Recent changes in land use and productivity in agro-pastoral Inner Mongolia, China

Brogaard, Sara

2003

MEDDELANDE FRÅN
LUNDS UNIVERSITETS GEOGRAFISKA INSITUTIONER
Avhandlingar 151

Recent changes in land use and productivity in agro-pastoral Inner Mongolia, China

Sara Brogaard

2003

Department of Physical Geography and Ecosystem Analysis

Author's address:

Centre for Environmental Studies/MICLU
Lund University
Sölvegatan 10
P.O Box 170
SE-221 00 Lund
Sweden

email: sara.brogaard@nateko.lu.se

URL: www.miclu.lu.se

ISSN: 0346-6787
ISBN: 91-973857-7-8

Cover photos: Sara Brogaard

Printed by KFS AB, Lund, Sweden 2003

Abstract

This study challenges the prevailing assumption that the expansion of cultivated land areas and increasing number of livestock in the agro-pastoral regions of northern China have aggravated the process of land degradation since the start of the rural reforms in 1978. Land-use and productivity trends in the Inner Mongolia Autonomous Region (IMAR), with special attention to the Keerqin steppe region, have been analysed. A combination of methods including household surveys, analysis of agro-statistics and satellite-based productivity modelling has been applied on different spatial scales.

Increase in grain yields was found, though considerable interannual variability persists, rendering livelihood insecure for farmers. Although statistics for cultivated land area are inferior the area of cultivate land seems to be increasing mainly in the pastoral counties. Farmers acknowledge the importance of the 30-year contract on cultivated land introduced in 1997 with respect to their investment in long-term management, but ranked the availability of chemical fertilizers and the economic means to buy them as more critical for crop production than soil erosion. This indicates the increase in use of and dependence on agro-chemicals, a trend confirmed by regional statistics, and concern is raised regarding the sustainability of the rapid agricultural development.

The spatio-temporal dynamics of primary production for the IMAR was analysed by means of a regionally adapted light use efficiency model. The model, driven by a combination of NOAA AVHRR data and climatic data, has been used to map monthly Gross Primary Production (GPP) for the period 1982-1999. Though the high inter-annual variability in primary production undermines the identification of significant trends, it is indicated that in the western regions there has been no change in biological production, whereas a large area in central IMAR shows a marked increases for the period 1982-99. A combination of increasing crop yields, an increase in precipitation, as well as afforestation projects are probable factors explaining the pattern of regional increase in primary production.

Table of contents

List of papers

The thesis is based on the following papers:

I. Brogaard, S. and Zhao, X. (2002). Changes in land management and attitudes: A case study from Inner Mongolia, China. *Ambio*, 31 (3), 219-225.
Reproduced with permission from the Royal Swedish Academy of Sciences.

II. Brogaard, S. and Li, X. (2003). Agricultural performance on marginal land in eastern Inner Mongolia, China – development in the pre- and post-1978 reform periods. *Land degradation and development* (Submitted November 2003).

III. Runnström, M., Brogaard. S. and Olsson, L. (2003). Estimation of PAR over Northern China in the context of NOAA AVHRR vegetation modelling. *Geocarto International* (Submitted August 2003).

IV. Brogaard, S., Runnström, M. and Seaquist, J. (2003). A. Primary production of Inner Mongolia, China, between 1982 and 1999, estimated by a satellite-driven light use efficiency model. *Global and Planetary Change* (Accepted).

In paper I both authors contributed to the formulation of the aim and discussion of the results and together did the household surveys. Other data were collected by Zhao. Brogaard was responsible for the structure and writing of the manuscript.

In paper II both authors contributed to the formulation of the aim and the discussion of the results and both authors performed data collection. Brogaard was responsible for the structure and the writing of the manuscript.

In paper III all authors contributed to the formulation of the aim, the structure as well as the discussion of the results. The first manuscript was written by Runnström and Brogaard. Runnström conducted the analyses to evaluate the consistency and diurnal precision and the calculation of flux from measurements of sunshine hours. The programming of the PAR model was conducted by Runnström and Brogaard. Brogaard performed the statistical evaluations of the model results and Brogaard and Olsson compared the results with the geo-stationary ISCCP data set.

