Chinese], *Chinese Journal of Grassland*, vol. 37(6), pp. 6–13.

Zhang, RZ, Yan, R, Nie, ZD, Yiu, YD, Jiang, C, Zhen, L, Zhang, YJ & Han, JG 2011, 'Prediction of fermentation quality of *Leymus chinensis* by near infrared reflectance spectroscopy', *International conference on remote sensing, environment and transportation engineering*, 24–26 June 2011, Nanjing, China.

Zhang, SY, Han, GD, Zhao, ML, Li, ZG, Chao, KT & Wu, RT 2010, 'The greenhouse feeding effect of weight gain of Wuzhumuqin sheep based on the typical model of raising in Inner Mongolia in winter' [Chinese], *Animal Husbandry & Feed Science*, vol. 31(2), pp. 45–48.

Zhang, XJ, Han, GD & Wang ZW 2014, 'Effect of different stocking rate on soil respiration in *Stipa breviflora* desert steppe' [Chinese], *Ecology and Environmental Sciences*, 2014–05.

Zhang, XQ, Jin, YM, Badgery, WB & Tana 2017, 'Diet selection and n-3 polyunsaturated fatty acid deposition in lambs as affected by restricted time at pasture', *Scientific Reports,* 7, 15641.

Zhang, XQ, Kemp, DR, Hou, XY, Langford, CM, Wang, K, Yan, WH 2016, 'Effects of shed modifications on ewe reproductive performance and lamb growth rate in Inner Mongolia', *The Rangeland Journal*, vol. 38, pp. 479–487.

Zhang, XQ, Kemp, DR, Ma, YB & Jiang, C 2017, 'Effect of warm shed feeding on liveweight loss and performance of ewes during the winter-spring period' [Chinese], *Acta Prataculturae Sinica*, vol. 26(6), pp. 203–209.

Zhang, XQ, Luo, HL, Hou, XY, Badgery, WB, Zhang, YJ, Jiang, C 2014, 'Effect of restricted time at pasture and indoor supplementation on ingestive behaviour, dry matter intake and weight gain of growing lambs', *Livestock Science*, vol. 167, pp. 137–143.

Zhang, YJ, Huang, D, Badgery, WB, Kemp, DR, Chen, WQ, Wang, XY & Liu, N 2015, 'Reduced grazing pressure delivers production and environmental benefits for the typical steppe of north China', *Scientific Reports*, 5, doi: 10.1038/srep16434.

Zhang, YJ 2011, 'Stocking rates studies in China', *Proceedings of the First Meeting of China-Australia Network for Grassland Farming Systems*, Xinjiang, China, 16–19 August 2011.

Zhang, ZL, Yu, YW, Fu, QG, Sun, Y & Hou, FJ 2015, 'Production and international trade analysis of animal products in China' [Chinese], *Acta Prataculturae Sinica*, vol. 24(7), pp. 163–171.

Zhang, ZQ, Jin, YM, Zhang, YJ, Yu, Z & Yan, WH 2014, 'Silage quality and preservation of *Urtica cannabina* ensiled alone and with additive treatment', *Grass and Forage Science*, vol. 69(3), pp. 405–414.

Zhao, HJ, Lian, Y, Yang, SW, Hua, LM, Feng, MT, Ma, ZF, Gong, WY & Wu, JP 2010, 'Comparison of feeding effect on Gansu alpine fine wool sheep between grazing and greenhouse feeding during winter season' [Chinese], *Pratacultural Science*, vol. 27(5), pp. 117–121

Zhao, QS, Hou, XY, Zhao, YQ, Xia, M, Duan, JJ & Tao, Y 2013, 'Effect of different grazing systems on nutrition of artificial pasture and sheep weight' [Chinese], *Chinese Journal of Grassland*, 2013–01.

Zheng, Y, Takahashi, T & Kemp, DR 2013, 'Energy and economic values of greenhouse sheds to replace winter grazing in north-western China', *Grassland Science*, vol. 59, pp. 156–159.

Zheng, Y, Takahashi, T & Kemp, DR 2013, 'Greenhouse sheds for increasing livestock bodyweight in Taipusi, Inner Mongolia', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, p. 1759.

Zheng, Y, Xu, Z, Hao, F, Ma, YB & Lin, LH 2010, 'Benefit analysis on greenhouse sheep breeding of typical steppe in Inner Mongolia' [Chinese], *Acta Ecologiae Animalis Domastici*, 2010–02.

Zheng, Y, Xu, Z, Liu, JL & Shi, SL 2010, 'Impacts of grazing intensity on body weight and reproductive performance of sheep' [Chinese], *Grassland & Turf*, 2010–06.

Zhou, P, Han, GD, Wang, C, Jiang, Y & Tang, SM 2011, 'Effects of stocking rates on carbon flux in the desert grassland and ecological systems of Inner Mongolia' [Chinese], *Journal of Inner Mongolia Agricultural University*, vol. 32(4), pp. 59–64.

Zhou, R, Zhao, SG, Liu, LS, Liu, Z, Li, HW, Yue, Y, Cheng, X & Wu, JP 2016, 'Effects of tail docking on slaughter performance and mutton quality in Lanzhou fat-tail sheep and Mongolian sheep' [Chinese], *Journal of Gansu Agricultural University*, 2016–04, pp. 14–19.

Grassland management (181)

Angerer, J, Han, GD, Fujisak, I & Havstad, K 2012, 'Climate change and ecosystems of Asia with emphasis on Inner Mongolia and Mongolia' *Rangelands*, vol. 30(3), pp. 46–51.

Arong, Li, ZG, Wang, J, Han, GD 2015, 'Influence of different utilization patterns on quantitative feature of main plant species in *Stipa grandis* steppe' [Chinese], *Journal of the Inner Mongolia Forestry Science & Technology*, 2015–2, pp. 36–40.

Arong, Qin, J, Wang, JF, Badalahu, Li, ZG, Wang, J & Han, GD 2015, 'The Impact of moving and grazing on Soil nutrient contents in *Stipa grandis* steppe' [Chinese], *Grassland and Prataculture*, 2015–02, pp. 34–39.

Badgery, WB, King, H, Murphy, B, Rawson, A & Warden, E 2013, 'The effects of management and vegetation on soil carbon stocks in temperate Australian grazing systems', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 1223–1226.

Badgery, W, Michalk, DL & Kemp, DR 2015, 'Sustainable management of temperate grasslands in Australia', in PK Ghosh, SK Mahanta, JB Singh & PS Pathak (eds), *Grassland: a global resource*, Rangeland Management Society of India, Jhansi, Uttar Pradesh, India, ch. 7, pp. 141–192.

Badgery, WB, Sargeant, K, Friend, M, Glude, S, Sanford, P, Behrendt, R, Mitchell, M, Murphy, S & Avery, A 2015, 'EverGraze: a partnership between researchers, farmers and advisors to deliver effective grassland management', in D Vijay, MK Srivastava, CK Gupta, DR Malaviya, MM Roy, SK Mahanta, JB Singh, A Maity & PK Ghosh (eds), *Sustainable use of grassland resources for forage production, biodiversity and environmental protection*, Proceedings of 23rd International Grassland Congress, New Delhi, India, Keynote Lectures, Range Management Society of India, Jhansi, Uttar Pradesh, India, pp. 236–247.

Badgery, WB, Simmons, AT, Murphy, BE, Rawson, A, Anderson, K & Lonergan, VE 2013, 'The influence of land use and management on soil carbon levels for crop-pasture systems in Central New South Wales, Australia', *Agriculture Ecosystems & Environment*, vol. 196, pp. 147–157.

Badgery, WB, Simmons, AT, Murphy, BW, Rawson, A, Anderson, K, Lonergan, VE & van de Ven, R 2013, 'Relationship between environmental and land-use variables on soil carbon levels at the regional scale in central New South Wales, Australia', *Soil Research*, vol. 51(7–8), pp. 645–656.

Badgery, WB, Zhang, YJ, Huang, D, Broadfoot, K, Kemp, DR & Mitchell, D 2015, 'Optimising stocking rate and grazing management to enhance environmental and production outcomes for native temperate grasslands', *Geophysical Research Abstracts*, 17, EGU2015–4294, European Geosciences Union (EGU) General Assembly 2015.

Behrendt, K, Cacho, OJ, Scott, JM & Jones, R 2016, 'Using seasonal stochastic dynamic programming to identify optimal management decisions that achieve maximum economic sustainable yields from grasslands under climate risk', *Agricultural Systems*, vol. 145, pp. 13–23.

Behrendt, K, Lu, HB, Takahashi, T, Kemp, DR, Li, ZG, Badgery, WB & Zhang, YJ 2017, 'Sustainable grassland systems: Modelling ecosystem and herder economic outcomes', *MoST/ACIAR Forum on Sustainable Chinese Grassland Livestock System Program*, Hohhot, Inner Mongolia Autonomous Region (IMAR), 2 April 2017.

Behrendt, K 2015, 'The value of modelling botanical composition change in grasslands', Proceedings of 23rd International Grassland Congress, 20–24 November 2015, New Delhi, India, oral paper available on web.

Cao, L, Li, CR, Tian, QS, Du, JC, Wang, ZW & Han, B 2016, 'The response of genetic diversity in desert steppe plants to simulated warming in Inner Mongolia, China', *Acta Ecologica Sinica*, vol. 36(21), pp. 6909–6918.

Chang, SJ, Liu, N, Wang, XY, Zhang, YJ & Xie, Y 2012, 'Alfalfa carbon and nitrogen sequestration patterns and effects of temperature and precipitation in three agro-pastoral ecotones of northern China', *PLoS ONE*, vol. 7(11), e50544.

Chen, GU, Chen, CJ, Du, YF, Wang, YT, Zhao, TQ & Zhao, ML 2017, 'Stocking rates affect the resource allocation patterns of *Artemisia frigida* in the inner Mongolian desert steppe' [Chinese], *Acta Ecologica Sinica*, vol. 37(7), pp. 2237–2243.