In paper IV all authors contributed to the formulation of the aim, the structure as well as the discussion of the results. The first manuscript was written Brogaard and Runnström. Runnström, besides having the main responsibility for the PAR computation, has conducted calibrations of the NDVI data set, the computation of daily rainfall, the point based CENTURY evaluation and compiled and analysed the distributed results. Brogaard conducted the other analyses, including changes of the hydrological components, adding of temperature algorithms, photosynthetic pathway, biological efficiency values, and the evaluation of controls of production. Seaquist has provided the first version of the model and valuable inputs on methodologies and the manuscripts in the course of the work

1. Introduction and aim

I first came in contact with the steppe region of northern China through a project on land degradation and desertification initiated by Professor Ulf Helldén. After the first field visits I had to re-evaluate many of my conceptions of dryland environmental change. Being trained in the Department of Physical Geography in Lund where dryland research has focused on the African continent I soon discerned some similarities but also fundamental differences between the two-dryland regions. When discussing the development over the last decades with Inner Mongolian farmers and pastoralists the standard reference point, whether the topic was fertilizer input, working hours or soil conservation, was found to be the set of rural reforms beginning in 1978. Certainly, climatic aspects, such as precipitation trends, droughts and spring time frost spells, are playing a very important role when it comes to agricultural or livestock production, and hence, in determining rural people's livelihoods in this region. Seen from a perspective of several decades however, the drastic policy shifts related to the reforms fundamentally changed the conditions for the land users. These aspects may also be seen as having a relatively greater impact on people's lives in the absence of a marked decline in precipitation such as occurred in the African Sahel (Hulme 2001).

After 1949 China shifted from a semi-feudal system to a communist system, with several periods of extreme political turbulence such as the Great Leap Forward and the Cultural Revolution. With the post-1978 reforms a shift from collective to household farming took place and together with market reforms the incentives for agricultural and pastoral production largely increased. Vaclav Smil, when discussing the development of the Chinese drylands means that "if one seeks confirmation of a thesis about social rather than natural causes of land degradation and about the importance of social as well as natural sciences in the understanding of this process, then China is a classic example" (1987, p 222). The reforms have also had major impact on the national land use pattern of China, which in turn have had effect on the northern marginal regions. As a consequence of the economic upswing the demand for land for other purposes than grain cultivation, such as urbanization, transport, horticulture and fishponds have increased, and the grain cultivated land base has been shrinking (Heilig 1996, Ash and Edmonds 1998, Li 1999). As an effect the pressure on marginal land in the northern dry regions in terms of more livestock and cultivation of marginal land, has been increasing further (Yang and Li 2000, Williams 1997, Hinton 1992, Lin and Zhang 1998).

When having studied parts of the vast material on Chinese drylands published in China (e.g. Zheng 1994, Sun and Yu 1996), as well as the sparse internationally published material (e.g. Luk 1983, Zhao and Gao 1997, Nianfeng et al. 1998), it also becomes evident that land degradation and desertification issues sometimes have been described in a similar manner as during the large desertification debates in the African Sahel during the 1970 and 1980s, where hasty conclusions on desert spread were often based on a few snapshots of land cover. In addition, initial analysis based on two Landsat

scenes indicates that the vegetation cover of the western part of the Keerqin steppe, an area considered to be one of the worst examples of desertification in China, had increased between 1975 and 1989, rather than the opposite (Brogaard and Prieler 1998). As few studies were found quantifying biological productivity over time over a larger regions of arid China there seemed to be an urgent need to produce a rigorous mapping of the vegetation trends, such as primary production, for the region.

Realizing the importance of the post-1979 rural reforms and related changes in land use rights, as well as their potential impacts on the sustainability of the agro-pastoral eco system of northern China, made me use the reforms as a general reference point of the study. The central aim of this thesis is to examine the post reform period in terms of management, land use and productivity with focus on the Inner Mongolia Autonomous Region (IMAR), and specifically, the agro-pastoral Keerqin steppe region in the eastern part of the province.

This aim was achieved through the following objectives:

- To identify farmers' views on land management and attitudes towards land use over the last 20-year period

- To examine changes in the pre- and post-reform period in terms of cultivated land area and agricultural performance based on statistics and interviews

- To analyse spatial and temporal patterns of primary productivity during the post-reform period for the Inner Mongolian grasslands using a satellite-based vegetation model

As can be seen in the thesis objectives above, different approaches to the general aim have been used in different phases of the project. The use of a combination of methods applied on different scales has been of the outmost importance in understanding the dynamics of the agro-pastoral system ranging from the farm level to the regional and provincial level.

2. Study area

The Keerqin steppe region constitutes the eastern part of the IMAR and was the region over which I did my first land cover change study (Brogaard and Prieler 1998). Due to the interesting setting in the transition zone from agricultural to pastoral China, this region also became the focus of the first part of the thesis, while the analysis of the second part includes the whole of the IMAR. This section introduces the study area starting with the province level continuing with the finer scales (Fig 1). Section 2.1 describes the IMAR (analysed in Paper 3 and 4), followed by a description of the Tongliao City Prefecture in the Keerqin Region (Paper 2), and finally the village-level case area near the Daqinggou Nature reserve is presented (Paper 1 and 2).