Chen, H, Zhang, Y, Zhao, ML & Han, GD 2013, 'Effects of different grazing intensities on vegetation characteristics of desert steppe' [Chinese], *Pratacultural Science*, 11, pp. 1814–1818.

Chen, JB, Hou, FJ, Chen, XJ, Wan, XL & Millner, J 2015, 'Stocking rate and grazing season modify soil respiration on the Loess Plateau, China', *Rangeland Ecology & Management*, vol. 68(1), pp. 48–53.

Chen, T, Christensen, M, Nan, ZB & Hou, FJ 2016, 'The effects of different intensities of long-term grazing on the direction and strength of plant–soil feedback in a semiarid grassland of north-west China', *Plant and Soil*, vol. 413(1–2), pp. 303–307.

—— 2017, 'Effects of grazing intensity on seed size, germination and fungal colonization of *Lespedeza davurica* in a semi-arid grassland of north-west China', *Journal of Arid Environments*, vol. 144, pp. 91–97.

Chen, T, Zhang, YW, Christensen, M, Li, CH, Hou, FJ & Nan, ZB 2017, 'Grazing intensity affects communities of culturable root-associated fungi in a semiarid grassland of north-west China. *Land Degradation and Development*, vol. 29(2), pp. 361–373.

Chen, WQ, Xu, R, Hu, TM, Chen, J, Zhang, YJ, Cao, WL, Wu, D, Wu, YT & Shen, Y 2017, 'Soil-mediated effects of acidification as the major driver of species loss following N enrichment in a semi-arid grassland', *Plant and Soil*, vol. 419(1–2), pp. 541–556.

Chen, WQ, Zhang, YJ, Mai, XH & Shen, Y 2016, 'Multiple mechanisms contributed to the reduced stability of Inner Mongolia grassland ecosystem following nitrogen enrichment', *Plant and Soil*, vol. 409(1–2):, pp. 283–296.

Chen, XJ, Wang, YR & Hou, FJ 2011, 'Mechanisms and controlling factors of grassland ecosystem greenhouse gas emissions' [Chinese], *Pratacultural Science*, vol. 28(5), pp. 722–728.

Dong, T, Li, Q, Zhao, ML, Jia, L, MuLa, A, Han, GD & Bai, WJ 2011, 'Effect of grazing intensity on root biomass of *Stipa grandis*' [Chinese], *Acta Agrestia Sinica*, 2011–02.

Du, YF, Gu, C, Wu, LJ, Xue, WJ, Chen, WJ, Li, ZG, Zhao, ML & Wang J 2016, 'Species abundance pattern in *Stipa breviflora* desert steppe under different stocking rates' [Chinese], *Chinese Journal of Ecology*, vol. 35(3), pp. 675–683.

Fan, YJ, Chang, XY, Yang, YH, Shi, HX & Hou, XY 2011, 'The biodiversity and stability of alpine meadow plant communities in relation to altitude gradient in three headwater resource regions', *African Journal of Biotechnology*, vol. 11(79), pp. 14422–14427.

Fan, YJ, Hou, XY, Shi, HX & Shi, SL 2013, 'Effects of grazing and fencing on carbon and nitrogen reserves in plants and soils of alpine meadow in the three headwater resource regions', *Russian Journal of Ecology*, vol. 44(1), pp. 80–88.

Gao, K, Zhu, TX, Wang, QB & Han, GD 2012, 'Effects of enclosure on the caloric values of main plant species, litters, and communities in *Leymus chinensis* steppe in Xilin River Basin, Inner Mongolia' [Chinese], *Ying Yong Sheng Tai Xue Bao*, vol. 23(4), pp. 998–1002.

Gao, XL, Zhao, ML, Wang, J, Han, B & Willms, WD 2013, 'Strategies on poisonous plants problem in China', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 1565–1568.

Guo, FH, Hou, XY, Ding, Y, Li, XL, Wu, ZN, Wang, Z, Hu, J, Lin, XL, Wu, XH & Xu, HM 2016, 'Plasticity of plant morphology and biomass allocation of *Leymus chinensis* under different phosphorus conditions' [Chinese], *Acta Prataculturae Sinica*, vol. 25(12), pp. 53–62.

Guo, YJ, Du, QF, Li, GD, Ni, Y, Zhang, Z & Ren, WB 2016, 'Soil phosphorus fractions and arbuscular mycorrhizal fungi diversity following long-term grazing exclusion on semi-arid steppes in Inner Mongolia', *Geoderma*, 269, pp. 79–90.

Guo, YR & Hou, FJ 2016, 'Relationship between vegetation and topography of snow cover in winter ranch of northern Qilian Mountains' [Chinese], *Journal of Southwestern University for Nationalities*, vol. 42(3), pp. 255–261.

Hackney, B, Orchard, P, Kemp, DR & Orchard, B 2011, 'Factors affecting pasture production in variable landscapes – how does it influence fertiliser use and other management issues?' *Proceedings NSW Grassland Society*, pp. 67–72.

Han, D, Wu, P, Zhang, Q, Han, GD & Tong, F. 2016, 'Recognition of typical grassland forage based on colour' [Chinese], *Transactions of the Chinese Society of Agricultural Engineering*, vol. 32(23), pp. 168–175.

Han, GD 2011, 'Ecosystem sustainability and management', *Third international conference on farming systems on the Loess Plateau,* Lanzhou University, June 2011.

—— 'The improvement of grazing system in desert steppe, Inner Mongolia' Gansu Natural Livestock Products sustainability of production systems workshop, June 2011.

—— 2014, 'Response of ecosystem carbon exchange to warming and nitrogen addition in a desert steppe in Eurasian steppe region', *From oceans to mountains: it's all ecology: 99th Ecological Society of America Annual Meeting*, 10–15 August 2014, Sacramento, California.

Han, JJ, Chen, JQ, Han, GD, Shao, CL, Sun, HL & Li, LH 2014, 'Legacy effects from historical grazing enhanced carbon sequestration in a desert steppe', *Journal of Arid Environments*, 107, pp. 1–9.

Han, WJ, Hou, XY, Olokhnuud, CL & Schellenberg, M 2014, 'The characteristics of plant communities along east-Eurasian steppe transect', *Journal of Integrative Agriculture*, vol. 13(6), pp. 1157–1164.

Hou, FJ, Wang, CM, Lou, SN, Hou, XY & Hu, TM 2016, 'Rangeland productivity in China' [Chinese], *Chinese Journal of Engineering Science*, vol. 18(1), pp. 80–93.

Hou, FJ 2017, *Research on Grassland Productivity and Food Safety in China*, China Science Press, Beijing.

Hou, XY, Ubugunov, L, Tserendash, S, Chen, HJ, Han, HJ, Yun, WJ, Yun, XJ, Yong, D, Wang, Z & Ji, L 2013, 'The changing patterns in grasslands and soil fertility along the Eastern Eurasian Steppe Transect across China – Mongolia – Russia', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 1109–1115.

Hou, XY, Wang, Z, Schellenberg, M, Ji, L, Yum, XJ 2014, 'The response of grassland productivity, soil carbon content and soil respiration rates to different grazing regimes in a desert steppe in northern China', *The Rangeland Journal*, vol. 36(6), pp. 573–582.

Hou, XY 2011, 'Climate change adaptation and adaptive management in Inner Mongolia grassland', *Proceedings of the First Meeting of China-Australia Network for Grassland Farming Systems*, Xinjiang, China, 16–19 August 2011.

Hou, XY 2015, 'Effect of overgrazing and enclosure on ecosystem functioning and biological capacity in the typical steppe', Proceedings of 23rd International Grassland Congress, 20–24 November 2015, New Delhi, India, oral paper available on web.

—— 'Soil respiration in a desert steppe varies by different grazing regimes in northern China', Proceedings of 23rd International Grassland Congress. 20–24 November 2015, New Delhi, India, available on web.

Hu, H, Chen, XJ, Hou, FJ, Wu, YP & Cheng, YX 2017, 'Bacterial and fungal community structures in loess plateau grasslands with different grazing intensities', *Frontiers in Microbiology*, 8, p. 606.

Hu, J, Hou, XY, Wang, Z, Ding, Y, Li, XL, Li, P & Ji, L 2015, 'Effects of mowing and grazing on soil nutrients and soil microbes in rhizosphere and bulk soil of *Stipa grandis* in a typical steppe', *Ying Yong Sheng Tai Xue Bao*, vol. 26(11), pp. 3482–3490.

Hu, JQ, Chen, XJ & Hou, FJ 2016, 'The response of plant community characteristics of alpine steppe to the winter grazing of Gansu wapiti' [Chinese], *Pratacultural Science*, vol. 33(6), pp. 1028–1034.

Jiang, YY, Tang, SM, Wang, CJ, Zhou, P, Tenuta & M, Han, GD 2012. 'Contribution of urine and dung patches from grazing sheep to methane and carbon dioxide fluxes in an Inner Mongolian desert grassland', *Asian Australasian Journal of Animal Sciences*, vol. 25(2), pp. 207–212.

Jiao, T, Wu, JP, Cao, WX, Qi, J & Zhao, SG 2013, 'Effect of grazing on soil fertility and trace elements of temperate desert steppe in north-western China', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 1554–1555.

Jiao, T, Wu, JP, Zhao, SG, Li, YJ, Zhao, GQ & Lei, ZM 2017, 'Distribution and utilization of nitrogen on moderately and heavily grazed temperate desert steppe using the 15N tracing technique', *Applied Soil Ecology*, vol. 124, pp. 69–74.

Kemp, DR, Badgery, WB & Michalk, DL 2015, 'Principles for grassland systems research for livelihood and environmental benefits', in PK Ghosh, SK Mahanta, JB Singh & PS Pathak (eds), *Grassland: a global resource*, Rangeland Management Society of India, Jhansi, Uttar Pradesh, India, ch. 13, pp. 283–310.