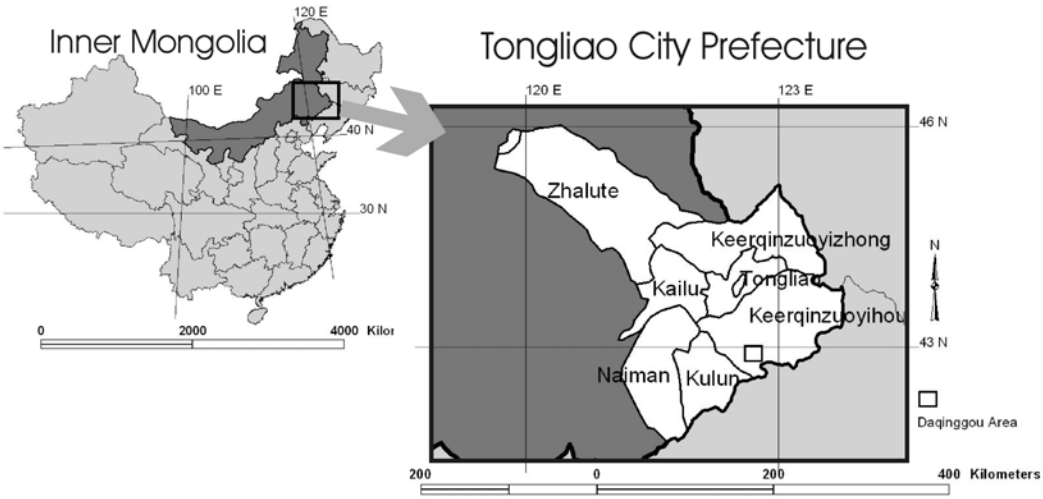

Fig 1. The three spatial scales of the study area, IMAR, the Tongliao City Prefecture and the small rectangle representing the Daqinggou local case area.

In this context a basic outline of the administrative structure in China is given. Under the Chinese's central government there are five autonomous regions, twenty-three provinces, and three large cities. In comparison with the provinces, the governments of the five autonomous regions have considerable legislative freedom in relation to minority groups living within the region (Longworth and Williamsson 1993). Provinces/autonomous regions are divided into prefectures and big cities. The prefectures and the big cities are divided into counties, which in turn consist of townships. Each township is divided into a number of administrative villages, sometimes consisting of several villages at some distance apart. In IMAR prefectures are called "leagues" and counties are often called "banners". These names refer to areas where a considerable number of Mongolians live and where pastoral activities

make up a considerable part of the economy (Longworth and Williamsson 1993). In this summary, however, the central Chinese name has normally been used to avoid the use of too many administrative terms.

2.1 Inner Mongolia Autonomous Region

The IMAR is the third largest of China's provinces with an area of almost 1,2 million km^2 and constitutes about 12 per cent of the total land area of China. On its northeast the region borders on Russia and Mongolia; and to the south on the provinces of Gansu, Ningxia, Shaanxi, Shanxi, Liaoning, Jilin and Heilongjiang. The climate is dominated by the monsoon, which is controlled by the Eurasian continental high- and low-pressure cells. Winters are dry and cold, with strong northwesterly winds regulated by the Siberian-Mongolian atmospheric high-pressure cell. During the coldest month the average temperature sinks to -30˚C in the mountainous northeastern regions. During the summer months the circulation is reversed, bringing warm and humid air masses from the Pacific, resulting in high temperatures and limited and varying rainfall. Most of the IMAR lies in the arid and semi-arid climate zones where annual precipitation ranges from less than 100 mm in the arid west to about 500 mm in the east (Zhu et al., 1986). Between 60 and 80 percent of the precipitation falls during the summer months (June to August) (Domrös and Gongbing 1988). The relative variability of annual rainfall is more than 20 per cent with the exception of the northeastern part of IMAR, and the monthly variability in the spring, early summer and fall is considerably larger (Cheng 1993). The harshness of the climate is emphasized by recurrent droughts, sandstorms, heavy snowfall causing livestock losses, but also cold injuries to crops in spring, local floods and hailstorms (Cheng 1993). Analysing periodicity for dry and wet years a relative short periodicity of 7 to 8 years was found in northern China (Cheng 1993). Liu and Zhang (2002) studying the precipitation trends in the Yellow River basin conclude that the precipitation in the period 1970-1989 is lower than in the period 1950-1969, in most parts of the river basin, while the precipitation between 1990 and 1995 was significantly less than in both these two periods. Zhou et al. (2000), cited in Cao et al. (2003), states that the North China Plain and the Liaohe Plain recovered in the later 1990's from the drought that sustained in the 1980's and earlier 1990's.

The steep rainfall gradient from the wetter east to the drier west gives rise to considerable variation in the species composition and bio-productivity of the Inner Mongolian grasslands and also determines the LU pattern (Fig 2). The northeast part of the IMAR is mountainous, giving rice to orographic precipitation, and the vegetation is dominated by broadleaf and needle-leaf forests. The dominating land cover is grassland where the vegetation pattern from east to west is temperate steppe region, mixed broadleaf deciduous and evergreen forest, which in the western part of the province passes into temperate the desert region (US National Research Council).

Grassland resources vary with topography, soil, ground water level, the impact of humans and animals impact etc. ranging from a good vegetation cover of high quality grasses such as *Caragana intermedia* and *Hedysarum scoparium*, to sparsely vegetated areas with *Stipa breviflora, Artemisia frigida* and *Caragana* scrub (Grasslands and Grassland Sciences, 1992). Sparsely vegetated areas consisting of sand dunes form Sandy Lands (*shamo*) that are often patchy mixtures of dune and grassland, e.g. the Mu Us on the Ordos Plateau and the Keerqin steppe.

The population of the IMAR attains to 24 million; the eastern part being more densely populated. About two-thirds of the population are engaged in agriculture and animal husbandry. The two main ethnic groups are Han Chinese (80 per cent of the population) and Mongolian (15 per cent) (Bilik 1996). The bulk of the agricultural income comes from the livestock sector, but the irrigated areas of the Great Bend of the Yellow River, Tumochuan and the Xiliao River are dominated by farming (China Population Information and Research Center 1999). Between 1980 and 1997 the number of livestock has increased from about 46 million heads to about 71 million (Statistical yearbook of Inner Mongolia 1998).

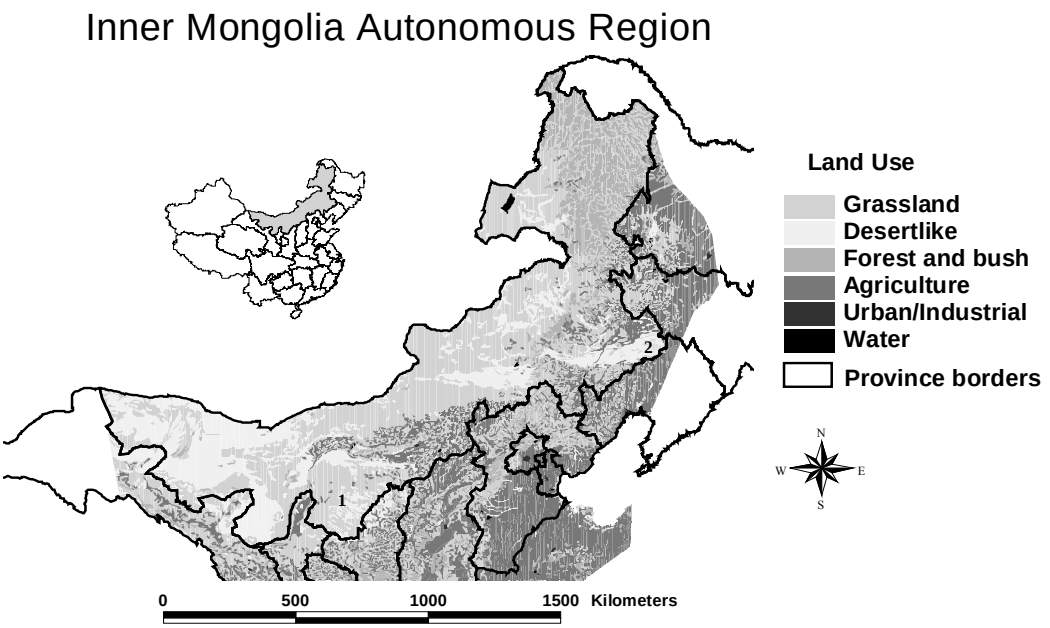

Fig 2. Simplified land use of the Inner Mongolian Autonomous Region. The position of two reference areas used in paper 4 is marked.

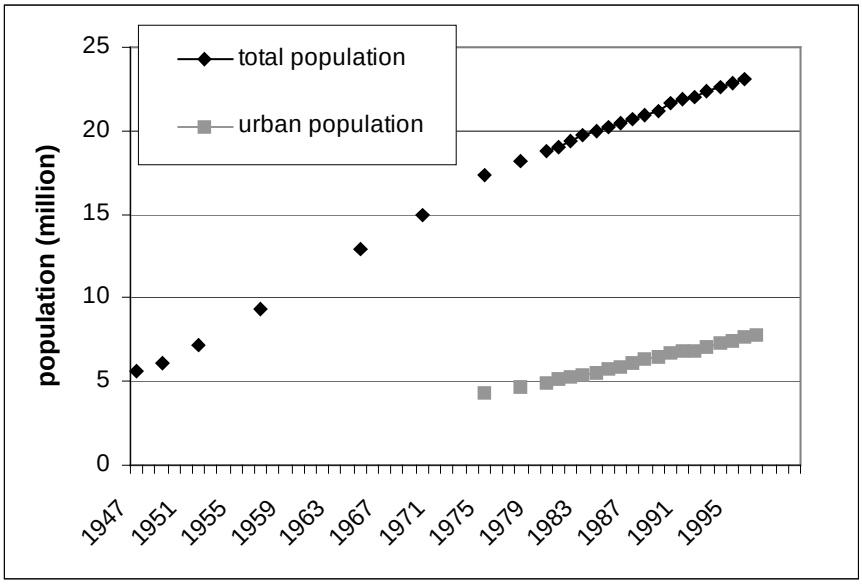

Fig 3. The population and the number of people registered in urban families of the Inner Mongolian Autonomous Region 1947-1997.