—— 'Sustainable grasslands: resolving management options for livelihood and environmental benefits', in D Vijay, MK Srivastava, CK Gupta, DR Malaviya, MM Roy, SK Mahanta, JB Singh, A Maity & PK Ghosh (eds), *Sustainable use of grassland resources for forage production, biodiversity and environmental protection,* Proceedings of 23rd International Grassland Congress, New Delhi, India, Keynote Lectures, Range Management Society of India, Jhansi, Uttar Pradesh, India, pp 259–269.

Kemp, DR, Hou, FJ, Nan, ZB, Wang, XY & Michalk, DL 2011, 'Integrated grazing farm systems management on the Loess Plateau', *Third international conference on farming systems on the Loess Plateau*, Lanzhou University, June 2011.

Kemp, DR & Michalk DL 2013, 'Revitalising grasslands to sustain our communities', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 5–6.

Li, CL, Hao, XY, Ellert, BH, Willms, WD, Zhao, ML & Han, GD 2012, 'Changes in soil C, N, and P with long-term (58 years) cattle grazing on rough fescue grassland', *Journal of Plant Nutrition & Soil Science*, vol. 175(3), pp. 339–344.

Li, L & Hou, FJ 2016, 'The major natural disasters of grassland production in China' [Chinese], *Pratacultural Science*, vol. 33(5), pp. 981–989.

Li, S, Hua, LM, Nie, Z & Zheng, Y 2015, 'Application of Dry Weight Rank rapid monitoring of grassland in alpine meadow' *Chinese Journal of Ecology*, vol. 34(12), pp. 3575–3580

Li, X, Li, R, Li, G, Wang, H, Li, Z & Hou, X 2016, 'Human-induced vegetation degradation and response of soil nitrogen storage in typical steppes in Inner Mongolia, China', *Journal of Arid Environments*, vol. 124, pp. 80–90.

Li, X, Wang, Z, Wu, X, Li, X, Hu, J, Shi, H, Guo, F, Zhang, Y & Hou, X 2015, 'Pathways of *Leymus chinensis* individual aboveground biomass decline in natural semiarid grassland induced by overgrazing: a study at the plant functional trait scale', *PLoS ONE*, vol. 10(5), e012443.

Li, XL, Hou, XY, Liu, ZY, Guo, FH, Ding, Y, Duan, JJ 2016, 'Long-term overgrazing-induced changes in topsoil water-retaining capacity in a typical steppe', *Rangeland Ecology & Management*, vol. 70(3), pp. 324–330.

Li, XL, Hou, XY, Ren WB, Taogetao, B, Liu, ZY, Badgery, WB, Li, YQ, Wu, XH & Xu, HM 2016, 'Long-term effects of mowing on plasticity and allometry of *Leymus chinensis* in a temperate semi-arid grassland, China', *Journal of Arid Land*, vol. 8(6), pp. 899–909.

Li, XL, Liu, ZY, Hou, XY, Wu, XH, Wang, Z, Hu, J & Wu, ZA 2015, 'Plant functional traits and their trade-offs in response to grazing: a review' [Chinese], *Chinese Bulletin of Botany*, 2015–02.

Li, XL, Liu, ZY, Ren, WB, Ding, Y, Ji, L, Guo, FH & Hou, XY 2016, 'Linking nutrient strategies with plant size along a grazing gradient: evidence from *Leymus chinensis* in a natural pasture', *Journal of Integrative Agriculture*, vol. 15(5), pp. 1132–1144.

Li, XL, Wu, ZN, Liu, ZY, Hou, XY, Badgery, WB, Guo, HQ, Zhao, QS, Hu, NN, Duan, JJ & Ren, WB 2015, 'Contrasting effects of long-term grazing and clipping on plant morphological plasticity: evidence from a rhizomatous grass', *PLoS ONE*, vol. 10(10), e0141055.

Li, Y, Iwaasa, A, Wang, Y, Jin, L, Han, GD & Zhao, ML 2014, 'Condensed tannins concentration of selected prairie legume forages as affected by phenological stages during two consecutive growth seasons in western Canada', *Canadian Journal of Plant Science*, vol. 94, pp. 817–826.

Li, YH, Han, GD, Wang, Z, Wang, ZW, Zhao, ML & Wang, S 2015, Nitrogen resorption efficiency of perennial plant decreases with warming and nitrogen addition in desert steppe' [Chinese], *Acta Ecologica Sinica*, vol. 35(18), pp. 5948–5956.

Li, YH, Han, GD, Wang, Z, Zhao, ML, Wang, ZW & Zhao, HB 2014, 'Influences of warming and nitrogen addition on plant reproductive phenology in Inner Mongolia desert steppe'[Chinese], *Chinese Journal of Grassland*, vol. 33(4), pp. 849–856.

Li, YH, Han, GD, Wang, Z, Wang, ZW, Zhao, ML & Wang, S 2015, Nitrogen resorption efficiency of perennial plant decreases with warming and nitrogen addition in desert steppe' [Chinese], *Acta Ecologica Sinica*, vol. 35(18), pp. 5948–5956.

Li, YL, Hong, M, Bai, WM, Han, GD, Wang, HM & Zhao, ML 2015, 'The responses of soil respiration to water and nitrogen in *Stipa breviflora* steppe' [Chinese], *Acta Ecologica Sinica*, vol. 35(6), pp. 17727–1733.

Li, YQ, Li, ZG, Dong, Z, Wang, ZW, Qu, ZQ & Han, GD 2016, 'Comparison on the anti-erosion characteristics under different grazing Intensities on the desert steppe based on the wind tunnel simulation', *Journal of Soil and Water Conservation*, vol. 30(3), pp. 103–108.

Li, ZG, Hou, FJ & An, Y 2011, 'Effects of grazing and light on productivity of artificial pasture of understory' [Chinese], *Pratacultural Science*, 2011–03.

Liang, JY, Jiao, T, Wu, JP, Gong, XY, Du, WH, Liu, HB & Xiao, YM 2015, 'The relationship between seasonal forage digestibility and forage nutritive value in different grazing pastures' [Chinese with English abstract], *Acta Prataculturae Sinica*, vol. 24(6), pp. 108–115.

Lin, HL, Wang, XL, Zhang, YJ, Liang, TG, Feng, QS & Ren, JZ 2013, 'Spatio-temporal dynamics on the distribution, extent, and net primary productivity of potential grassland in response to climate changes in China', *The Rangeland Journal*, vol. 35(4), pp. 409–425.

Lin, HL & Zhang, YJ. (2013, Evaluation of six methods to predict grassland net primary productivity along an altitudinal gradient in the Alxa Rangeland, Western Inner Mongolia, China', *Grassland Science*, vol. 59(2), pp. 100–110.

Lin, Y, Han, G, Zhao, M & Chang, SX 2010, 'Spatial vegetation patterns as early signs of desertification: a case study of a desert steppe in Inner Mongolia, China', *Landscape Ecology*, vol. 25, pp. 1519–1527.

Liu, BK, Du, YE, Li, L, Feng, QS, Xie, HJ, Liang, TG, Hou, FJ & Ren, JZ 2016, 'Outburst flooding of the moraine-dammed Zhuonai Lake on Tibetan Plateau: causes and Impacts', Institute of Electrical and Electronics Engineers (IEEE), *IEEE Geoscience & Remote Sensing Letters*, vol. 13(4), pp. 570–574.

Liu, BK, Hou, FJ & Du, Y 2011, 'Research of potential carbon sequestration for grassland in Qinghai Province', *Acta Agriculturae Scandinavica, Section B – Soil & Plant Science*, vol. 61(4), pp. 356–364.

Liu, F, Han, GD, Wang, ZW, Li, ZG, Wang, CJ 2015, 'Effect of stocking rate on plant nutrients with different seasons in *Stipa breviflora* desert steppe' [Chinese], *Grassland and Prataculture*, vol. 27(02), pp. 40–44.

Liu, G, Zhang, Y, Havstad, K, Mao, P & Han, J 2014, 'Competition of *Leymus chinensis* and *Bromus inermis* in response to gap size and neighbouring root exclusion', *Grass and Forage Science*, vol. 69(3), pp. 479–487.

Liu, HB, Li, L, Pu, X & Du, WH 2017, 'Study on the feed balance situation of the alpine meadow area on the eastern edge of the Qinghai-Tibetan Plateau: based on a steady state model simulation', [Chinese with English abstract], *Grassland and Turf*, vol. 37(4), pp. 26–37, 46.

Liu, HB, Wu, JP, Tian, X & Du, WH 2016, 'Dynamic of aboveground biomass and soil moisture as affected by short-term grazing exclusion on eastern alpine meadow of Qinghai-Tibet plateau, China', *Chilean Journal of Agricultural Research*, vol. 76(3), pp. 321–329.

Liu, HB, Wu, JP, Wang, W, Jin, XL, Liu, ZH & Du, WH 2013, 'Dynamics of aboveground biomass and soil moisture as affected by short-term grazing exclusion in eastern alpine meadows of the Qinghai-Tibet plateau', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 930–931.

Liu, JD, Han, GD, Wan, ZW, Wang, J & Li, ZG 2014, 'Effect of stocking rate on soil physical property with different seasons in *Stipa breviflora* desert steppe' [Chinese], *Journal of Hulunbeier College*, 2014–02, pp. 104–107.

Liu, JH, Hao, DY, Han, GD, Wang, ZW & Qian, J 2017, 'Plant community organization in a *Stipa breviflora* desert steppe and its response to heavy grazing' [Chinese], *Ecology and Environmental Sciences*, vol. 26(7), pp. 1093–1099.

Liu, N, Kan, HM, Yang, GW & Zhang, YJ 2015, 'Changes in plant, soil, and microbes in a typical steppe from simulated grazing: explaining potential change in soil C', *Ecological Monographs*, vol. 85(2), pp. 269–286.

Liu, N, Zhang, YJ, Chang, SJ, Kan, HM & Lin, LJ 2012, 'Impact of grazing on soil carbon and microbial biomass in typical steppe and desert steppe of Inner Mongolia', *PLoS ONE*, vol. 7(5), e36434, doi: 10.1371/journal.pone.0036434.

Liu, N, Zhang, YJ, Kan, HM & Lu, WJ 2013, 'Influence of grassland management on carbon allocation in a semiarid temperate steppe', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 1231–1232.

Liu, QL, Tian, XH & Du, WH 2016, 'Effects of seeding rate and sowing date on productivity of different oat cultivars in alpine pastoral area in Gansu' [Chinese], *Grassland and Turf*, 2016–02, pp. 71–75.

Liu, TZ, Nan, ZB & Hou, FJ 2011, 'Grazing intensity effects on soil nitrogen mineralization in semi-arid grassland on the Loess Plateau of northern China', *Nutrient Cycling in Agroecosystems*, vol. 91, pp. 67–75.

Liu, WH, Zhang, YJ, Shi, SL, Un, J & Wei, XX 2017, 'Effect of variety, fertilization and mixture sowing on oat biomass allocation in the alpine cultivated pasture' [Chinese], *Journal of Plant Nutrition and Fertilizer*, vol. 23(2), pp. 398–407.

Liu, Y, Tian, FP, Jia, PY, Zhang, JG, Hou, FJ& Wu, GL 2017, 'Leguminous species sequester more carbon than gramineous species in cultivated grasslands of a semi-arid area', *Solid Earth*, vol. 8(1), pp. 83–91.

Lou, SN, Chen, XJ & Hou, FJ 2017, 'Carbon balance analysis methods of grassland agro-ecosystems' [Chinese], *Acta Ecologica Sinica*, vol. 37(2), pp. 557–565.

Lu, WJ, Liu, N, Zhang, YJ, Zhou, JQ, Guo, YP & Yang, X 2017, 'Impact of vegetation community on litter decomposition: evidence from a reciprocal transplant study with 13 C labelled plant litter', *Soil Biology and Biochemistry*, vol. 112, pp. 248–257.

Lu, WJ, Liu, N & Zhang, YJ 2016, 'Effect of available nitrogen and phosphorus stoichiometry on litter decomposition dynamics' [Chinese], *Chinese Scientific Papers Online*, CLC number: S812.2, p. 7.

Lu, WJ, Zhang, YJ & Liu, N 2015, 'Changes in stable fraction of soil organic carbon and microbial structure in response of grazing intensity', Proceedings of 23rd International Grassland Congress. November 20–24 2015, New Delhi, India, available on web.

Ma, DT, Gu, YX, Hou, FJ, Zhai, XY, Wang, W, Tian, M, Wang, CZ & Yan, XB 2014, 'Plant genetic diversity and grazing management on the Qinghai-Tibetan Plateau: a case study of a dominant native wheatgrass (*Elymus nutans*)', *Biochemical Systematics and Ecology*, 56, pp. 16–23.

Ma, ZW, Wang, YX, Wang, H, A Bu, Man, Zhang, ZM & Hou, FJ 2017, 'Litter and its function in grazing ecosystems' [Chinese], *Acta Prataculturae Sinica*, vol. 26(7), pp. 201–212.

McAuliffe, G, Takahashi, T, Orr, R, Harris, P & Lee M 2017, 'Distributions of emissions intensity for individual beef cattle reared on pasture-based production systems', *Journal of Cleaner Production*, 171, pp. 1672–1680.

Misselbrook, T, Carswell, A, McAuliffe, G, Takahashi, T, Cardenas, L & Lee, M 2016, 'Nitrogen budgets for lowland temperate beef and sheep grazing systems: The North Wyke Farm Platform, *Solutions to improve nitrogen use efficiency for the world*, Proceedings of the 2016 International Nitrogen Initiative Conference, 4–8 December 2016, Melbourne, Australia.

Mitchell, M, Virgona, J, Jacobs, J & Kemp, DR 2013, 'Seed ecology of *Microlaena stipoides* in grazing systems of south-eastern Australia', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 365–366.

Muhuddin, RA, Badgery, WB, Mwendwa, J, Herrman, N & Moore, AD 2015, 'Modelling the effects of mixed farming systems on soil carbon and crop-livestock productivity in central-west NSW', *Building productive, diverse and sustainable landscapes*, *Proceedings of the 17th Australian Agronomy conference*, 20-24 September 2015, Hobart, Australia.

Pan, ZL, Wang, ZW, Han, GD, Wu, Q, Liu, F & Wang, RZ 2016, 'Responses of methane fluxes on warming and nitrogen addition in *Stipa breviflora* desert steppe' [Chinese], *Ecology and Environmental Sciences*, 2016–02.

Pearson, LJ, Crean, J, Badgery, WB, Murphy, BW, Rawson, A, Capon, T & Reeson, AF 2012, 'Soil carbon sequestration in mixed farming landscapes: insights from the Lachlan soil carbon project', *56th AARES annual conference*, Fremantle, Western Australia, 7–10 February 2012.

Rabbi, SMF, Tighe, M, Delgado-Baquerizo, M, Cowie, A, Robertson, F, Dalal, R, Page, K, Crawford, D, Wilson, BR, Schwenke, G, Mcleod, M, Badgery, WB, Dang, YP, Bell, M, O'Leary, G, Liu, DL & Baldock, J 2015, 'Climate and soil properties limit the positive effects of land use reversion on carbon storage in Eastern Australia', *Scientific Reports*, 5, 17866.

—— 'Land use and management practices have little influence on agricultural soil organic carbon stocks in Eastern Australia', *5th International Symposium on Soil Organic Matter*, Georg-August-University, Göttingen, Germany, 20–24 September 2015.

Ren, HY, Gui, WY, Bai, YF, Stein, C, Rodrigues, JLM, Wilson, GWT, Cobb, AB, Zhang, YJ & Yang, GW 2017, 'Long-term effects of grazing and topography on extra-radical hyphae of arbuscular mycorrhizal fungi in semi-arid grasslands', *Mycorrhiza*, vol. 28(5–6), pp. 117–127.

Ren, HY, Han, GD, Ohm, M, Schönbach, P, Gierus, M & Taude, F 2015, 'Do sheep grazing patterns affect ecosystem functioning in steppe grassland ecosystems in Inner Mongolia?', *Agriculture Ecosystems & Environment*, vol. 213, pp. 1–10.

Ren, HY, Han, GD, Schönbach, P, Gierus, M & Taube, F 2016, 'Forage nutritional characteristics and yield dynamics in a grazed semiarid steppe ecosystem of Inner Mongolia, China', *Ecological Indicators*, vol. 60. pp. 460–469.

Ren, HY, Taube, F, Stein, C, Zhang, YJ, Bai, YF & Hu, SJ 2017, 'Grazing weakens temporal stabilizing effects of diversity in the Eurasian steppe', *Ecology and Evolution*, vol. 8, pp. 231–241.

Ren, W, Hu, N, Hou, X, Zhang, J, Guo, H, Liu, Z, Kong, L, Wu, Z, Wang, H & Li, X 2017, 'Long-term overgrazing-induced memory decreases photosynthesis of clonal offspring in a perennial grassland plant', *Frontiers in Plant Science*, 8, article 419.

Sarula, Chen, HJ, Hou, XY, Ubugunov, L, Vishnyakova, O, Wu, XH, Ren, WB & Ding, Y 2014, 'Carbon storage under different grazing management in the typical steppe', *Soil Science*, vol.47(11), pp. 1152–1160.

Shen, Y, Chen, WQ, Yang, GW, Yang, N, Liu, N, Sun, X, Chen, JS & Zhang, YJ 2016, 'Can litter addition mediate plant productivity responses to increased precipitation and nitrogen deposition in a typical steppe?', *Ecological Research*, vol. 31(4), pp. 579–587.

Shen, YY, Nan, ZB, Hou, FJ, Tian, LH & Yang, HM 2013, 'The role of alfalfa and forage resources in crop-livestock systems in a rain-fed region of north-western China', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 947–950.

Song, Q, Tian, XH & Du, WH 2016, 'Studies on production performance of new triticale lines in alpine pastoral areas of Gansu' [Chinese], *Pratacultural Science*, 2016–07.

Sun, Y, Zhao, X, Hou, FJ, Wang, ZF & Chang, SH 2018, 'Grazing elevates litter decomposition but slows nitrogen release in an alpine meadow', *Biogeosciences*, vol. 15(13), pp. 4233–4243.

Takahashi, T, Behrendt, K, Yuan, Q, Qiao, J, Liu, H, Kemp, DR & Jones, R 2017, 'Modelling sustainable herder and grassland management strategies', Presentation to ACIAR workshop, Hohhot IMAR, 2 April 2017, and ACIAR/MULS/RIAH workshop 'Modelling grassland-livestock management for improved grasslands in Mongolia', Ulaanbaatar, Mongolia, 6 April 2017.

Takahashi, T, Maruya, K & Nakajima, T 2016, 'Non-farmers' willingness to farm: a large-scale choice experiment to identify policy options that can induce new entry to the agricultural industry', *90th annual conference of the Agricultural Economics Society*, University of Warwick, England, 4–6 April 2016.

Tang, S, Zhang, Y, Guo, Y, Zhai, X, Wilkes, A, Han, GD, Jiang, Y, Liu, K & Zhou, P 2015, 'Changes of soil CO_2 flux under different stocking rates during spring-thaw period in a northern desert steppe, China', *Atmospheric Environment*, 122, pp. 342–348.

Tang, SM, Wang, CJ, Wilkes, A, Zhou, P, Jiang, YY, Han, GD, Zhao, ML, Ding, H & Schönbach, P 2013, 'Contribution of grazing to soil atmosphere CH_4 exchange during the growing season in a continental steppe', *Atmospheric Environment*, 67, pp. 170–176.