The Chinese Central Government has relocated institutions and people from the industrialized high-density regions to the less populated semi-arid regions of the country. According to Zhao (1996) 25-30 million people have immigrated to these regions, mainly during the 19th century and the first half of the 20th century. Sheehy (1992) argues that the increase of the human population has the greatest impact on desertification of Northern China associated with political economic and social systems that have evolved. The extensively managed production systems characterized by grazing animals and nomadism with settled farmers in only a few scattered places was in opposition to the political and cultural system of agricultural China. The opening up of new agricultural land in arid and semi-arid steppe regions serves several purposes including i) reducing the population density in populated agricultural areas, ii) increasing the number of loyal citizens in the sparsely settled border regions, and iii) potentially increasing the total food production necessary to sustain an increasing population.

2.2 Tongliao City Prefecture

The Tongliao City Prefecture (named Zhelimu League until 1999) comprises 60000 km^2 and is a part of the Keerqin (Horqin) Steppe, which also occupies the western parts of Jilin and Liaoning Province. Average annual precipitation ranges from 320 mm to 490 mm over the area, of which about 90 per cent falls during the growing season (April to September) with a variability of 20-30 per cent. In the spring, when the vegetation cover is sparse, wind frequency is particularly high and sand storms may cause damages to young crops through sandblasting. Mean temperature in January is around - 12°C and 23° C in July.

The Xiliao River plain, which makes up the central part of the Keerqin steppe, consists of alluvial sediments that have been re-formed by wind action and now make up the vegetated and unvegetated dunes of the plain (Zhu et al. 1988). To the west the area is bordered by mountains and to the south by loess hills. In alluvial soils along rivers and in inter dune lowland productivity is high, and low in aeolian sandy soils, particularly in mobile sand dunes. Land use in the area can be classified as semi-pastoral in the marginal zone of dry-farming (Zhu et al. 1988). Maize, wheat, sorghum, millet and beans, with patches of rice in the river valleys or depressions, are the dominating crops. The livestock population consists mainly of sheep and cattle, but also of goats and horses.

Administratively the Tongliao City Prefecture consists of eight counties and is classified as semi-pastoral by the central government. The counties are in turn being classified as semi-pastoral or pastoral with variations in land use and agricultural systems. The Holingoule County, located in the most northern part of Zhalute, was form in 1978 and has been merged with Zhalute County in the analysis to enable a time-series study. Zhalute, is the largest county in terms of land area, and has the lowest amount of farmland per capita, while the Tongliao county is the smallest, with the highest average population density, farmland per capita, the largest share of irrigated land, as well as the highest income for agricultural and pastoral households. The proportion of minority nationalities, dominated by the Mongolian ethnic background, ranges from 11 to 70 per cent (Table 1).

Table 1. Socio-economic data for the counties in the Tongliao City Prefecture.

County	Central government Classification (1990)	Population density 1996 (pers/km2)	Total population growth 1947 1996	Minority nationality (% 1990)	Arable land area of total land (%)	Usable pasture land of total land (%)	Average income in ag. and pastoral household
Tongliao	Semi-pastoral	211	3.9	30	34	25	2020
Kailu	Semi-pastoral	83	2.2	11	18	41	1854
Kulun	Semi-pastoral	37	1.5	55	20	40	990
Naiman	Semi-pastoral	51	1.9	32	11	42	1341
Keerqinzuoyi	Pastoral	33	2.5	69	10	61	1179
Keerqinzuoyi zhong	Pastoral	55	2.1	-	18	55	1478
Zhalute	Pastoral	17	11.1	39	6	42	1390

The original natural vegetation cover of the Keerqin area is assumed to have been tree-scattered grassland with a mixture of deciduous and coniferous trees. A successive decline in forest cover from south to north, starting with deciduous trees such as *Querqus*, *Ulmus* and *Juglans*, followed by *Pinus*, has been found through compiling pollen records of Northeast China over the last 5000 years (Ren and Zhang 1998). The decline could not be found to coincide with climatic changes on the millennium to century time scales and were hence interpreted as being foremost a result of human activity. Human activitiy in the Keerqin area has been traced back to the Neolithic Age about 5000 years ago. Since then different tribes and dynasties have succeeded one another in the area. The historical pattern of the transformation of the tree scattered grassland to today's partly vegetated dune landscape is thought to have occurred through a sequence of cultivation of grazing land, subsequent abandonment following misuse of water resources, over-cultivation, overgrazing, or warfare and, finally, translocation of people to other grazing lands to repeat the process (Zhu et al. 1988, Sheehy 1992).