Thapa, R, Kemp, DR, Michalk, DL, Badgery, WB & Simmons, AT 2011, 'Seedling recruitment of native perennial grasses within existing swards', *Crop and Pasture Science*, vol. 62(7), pp. 591–602.

Thapa, R & Kemp DR 2011, 'Regression trees help develop improved grassland recruitment guidelines', *Proceedings IX International Rangeland Congress*, 2–8 April 2011, Rosario, Argentina.

Ubugunov, L, Rupyshev, Y, Ubugunov, V, Hou, XY, Vishnyakova, O, Lavrentieva, I, Ubugunova, V, Ren, WB & Ding, Y 2014, 'Impact of climate and grazing on biomass components of eastern Russia typical steppe', *Journal of Integrative Agriculture*, vol. 13(6), pp. 1183–1192.

Wan, SQ, Xia, JY, Guo, JX, Han, GD & Ma, KP 2010, ' Responses of temperate steppe to climate warming and N enrichment along a precipitation gradient', *Global warming: the legacy of our past, the challenge for our future*, Ecological Society of America, *95th ESA Annual Convention*, Pittsburgh, Pennsylvania, USA.

Wang, CJ, Tang, SM, Wilkes, A, Jiang, YY, Han, GD & Huang, D 2012, 'Effect of stocking rate on soil-atmosphere CH_4 flux during spring freeze-thaw cycles in a northern desert steppe, China', *PLoS ONE*, vol. 7(5), e36794.

Wang, CJ, Wang, SP, Zhou, H, Li, ZQ & Han GD 2011, 'Influences of grassland degradation on forage availability by sheep in the inner Mongolian steppes of China' *Animal Science Journal*, vol. 82(4), pp. 537–542.

Wang, H, Gan, Y, He, Y, Brandt, K, Qin, XB, Li, ZG 2015, 'Can surface residue alleviate water and heat stress?', *Canadian Journal of Plant Science*, 95, pp. 1–4.

Wang, H, Hou, FJ, Yuan, H, Wan, XL, Xu, L, Chen, XJ & Chang, SH 2013, 'Relationship between stocking rate and species richness on alpine steppe' [Chinese], *Pratacultural Science*, vol. 30(03), pp. 328–333.

Wang, J, Zhao, ML, Willms, WD, Han, GD, Wang, ZW & Bai, YF 2011, 'Can plant litter affect net primary production of a typical steppe in Inner Mongolia?' *Journal of Vegetation Science*, vol. 22(2), 367376.

Wang, S, Han, GD & Bao, YH 2016, 'Difference in FVC changes between desert grasslands with different stocking rates in response to air temperature and precipitation', *Proceedings of the international conference on modern economic development and environment protection*, 28–29 May 2016, Chengdu, China, pp. 250–259.

Wang, XX, Wang, ZF, Cheng, YX & Hou, FJ 2013, 'Vegetation community convergence of pastoralists' pasture at different economic levels in desert steppe' [Chinese], *Pratacultural Science*, vol. 31(3), pp. 381–387.

Wang, XY, Huang, D, Zhang, YJ, Chen, WQ & Wang, CJ 2013, 'Dynamic changes of CH_4 and CO_2 emission from sheep urine and dung patches grazing in typical steppe', *Atmospheric Environment*, 70, pp. 576–581.

Wang, X, Zhang, Y, Huang, D, Li, Z & Zhang, X 2015, 'Methane uptake and emissions in a typical steppe grazing system during the grazing season', *Atmospheric Environment*, vol. 105, pp. 14–21.

Wang, YT, Zhang, Y, Du, YF, Wang, X, Zhao, TQ, Gu, C, Chen, WJ & Zhao, ML 2017, 'Spatial heterogeneity of soil moisture in *Stipa breviflora* grasslands under different stocking rates' [Chinese], *Pratacultural Science*, vol. 34(6), pp. 1159–1167.

Wang, Z, Hou, XY, Schellenberg, M, Yan, Q, Yun, XJ, Wei, ZJ, Jiang, C & Wang, YF 2014, 'Different responses of plant species to deferment of sheep grazing in a desert steppe of Inner Mongolia, China', *The Rangeland Journal*, vol. 36(6), pp. 583–592.

Wang, Z, Ji, L, Hou, XY & Schellenberg, M 2016, 'Soil respiration in semiarid temperate grasslands under various land management' *PLoS ONE*, vol. 11(1), e0147987.

Wang, Z, Li, YH, Hao, XY, Zhao, ML & Han, GD 2015, 'Responses of plant community coverage to simulated warming and nitrogen addition in a desert steppe in northern China', *Ecological Research*, 30, pp. 605–614.

Wang, Z, Yun, XJ, Wei, ZJ, Schellenberg, M, Wang, YF, Yang, X & Hou, XY 2014, 'Responses of plant community and soil properties to inter-annual precipitation variability and grazing durations in a desert steppe in Inner Mongolia', *Journal of Integrative Agriculture*, vol. 13(6), pp. 1171–1182.

Wang, Z, Zhang, Q, Ding, Y, Hou, XY, Sarula, Li, XL, Chen, HJ, Yin, YT, Jhu, J, Liu, ZL & Xin, XP 2014, 'Response of the annual biomass production of a typical steppe plant community to precipitation fluctuations', *The Rangeland Journal*, vol. 36(6), pp. 527–534.

Wang, ZW, Han, GD, Hao, XY, Zhao, ML, Ding, HJ, Li, ZG, Wang, J, Hamilton, A, Liu, YZ, Lata, A & Hexige BY 2017, 'Effect of manipulating animal stocking rate on the carbon storage capacity in a degraded desert steppe', *Ecological Research*, 32, pp. 1001–1009.

Wang, ZW, Hao, XY, Shan, D, Han, GD, Zhao, ML, Willms, WD, Wang, Z & Han, X 2011, 'Influence of increasing temperature and nitrogen input on greenhouse gas emissions from a desert steppe soil in Inner Mongolia', *Soil Science and Plant Nutrition*, vol. 57, pp. 508–518.

Wang, ZW, Jiao, SY, Hang, GD, Zhao, ML, Dong, HJ, Zhang, XJ, Wang, XL, Ayers, EL, Willms, WD, Havstad, K, Lata, A & Liu, YZ 2014, 'Effects of stocking rate on the variability of peak standing crop in a desert steppe of Eurasian grassland', *Environmental Management*, 53, pp. 266–273.

Wu, CC, Gao, XY & Hou, FJ 2017, 'Carbon balance of household production system in the transition zone from the Loess Plateau to the Qinghai-Tibet Plateau, China' [Chinese], *Chinese Journal of Applied Ecology*, vol. 28(10), pp. 3341–3350.

Wu, Q, Han, GD, Wang, CJ, Liu, XJ, Wang, ZW & Li, ZG 2015, 'Effects of mixed grazing system on plant community in the desert steppe in a short time' [Chinese], *Grassland and Prataculture*, 2015–01, pp. 40–45.

Wu, Q, Han, GD, Wang, ZW, Pan, ZL, Liu, F, Wang, RZ, Zhang, RY, Qin, J & Li, JW 2016, 'Effects of warming and N addition on ecosystem carbon exchange in a desert steppe' [Chinese], *Chinese Journal of Ecology*, vol. 35(6):, pp. 1427–1434.

Xue, Y, Yin, GM, Zhang, YJ, Liu, YZ, Tian, YJ & Sun, QZ 2014, 'Response strategy of morphology of *Artemisia frigida* to grazing intensity' [Chinese], *Chinese Journal of Grassland*, vol. 36(6), pp. 18–22.

Yang, GW, Liu, N, Lu, WJ, Wang, S, Kan, HM, Zhang, YJ, Xu, L & Chen, YL 2014, 'The interaction between arbuscular mycorrhizal fungi and soil phosphorus availability influences plant community productivity and ecosystem stability', *Journal of Ecology*, vol. 102(4), pp. 1072–1082.

Yang, GW, Liu, N, Zhou, HS & Yang, YJ 2013), 'Differences in species composition of the soil seed banks among degraded patches in an agro-pastoral transition zone in Inner Mongolian steppe', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 1091–1094.

Yang, GW, Yang, X, Zhang, WJ, Wei, YQ, Lu, WJ, Sun, JJ, Liu, N, Kan, HM, Shen, Y & Zhang, YJ 2016, 'Arbuscular mycorrhizal fungi affect plant community structure under various nutrient conditions and stabilize the community productivity, *Oikos*, vol. 125(4), pp. 576–585.

Yang, TT, Li, P, Xu, XH, Hou, XY, Liu, PT & Yao, GZ 2014, 'Arbuscular mycorrhizal fungi affect seedling recruitment: a potential mechanism by which N deposition favors the dominance of grasses over forbs', *The Rangeland Journal*, vol. 36(6), pp. 545–555.

Yin, QY, Gao, TT, Liu, HF, Wei, CX & Wang, HC 2015, 'Application of Dry Weight Rank method in estimating biomass of natural grassland' [Chinese], *Pratacultural Science*, vol. 32(3), pp. 464–469.

Yin, YT, Hou, XY & Yun, XJ 2011, 'Advances in the climate change influencing grassland ecosystems in Inner Mongolia' [Chinese], *Pratacultural Science*, 2011–06.

Yin, YT, Ren, JZ & Hou, XY 2013, 'Vegetation community convergence of pastoralists' pasture at different economic levels in desert steppe', *Journal of Integrative Agriculture*, vol. 13(6), pp. 1165–1160.

Yuan, H & Hou, FJ 2015, 'Grazing intensity and soil depth effects on soil properties in alpine meadow pastures of Qilian Mountain in north-west China', *Acta Agriculturae Scandinavica, Section B – Soil & Plant Science*, vol. 65(3), pp. 222–232.