The land-use changes in NE China for the period 1930-1990 were studied by Himiyama (1997) based on 1:100 000 maps produced during the Japanese occupation of Manchuria and a 1990 land use map. The analysed area stretches from the eastern part of Inner Mongolia, including the Liaohe River Plain over the Liaoning, Jilin and Heliongjiang Provinces. Particularly interesting is the development of the "rough land" from the 1930´s map, referring to unused land with sparse vegetation. Himiyama found that even through parts of this area of "rough land" was equivalent to grassland in the 1990 map, considerable extents of this land in Jilin and Heilongiang had been converted to dryland agriculture, while rough land south-east of Harbin as well as in the western part of Liaoning had been converted to broad-leaved forest. Most of the rough land in the eastern part of Inner Mongolia, however, remained as it was in the 1930s.

According to Mei (1985) cited in Sheehy (1992), in an analysis based on Landsat MSS imagery, conclude that the contemporary desertification of the grasslands of the Keerqin sandy land was the result from (1) conversion of grazingland with highest productivity to marginal farmland near rivers and villages; (2) overgrazing by livestock near villages and along rivers; (3) intensive cultivation of formerly stabilized dunes; and (4) conversion of loess uplands to rainfed farming. On the other hand, a preliminary study of land cover and land use changes between 1975 and 1989 in the western part of the Keerqin steppe, also based on Landsat MSS (Brogaard and Prieler 1997), indicated an increase in cultivated land area, foremost along the Xiliao River system, as well as an increase of 60-100 per cent vegetation cover grassland on a former 10-60 per cent cover grassland, as well as a decrease in sandy surfaces with less then 10 per cent vegetation cover. As parallel, a thorough analysis based on NDVI patterns of three Landsat images from 1978, 1987 and 1996 for the Mu Us Sandy Land, indicated that biomass production has increased and few signs of declining biological production was found (Runnström 2003).

The impact of both cultivation and grazing has been studied in various experiments carried out by researchers connected to the Naiman Desert Research Station. Plot based studies have shown that wind erosion on newly reclaimed cropland, i.e. original grassland with a gentle slope and sandy soils, results in severe loss of top soil within two years, and elevation differences of 30-60 cm between the eroded cropland and the sand-covered adjacent grassland (Xu, Liu and Zhao 1996). Studying the effects of grazing intensity on productivity a grassland area was divided into four plots and fenced. Three which where grazed with different intensity and one was used as a control plot. The management practices were maintained for 5 years. The area excluded from grazing recovered rapidly and both grass yields and root biomass increased rapidly while lower grazing pressure resulted in increasing real grass production (existing production and regrowth). Long periods of light grazing, however, caused decline of regrowth capacity. The quality of the grassland in terms of species composition declined with increasing grazing pressure (Zhao et al. 1998).

2.3 The Daqinggou area

The Daqinggou area village-level study area is located at 43° 45’ N and 122° 10’ E, and belongs to the Keerqinzuoyihou county in the southern part of Tongliao City Prefecture, within Chaohai and Mando Township. The study area was selected due to the interesting vegetation contrast within the Daqinggou nature reserve and the surrounding dune type landscape and the availability of a detailed land use map. The area covers about 600 km^2 in size and consists of a dune landscape with scattered cropland, representing the typical agro-pastoral land use system, with the Daqinggou Nature Reserve encompassing part of the area. The nature reserve is believed to represent the natural vegetation state of this part of the Keerqin steppe.

The Reserve encompasses a branched river Valley (Daqinggou and Xiaoqinggou) and has been protected from intense grazing and cultivation by different groups since the late 1800s. In 1988 the area became a national nature reserve that today receives 30, 000 visitors a year. The vegetation of the upper part of the valley stretching outwards to the surrounding dune area is mainly composed of elm (*Ulmus macrocarpa*) and apricot (*Prunus armeniaca*), and other tree species while the surrounding undulating dune area is mainly covered with scattered shrub such as *Artemisia halondendron*, and *Caragana microphylla* (Liu et al. 1996) with scattered crop land.

Livelihoods are based on a combination of cultivation and animal husbandry and 85 per cent of the total population in the county have incomes based on agriculture and animal husbandry. Maize is the dominating crop and livestock consists mainly of sheep, goats and cattle and horses. During the last 50 year period, for which statistical records are available, the population in the area has increased considerably with the total in Keerqinzuoyihou County having a little more than 380 000 inhabitants (around 33 persons/km^2). The dominating ethnic group is Mongolian, composing around 75 percent of the population.