Zhai, XJ, Lu, TT, Tang, SM, Liu, XJ, Ma, XZ, Han, GD, Wilkes, A & Wang, CJ 2015, 'Methane emission from sheep respiration and sheepfolds during the grazing season in a desert grassland', *The Open Atmospheric Science Journal*, 9, pp. 23–28.

Zhai, XY, Guo, YX, Hou, FJ, Liu, Y, Ma, DT, Wang, W & Yan, XB 2015, 'Population genetic structure and germplasm conservation of *Stipa purpurea* on Qinghai-Tibetan Plateau under grazing', *Biochemical Systematics and Ecology*, 62, pp. 51–55.

Zhai, YY, Cheng, YX, Chang, SH & Hou, FJ 2015, 'Mechanism of greenhouse gas emission from agro-ecosystem soil in arid regions' [Chinese], *Chinese Journal of Grassland*, vol. 31(9), pp. 231–236.

Zhang, G, Li, X, Kang, YM, Han, G, Hong, M & Sakurai, K 2012, 'Spatiotemporal variability of net primary production over the past half century in Inner Mongolia grassland of China', *Journal of Food Agriculture and Environment*, vol. 10(2), pp. 1168–1173.

Zhang, G, Li, X, Kang, YM, Han, G, Hong, M & Sakurai, K 2013, 'Effect of grassland degradation on soil aggregate size distribution and stability in Inner Mongolia of China', *Journal of Food Agriculture and Environment*, vol. 11(2), pp. 1358–1362.

Zhang, GG, Kang, YM, Han, GD, Mei, H & Sakurai, K 2011, 'Grassland degradation reduces the carbon sequestration capacity of the vegetation and enhances the soil carbon and nitrogen loss', *Acta Agriculturae Scandinavica, Section B – Soil & Plant Science*, vol. 61(4), pp. 356–364.

Zhang, GG, Kang, YM, Han, GD & Sukurai, K 2010, 'Effect of climate change over the past half century on the distribution, extent and NPP of ecosystems of Inner Mongolia', *Global Change Biology*, vol. 17(1), pp. 377–389.

Zhang, J, Han, GD, Wang, H, Iwaasa, A & Sottie E, 2016, 'Effect of soil moisture on grass yield in typical steppe of China' in A Iwaasa, HA Lardner, W Willms, M Schellenberg & K Larson (eds), *The future management of grazing and wild lands in a high-tech world*, *Proceedings of the 10th International Rangeland Congress*, Saskatoon, Canada, pp. 903–904.

Zhang, MY, Huang, D, Wang, K, Zhang, YJ, Wang, CJ, Wang, RC & You, YL, 2012, 'Grassland gap effects on *Elymus dahuricus* Turcz. seedling emergence, survival and growth', *Journal of Arid Environments*, vol. 77(1), pp. 11–16.

Zhang, NL, Wan, SQ, Guo, JX, Hang, GD, Gutknecht, J, Schmid, B, Yu, L, Liu, WX, Bi, J, Wang, Z & Ma, KP 2015, 'Precipitation modifies the effects of warming and nitrogen addition on soil microbial communities in northern Chinese grasslands', *Soil Biology and Biochemistry*, 89, pp. 12–23.

Zhang, Q, Ding, Y, Ma, WJ, Kung, S, Li, X, Niu, JM, Hou, XY, Li, XL & Sarula 2014, 'Grazing primarily drives the relative abundance change of C4 plants in the typical steppe grasslands across households at a regional scale', *The Rangeland Journal*, vol. 36(6), pp. 565–572.

Zhang, Q, Hou, XY, Li, YH, Niu, JM, Zhou, YL, Ding, Y, Zhao, LQ, Li, X, Ma, WJ & Kang, S 2014, 'Alpha, beta and gamma diversity differ in response to precipitation in the Inner Mongolia grassland', *PLoS ONE*, vol. 9(3), e93518.

Zhang, RZ, Huang, D, Wang, K, Zhang, YJ & Wang, CJ 2011, 'Effect of mowing and grazing on ramet emergence of *Leymus racemosus* in the inner Mongolia steppe during the spring regreening period', *African Journal of Biotechnology*, vol. 10(12), pp. 2216–2222.

Zhang, T, Liu, Y, Yuan, H, Zhang, Y & Hou, FJ 2012, 'Effects of cultivation on soil properties in alpine meadow' [Chinese], *Pratacultural Science*, vol. 29(1), pp. 1655–1659.

Zhang, WJ, Zhang, F, Qi, JG & Hou, FJ 2017, 'Modelling impacts of climate change and grazing effects on plant biomass and soil organic carbon in the Qinghai–Tibetan grasslands', *Biogeosciences*, vol. 14(23), pp. 5455–5470.

Zhang, Y, Chen, XJ, Cheng, YX, Chang, YX, Chang, SH & Hou, FJ 2015, 'Effects of stocking rates on functional group diversity and forage quality in rangeland of Qilian Mountain, China', *Journal of Environmental Biology*, *Special Issue*, vol. 36(4), pp. 713–719.

Zhang, YJ, Chen, WQ, Huang, D, Li, ZQ & Rong, YP 2013, 'Effects of grazing management on grassland production and animal performance', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 806–808.

Zhang, YJ, Zhang, LZ, Wang, ML, Li, XL, Yang, QC, Hanson, J & Jorge, MA 2013, 'Drivers of change for grassland and forage systems: A case study of China', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 80–89.

Zhang, YJ 2011, 'Quantitative analysis for the pasture and crop integration production', *Third international conference on farming systems on the Loess Plateau*, Lanzhou University, June 2011.

Zhao, ML, Gao, XL, Wang, J, Han, GD, Bai, YF, Willms, W 2016, 'Effect of litter on the vegetation of the desert steppe in Inner Mongolia', in A Iwaasa, HA Lardner, W Willms, M Schellenberg & K Larson (eds), *The future management of grazing and wild lands in a high-tech world*, *Proceedings of the 10th International Rangeland Congress*, Saskatoon, Canada, pp. 879–801.

Zhao, ML, Wierenga, T & Panter K (eds) 2015, *Poisonous plants: toxicology, ecology, management and medicine*, ISOPP9, Hohhot, Inner Mongolia, China.

Zhao, Y, Ding, Y, Hou, X, Li, FY, Han, W & Yun, X 2017, 'Effects of temperature and grazing on soil organic carbon storage in grasslands along the Eurasian steppe eastern transect', *PLoS ONE*, vol. 12(10), e0186980.

Zhen, L, Yang, GW, Yang, HJ, Chen, YL, Liu, N & Zhang, YJ 2014, 'Arbuscular mycorrhizal fungi affect seedling recruitment: a potential mechanism by which N deposition favors the dominance of grasses over forbs', *Plant and Soil*, vol. 375(1–2), pp. 127–136.

Zheng, Y, Xu, Z, Kemp, DR, Takahashi, T & Jones, R 2010, 'Modelling optimal grazing management for grassland rehabilitation on the typical steppe: a case study in Taipusi', *Philippines Agricultural Science*, 93, pp. 420–428.

Zhou, HS, Yang, GW & Zhang, YJ 2011, 'The impact of soil available phosphorus on the AM fungi and the organic acids exudation at different patches in northern steppe of China', *Journal of Animal and Veterinary Advances*, vol. 11(24), pp. 4553–4558.

Contributions to policy (43)

Behrendt, K, Deblitz, C, Schutz, W, Li, ZG &. Ribeiro, G. 2015, 'Can rangeland livestock systems compete in a global market? Evidence from the past and present', in A Iwaasa, HA Lardner, W Willms, M Schellenberg & K Larson (eds), *The future management of grazing and wild lands in a high-tech world*, Proceedings of the 10th International Rangeland Congress, Saskatoon, Canada, pp. 123–125.

Briske, DD, Zhao, M, Han, G, Xiu, C, Kemp, DR, Willms, W, Havstad, K, Kang, L, Wang, Z, Wu, J, Han, X & Bai, Y 2015, 'Strategies to alleviate poverty and grassland degradation in Inner Mongolia: intensification vs production efficiency of livestock systems', *Journal of Environmental Management*, vol. 152c, pp. 177–182.

Ding, WQ, Li, P, Ren, WB, Hou, XY, Sun, XL, Li, XL, Xie, JH & Dong, Y 2014, 'Evaluation of the livelihood vulnerability of pastoral households in Northern China to natural disasters and climate change', *The Rangeland Journal*, vol. 36(6), pp. 535–543.

Han, GD, Liu, T, Wang, ZW, Li, ZG, Zhao, ML, Havstad, K, Wu, JG & Kemp, DR 2013, 'Adaptive management of grazing lands', in J Chen (ed.), *Dryland east Asia, land dynamics amid social and climate change*, Higher Education Press, Beijing, China, pp. 447–464.

Harris, P, Takahashi, T & Lee, M 2017, 'Visualisation of uncertainty for the trade-off triangle used in sustainable agriculture' *19th EGU general assembly*, European Geosciences Union 2017, Proceedings from the conference held 23–28 April 2017 in Vienna, Austria, p.18815.

Herrick J, Arnalds, O, Bestelmeyer, B, Bringezu, S, Han, GD, Johnson, MV, Kimiti, D, Lu, YH, Montanarella, L, Pengue, W, Toth, G, Tukahirwa, J, Urama, K, Velayutham, M, Zeleke, G & Zhang, L 2016, *Unlocking the sustainable potential of land resources: evaluation systems, strategies and tools*, Working Group on Land and Soils of the International Resource Panel, United Nations Environment Programme, Nairobi, Kenya.

Hou, FJ 2014, 'Adaptation of mixed crop livestock systems in Asia', in J Fuhrer & P Gregory (eds), *Climate change impact and adaptation in agricultural systems*, CABI Publishing, Wallingford, pp. 153–166.

Hou, XY, Han, Y & Li, F 2012, 'The perception and adaptation of herdsmen to climate change and climate variability in the desert steppe region of northern China', *The Rangeland Journal*, vol. 34, pp. 349–357.

Hou, XY, Yin, YT, Michalk, DL, Yun, XJ, Ding, Y & Ren, JZ 2014, 'Herders' opinions about desirable stocking rates and overstocking in the rangelands of northern China', *The Rangeland Journal*, vol. 36(6), pp. 601–610.

Hou, XY 2014, 'Impact of climate change and grazing on temperate steppe', *Journal of Integrative Agriculture*, vol. 13(6), pp. 1155–1156.

Hua, LM 2011, 'Application and practice of IEM on rangeland animal husbandry development project funded by WB/GEF in Gansu, China', Gansu Natural Livestock Products sustainability of production systems workshop, June 2011.

Kemp, DR, Han, GD, Hou, XY, Wu, JP, Hou, FJ, Zhang, YJ, 2012, 'Innovative grassland management systems for environmental and livelihood benefits', *International conference on modern animal husbandry development: objective, path and policy*, Inner Mongolia Agricultural University, 6–7 September 2012.

Kemp, DR, Han, GD, Hou, FJ, Hou, XY, Li, ZG, Sun, Y, Wang, ZW, Wu, JP, Zhang, XQ, Zhang, YJ & Gong, XY 2018, 'Sustainable management of Chinese grasslands: issues and knowledge', *Frontiers of Agricultural Science and Engineering*, vol. 5, pp. 9–23, doi: 10.15302/J-FASE-2018204.

Kemp, DR, Han, GD, Hou, XY, Michalk, DL, Hou, FJ, Wu, JP & Zhang, YJ 2013, 'Innovative grassland management systems for environmental and livelihood benefits', *Proceedings of the National Academy of Sciences of the United States of America*, vol. 110 (21), pp. 8369–8374, doi: 10.1073/pnas.1208063110.

Kemp, DR, Han, GD, Hou, XY, Michalk, DL, Hou, FJ, Wu, JP & Zhang, YJ 2011, 'Solving the problems of degraded grasslands, the environment, livestock and household incomes in northern and western China', *Independent Science & Partnership Council, Consultative Group International Agricultural Research, Science Forum 2011*, Beijing, China, 17–19 October 2011.

Kemp, DR, Han, GD, Michalk, DL, Wang, ZW & Zhou, MG 2012, 'The search for sustainable stocking rates on Chinese desert steppe', in I Yunusa (ed.), *Capturing opportunities and overcoming obstacles in Australian agronomy*, Proceedings of 16th Australian Agronomy conference 2012, 14–18 October 2012, Armidale, NSW.

Kemp, DR, Nan, ZB & Wu, JP 2014, 'Livestock production and environmental improvement, economic pillars along the Silk Road', *Proceedings of the Silk Road Economic Belt 'one belt one road' cultural roundtable conference,* Lanzhou University, China, 23–29 August 2014, pp. 1–11.

Kemp, DR & Wu, JP 2011, 'Steps for livestock and grassland improvement', *Appraisal meeting on Animal Husbandry Plan for Sunan and Kangle County*, June 2011.

Kemp, DR 2011, 'Issues for livestock and grassland system improvement', Gansu Natural Livestock Products sustainability of production systems workshop, June 2011.

Kemp, DR 2017, *Sustainable Chinese Grassland Livestock Systems Program: policy briefs presented to the Chinese government*, Presentation at project workshops, Hohhot and Beijing, April 2017.

Li, P, Sun, XL, Zhang, JL, Zhang, X, Ren, WB 2017, 'Problems and suggestions on the grassland eco-compensation policy' [Chinese], *Chinese Journal of Grassland*, vol. 39(1), pp. 1–6.

Li, XL, Ding, Y, Yin, YT, Yang, TT, Liu, ZY, Ren, WB, Zhang, JL, Sarula, Li, YH & Hou XY 2017, 'Patterns of herders' adaptation to changes in social-ecological systems across northern China's grasslands over the past three decades', *The Rangeland Journal*, vol. 39, pp. 317–328.

Li, XL, Wang, Z, Hou, XY, Liu, ZY, Sarula, Yin, YT, Ding, Y & Hu, J 2014, 'Herders' perception of climate change does not always fit with actual climate change', *The Rangeland Journal*, vol. 36(6), pp. 557–564.

Li, YH, Han, GD, Wang, ZW, Bai, WM, Zhao, ML 2014, 'The response of soil seed bank to clipping and grazing in a *Stipa krylovii* steppe, Inner Mongolia' [Chinese], *Chinese Journal of Ecology*, vol. 33(1), p. 109.

Li, ZG, Han, GD, Zhao, ML, Wang, J, Wang, ZW & Kemp, DR 2015, 'Identifying management strategies to improve sustainability and household income for herders on the desert steppe in Inner Mongolia, China', *Agricultural Systems*, vol. 132, pp. 62–72, doi: 10.1016/j.agsy.2014.08.011.

Li, ZG, Han, GD, Zhao, ML, Wang, ZW & Wang, J 2015, 'An overview of the prospects for family farms' [Chinese], *Acta Prataculturae Sinica*, vol. 24(1), pp. 158–167.

Lorimer-Ward, K, Badgery, WB, Crean, J, Murphy, B, Rawson, A, Pearson, L, Simmons, A, Anderson, K, Warden, E, Packer, I, Trengove, D, Kovac, M 2013, 'Between science, economics and policy to develop and implement a pilot market-based instrument for soil carbon', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 1181–1184.

Michalk, DL 2017, 'Policies, practices, technology and capacity building on livestock: lessons learnt', *Workshop on Strengthening APEC Cooperation on Food Security and Climate Change*, Ha Noi, Viet Nam 19–21 April 2017, 2017/PPFS/WKSP1/005, p. 12.

—— 'Policy development, coordination and coherence on the livestock sector', *Workshop on Strengthening APEC Cooperation on Food Security and Climate Change*, Ha Noi, Viet Nam 19–21 April 2017, 2017/PPFS/WKSP1/017, p. 11.

Nan, ZB 2011, 'Developing grassland agriculture, improving the economy in agricultural and grazing area', Gansu Natural Livestock Products sustainability of production systems workshop, June 2011.

Robinson, B, Li, P & Hou, XY 2017, 'Institutional change in social-ecological systems: the evolution of grassland management in Inner Mongolia', *Global Environmental Change*, 47, pp. 64–75.

Takahashi, T & Lee, M 2016, 'Beyond *ad hoc* debates: a general equilibrium model incorporating the food–feed competition for agricultural land', in A Iwaasa, HA Lardner, W Willms, M Schellenberg & K Larson (eds), *The future management of grazing and wild lands in a high-tech world*, Proceedings of the 10th International Rangeland Congress, Saskatoon, Canada, pp. 391–392.

Waldron, S, Kemp, DR, Bennett, J & Wallace, J 2011, 'Potential for a payment for environmental services scheme to improve grasslands in northern China', *Report to the Australian Centre for International Agricultural Research,* p. 28.

Wan, D, Wan, Y, Yang, Q, Zou, B, Ren, W, Ding, Y, Wang, Z, Wang, R, Wang K & Hou, XY 2017, 'Selection of reference genes for qRT-PCR analysis of gene expression in *Stipa grandis* during environmental stresses', *PLoS ONE*, vol. 12(1), e0169465.

Wang, CJ, Han, GD, Wang, SP, Zhai, XJ, Brown, J, Havstad, KM, Ma, XZ, Wilkes, A, Zhao, ML, Tang, SM, Zhou, P, Jiang, YY, Lu, TT, Wang, ZW & Li, ZG 2014, 'Sound management may sequester methane in grazed rangeland ecosystems', *Science Reports*, vol. 4(4444), doi: 10.1038/srep04444.

Wang, W, Koslowski, F, Nayak, DR, Smith, P, Saetnan, E, Ju, XT, Guo, LP, Han, GD, de Perthuis, C, Lin, ED & Moran, D 2014, 'Greenhouse gas mitigation in Chinese agriculture: distinguishing technical and economic potentials', *Global Environmental Change*, 25, pp. 53–62.

Wang, Z, Hu, J, Li, XL, A-La-Mu-Si, Ding, Y, Hou, XY & Yu, H 2016, 'Effects of land use on biomass of dominant plants in typical steppe' [Chinese], *Acta Prataculturae Sinica*, vol. 26(6), pp. 185–189.

Wu, XH, Li, P, Jiang, C, Liu, PT, He, J & Hou, XY 2014, 'Climate changes during the past 31 years and their contribution to the changes in the productivity of rangeland vegetation in the Inner Mongolian typical steppe', *The Rangeland Journal*, vol. 36(6), pp. 519–526.

Yin, YT, Hou, XY, Michalk, DL, Yun, XJ, Ding, Y, Li, XL & Ren, JZ 2013, 'Herder mental stocking rate in the rangeland regions of northern China', in DL Michalk, GD Millar, WB Badgery & KM Broadfoot (eds), *Revitalising grasslands to sustain our communities*, Proceedings of the 22nd International Grassland Congress 2013, September 2013, Sydney, Australia, pp. 1833–1836.

Yin, YT 2015, 'Herders' forage livestock decision behaviour in northern grassland regions of China, Proceedings of 23rd International Grassland Congress, 20–24 November 2015, New Delhi, India, available on web.

Zhang, G, Kang, Y, Han, GD, Mei, H & Sakurai, K 2013, 'How to restore the degraded grassland in Inner Mongolia of China?' *Journal of Food Agriculture and Environment*, vol. 11(2), pp. 1124–1127, doi: 10.1234/4.2013.4517.

Zhang, YJ, Zhang, X, Wang, X, Liu, N & Kan, HM 2014, 'Establishing the carrying capacity of the grasslands of China: a review', *The Rangeland Journal*, vol. 36(1), pp. 1–9.

Zhang, YJ 2011, 'Brief on development of forage industry and its technology system during national twelfth five-year plan period in China, Gansu Natural Livestock Products sustainability of production systems workshop, June 2011.