3. Dryland environmental change and land use

This section will outline some of the concepts and controversies concerning dryland environmental change and development, first in a general perspective, followed by a more Chinese-specific framework.

3.1 Concepts and controversies

People living in arid environments are subjected to high vulnerability due to a resource base that is often meagre in combination with highly variable climatic conditions, in particular reoccurring droughts. In regions such as the Sahel or NE Brazil droughts frequently trigger subsistence crises, hunger and famine, whereas in southern Europe or the US Great Plains, although vulnerability to material losses remains, no one starves when drought strikes (Ribot 1996). According to Conway and Barbier (1990) issues of environmental and societal vulnerability to drought are frequently related to the way in which marginal lands are used by society. Production-led policies for both food and export crops are often designed without sufficient knowledge of the conditions and of their implications, particularly for sustainable agricultural development.

A phenomenon that during the last 30 years has become strongly associated with arid environments is desertification. Desertification as a concept was highlighted by the environmental degradation witnessed during the Sahel droughts in the early 1970s and 1980s. During these periods, but even today, the media publish drastic figures of deserts expanding at remarkable rates on former rainfed cropland or grassland (Brown 2001). According to Olsson (1993) the pseudoscientific debate on desertification undermined developing policies in many countries and obscured the real causes of human suffering that can be attributed rather to malfunctioning markets and unjust credit systems. As apposed to these "degradation by man" assumptions, Hellden (1992), when summarizing research on 30 years studies on desertification at Lund University, concluded that no widespread changes in vegetation cover took place that could not be explained by climatic variation, and that crop-yield variation could mainly be explained in terms of climatic variation rather than by human impact.

Although great efforts have been made to develop definitions of the term desertification, the term is still treated with reservation. The differences seem to have more to do with the changing perceptions between man and the environment than with changing environmental conditions (Dahlberg 1996). One of the frequently used definitions is the one by UN (1992): *Desertification is land degradation in arid, semi-arid to sub humid areas resulting from various factors, including climatic variations*. While land degradation occurs everywhere, it is only defined as "desertification" when it occurs in dryland. Rasmussen (1999) argues that the terminology is still vague and questions the usefulness of merging a variety of processes such as impoverishment of vegetation, soil erosion, depletion of soil nutrients, changes in the physical nature of soil, soil salinization, etc. under the single heading of land degradation. Another problem is related to the handling of scale in desertification studies. Processes found in micro-scale case studies that may be termed desertification and degradation are often generalized to regional and national levels, seldom empirically tested (Reenberg 1995).

The impact of land degradation effecting farming systems either changes the productive capacity of cropland, or rangelands, or both of these land-use types. One of the important factors behind the degradation of rangelands has been the concept of over-grazing, derived from the concept of carrying capacity. According to Behnke and Scoones (1993) carrying capacity implies that the increase in animal numbers is controlled by the availability of forage and the carrying capacity is reached at the point of equilibrium where death rates equal birth rates. At this point livestock number may be rather large but not in good condition; neither will the vegetation be dense nor will the plant communities be composed of the same species as in the absence of animals. This implies, there is no single biological optimal carrying capacity, which can be defined independently of the different management objectives, and it therefore makes little sense to speak about overgrazing unless managers also specify the kind of management system they want to maintain (Behnke and Scoones 1993). The unpredictable and variable rainfall in many pastoral areas has presented a further challenged to the carrying capacity concept since it implies that other plant growth

conditions are relatively constant. In dry areas with fluctuating rainfall, multi-year droughts may result in the collapse of both plants and animal populations (Ellis and Swift 1988). According to this "new range ecology", to date mostly concerned with African environments (Banks 2001), rangelands in these highly variable environments are in constant disequilibria rather than striving towards a equilibrium state. According to Ho (2001) the new range ecology is starting to belatedly be applied to China's rangelands.

Conventional range management has relied on vegetation indicators to assess range degradation. According to Behnke and Scoones (1993) biophysical indicators of degradation are: Soil changes (including decreasing fertility, water-holding capacity, and soil loss in excess of soil formation), vegetation changes and changes in livestock production. As regards vegetation changes they include; (1) Changes in vegetation productivity over time, unrelated to rain fall patterns, (2) changes in vegetation cover, (3) changes of plant species composition of use to animals and (4) change in type of vegetation that resulting in decreased fodder (e.g. severe bush encroachment). Because vegetation in semi-arid rangeland areas is continuously disturbed, it has adapted to disturbance and the productivity and composition in such rangeland may be unstable in the short run but resilient over the long term (Holling 1973). Degradation could be said to occur only when the vegetation had crossed critical thresholds that prevent or severely inhibit the subsequent return to a more productive state. In practice, it has proved very difficult to differentiate between permanent human-induced "degradation", as opposed to temporary rainfall induced vegetation change (Ahlcrona 1989, Warren and Agnew 1989).