Training/driving change (34)

Badgery, W 2015, 'Grazing management to enhance production and environmental outcomes', Proceedings of the Efficiency and Sustainability of Ruminant Production Systems Forum, Jinchang, Gansu, China, 18–21 August 2015.

Jones, RJ 2011, 'Use of the *StageTWO* model', Australian Centre for International Agricultural Research modelling workshop, Gansu, China, June 2011.

Kemp, DR, Han, GD & Zhang, YJ 2011, *Third international conference on farming systems on the Loess Plateau*, Lanzhou University, June 2011.

Kemp, DR 2011, 'Analysing plant systems', lecture at China Agricultural University, May 2011.

—— 'Basic animal production from grazing', lecture at China Agricultural University, May 2011.

—— 'Climate for Australian grasslands: pasture supply', Lecture at China Agricultural University, May 2011.

—— 'Future grassland and landscape management', Lecture at China Agricultural University, May 2011.

—— 'Principles of grazing systems', lecture at China Agricultural University, May 2011.

—— 'Simplifying and managing sustainable grazing systems', lecture at China Agricultural University, May 2011.

—— 'Use of the *StageONE* model', Australian Centre for International Agricultural Research modelling workshop, Gansu, China, June 2011.

—— 2012, 'Thoughts on adapting livestock on grasslands to climate change', International Workshop on Climate Change and Grassland Management, Inner Mongolia Agricultural University, 6–8 September 2012.

—— 2013, 'Sustainable livestock grazing systems on Chinese temperate grasslands', seminar given to Mongolian Department of Agriculture, Ulaanbaatar, June 2013.

—— 'Sustainable livestock grazing systems on Chinese temperate grasslands: strategy and progress', presentation given to Academic Workshop on Sustainable Grazing and Grassland Ecosystems, National Wool and Cashmere Industrial Technology System, Ministry of Agriculture, Gansu Agricultural University, Lanzhou, China, 10–11 November 2013.

—— 2015, 'How do we estimate the optimal stocking rate for sustainable grasslands?', Proceedings of the Efficiency and Sustainability of Ruminant Production Systems Forum, Jinchang, Gansu, China, 18–21 August 2015.

Langford, C 2011, 'Prime lamb and meat production in Australia', presentation to staff and students at Lanzhou University.

—— 2013, 'PROGRAZE and EVERGRAZE national programs in Australia', presentation given to academic workshop on Sustainable Grazing and Grassland Ecosystems, National Wool and Cashmere Industrial Technology System, Ministry of Agriculture, Gansu Agricultural University, Lanzhou, China, 10–11 November 2013.

—— 2015, 'Management for the production of fine merino wool in China', Proceedings of the Efficiency and Sustainability of Ruminant Production Systems Forum, Jinchang, Gansu, China, 18–21 August 2015.

Li, ZG, Zhao, MG, Han, GD, Kemp, DR, Langford, C, Michalk, DL & Junk, G 2013, 'Livestock production training manual – first section (Inner Mongolia)', Inner Mongolia Agricultural University, p. 20.

Michalk, DL 2013, 'Revitalising grasslands to sustain our communities: challenges and issues emerging from the 22nd International Grassland Congress', presentation given to academic workshop on Sustainable Grazing and Grassland Ecosystems, National Wool and Cashmere Industrial Technology System, Ministry of Agriculture, Gansu Agricultural University, Lanzhou, China, 10–11 November 2013.

——2015, 'Achieving high quality sheep products through application of precision management principles', Proceedings of the Efficiency and Sustainability of Ruminant Production Systems forum, Jinchang, Gansu, China, 18–21 August 2015.

Michalk, DL & ACIAR Team 2017, 'Policies, practices and markets: the cornerstone of sustainable grasslands', Keynote address at the Inauguration Meeting of Chinese Grassland Society to set up a specialized committee on grassland economics and policies, Hohhot, Inner Mongolia, 31 March 2017.

Michalk, DL, Kemp, DR & Wu, JP 2016, 'Effect of precision management on product quality and grassland condition', Mongolian Plateau grassland workshop, Hohhot, 14–21 June 2016.

—— 'Effect of precision management on production and quality in the Australian sheep industry', Gansu Academy of Agricultural Sciences workshop, Lanzhou, Gansu Province, August 2016.

Millar, G & Michalk DL 2012, 'Rapid assessment methods', training course, Gansu Agricultural University, Lanzhou, Gansu Province, 14–17 September 2012.

—— 'Rapid assessment methods', training course, Inner Mongolia Agricultural University and the Chinese Academy of Agricultural Science, Grassland Research Institute, Hohhot, Inner Mongolia, 19–22 September 2012.

—— 'Rapid assessment methods', training course, China Agricultural University, Beijing, 24–27 September 2012.

—— 'The use rapid assessment (Dry Weight Rank or BOTANAL) methods for grassland monitoring', training course development, Lanzhou University, Lanzhou, Gansu Province, 21–28 June 2012.

—— 2014, 'Demonstration of field application of rapid assessment method', China Agricultural University Hebei grazing experiment, 20–23 August 2014.

—— 'Field application of rapid assessment method', monitoring grasslands on farms Siziwang Banner, Mongolia, 13–17 August 2014.

Wu, JP (Convenor) 2013, 'Sustainable grazing and grassland ecosystems' workshop, Gansu Agricultural University, Lanzhou, 10–11 November 2013.

—— 2014, 'Technical support and innovation systems for sustainable development in modern ruminants industry' workshop, Gansu, China, 8–9 August 2014.

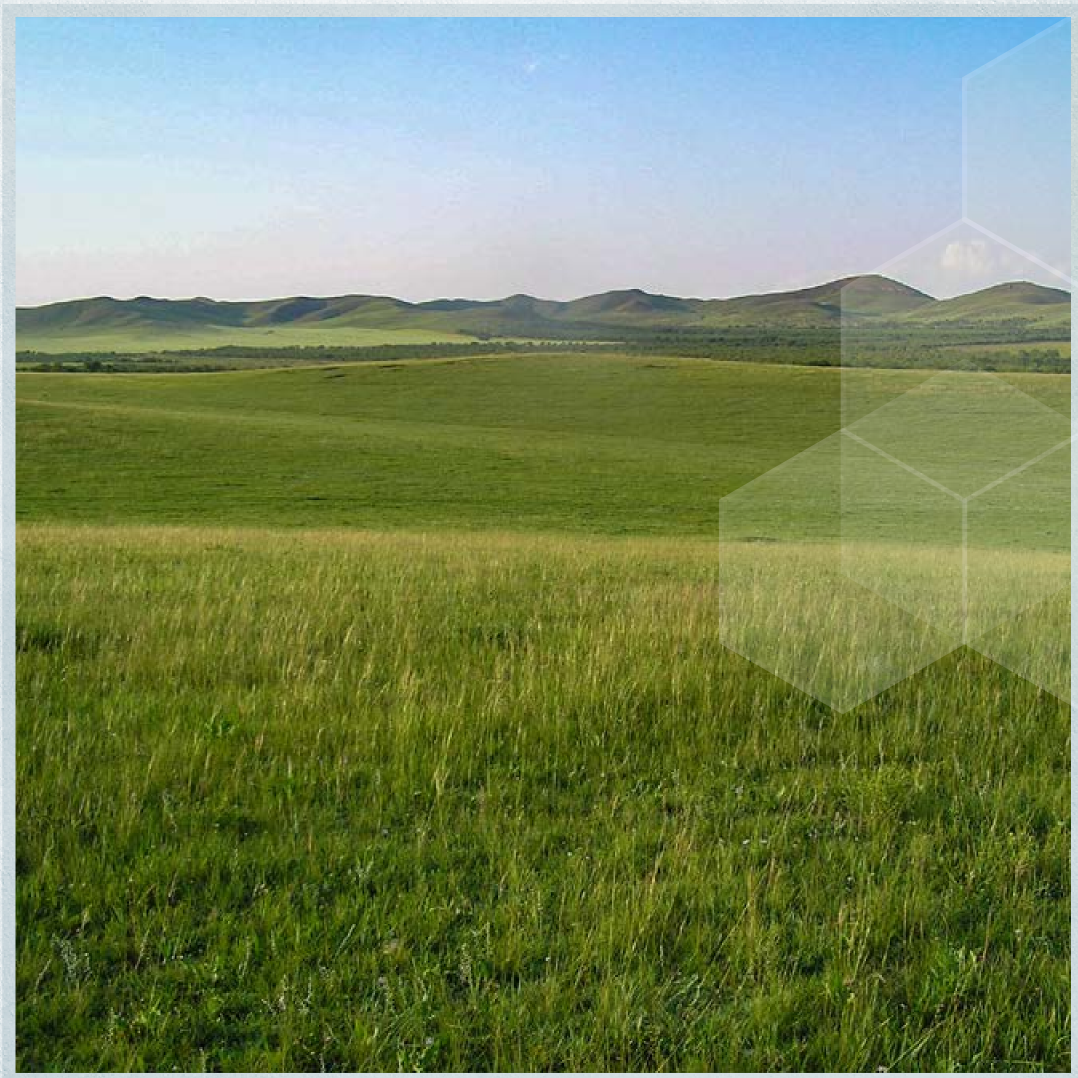
—— 2015, Forum on the efficiency and sustainability of ruminant production systems, Gansu, China, 18–21 August 2015.

Yang, L 2011, 'Use of the precision livestock management (*PhaseONE*) model', Australian Centre for International Agricultural Research modelling workshop, Gansu, China, June 2011.

Zhang, YJ 2010, 'Experimental design and methods', workshop for students and technicians at China Agricultural University, May 2010.

—— 2012, 'Experiment data analysis', workshop for students and technicians at China Agricultural University, October 2012.

—— 2013, 'Scientific paper writing', workshop for students and technicians at China Agricultural University, August 2013.



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