The existence of long remote sensing data series in as from the NOAA AVHRR sensors, it has enabled the study of large-area, and even global vegetation developments over a 20-year period. The data have been particularly useful for detecting the relative amount of actively photosynthezising vegetation based on the unique spectral signature of green leaves detected through an index such as the Normalized Difference Vegetation Index (NDVI) (Tucker and Sellers 1986). Long-term studies made with this data set has underlined the climatic impact on vegetation development in a semi-arid and arid environment (Tucker et al. 1991, Eklundh 1996) and hence can be interpreted as in support of the event driven "new ecology".

3.3 Dryland agriculture – intensification perspectives

Despite all controversies that have arisen on dryland environmental change and the definitions of desertification, consensus has emerged over the last 20 years. Physical and social scientists agree that solutions to land degradation swell as sustainable development in arid environments require an interdisciplinary framework (Blakie 1985, Blaike and Brookfield 1987, Olsson 1993, Lindskog and Tengberg 1994, Reenberg 1995, Kinlund 1996, Biot et al. 1995, Williams 1996). Although physical and biological forces are at work in nature actually transforming soils and landscape, prevailing economic, political and social conditions, not only direct those forces, but interpret their effects as well (Williams 1996). In the book "The political Economy of Soil degradation", Piers Blaikie (1985) points to a group of processes operating at different scales and at different periodicities that creates the conditions under which land degradation occurs and concludes that the most important factors determining the environment in which the farmer acts are political and economic. According to Warren (1998) the main problem behind simplified assumptions on the direct linkage between soil loss and loss of sustainability is twofold: lack of long-term spatial empirical data as well as misinterpretations of the complex relations between economic and social relations and soil fertility. Soil fertility has to be evaluated in a particular social context; loss of soil fertility is not necessarily the same as degradation if investments can be made to compensate for loss.

Case-studies have shown that the effect of population growth in arid environments need not result in the expansion of cultivated land areas and soil depletion and erosion, but that farmers may actively respond to changed demographic conditions by increasing land productivity if external conditions such as access to markets and available agrochemical inputs provide sufficiently favourable (Mortimore and Tiffen 1994, Harris 1996, Mertz and Reenberg 1999). Mortimore (1993) discusses two possible development pathways of increasing populations insemi-arid environments or low potential areas; one according to the Malthusian destructive linkage between population growth and environmental degradation, and the other, via a Boserup intensification pathway of increased labour input, improved fertilization practices, new cultivars and better crop-livestock interactions, leading to increased farm output and improved household food security. However, the Boserup type of development (Boserup 1965) deals with pre-industrial agriculture, an endogenous process of adoption within agrarian societies that have exhausted the productive capacities of their established agrarian ecosystems. The Asian Green Revolution development, with typical examples from China and Vietnam, include the components of new seeds, fertilizers, pesticides and knowledge in combination with guarantees to sell their products with profit, is a state-lead planned development process (Djurfeldt et al. 1997).

An important distinction has to be made between "green revolution" agriculture on more favourable land such as areas which generally are fertile, irrigated or otherwise well-watered, uniform and flat, and "low resource" agriculture in areas which usually are less fertile, rainfed, diverse and undulating. Marginal lands in the Third World, which are typical of most of sub-Saharan Africa but also of the semi-arid and arid lands, upland, swamplands and converted forestlands of Asia and Latin America, are characterized not only by lower quality and lower productivity but also by their greater insecurity (Conway and Barbier 1990). Changes in marginal farming systems such as the introduction of productivity-increasing technologies and crop specialization may actually impose additional stresses that make the system even more vulnerable if they are not adapted to the prevailing conditions. Although the productivity of marginal lands may not reach the high yields of more favourable lands, experience shows that a combination of appropriate farming techniques, research and extension, inputs, economic incentives, infrastructure and, above all participation and commitment by the land users, can lead to successful projects under the most unfavourable agricultural conditions (Conway and Barbier 1990).

3.4 Dryland research and rehabilitation in China

Based on field surveys and aerial photographs the total area of deserts in China is 1, 3 million km^2 occupying around 13 percent of the total area of China (Zhu et al. 1986). This area includes sandy deserts (shamo) and gravel deserts (gobi) as well as desertification prone land, which is defined as desert-like landscapes in previously non desert land. Out of these the sandy deserts occupy about 45 percent, which in turn include both mobile dunes, semi-fixed and fixed dunes, and wind eroded land. Xinjang has the largest area of deserts followed by Inner Mongolia (Zhu et al. 1986). According to Ding et al. (1998) the study of the Chinese deserts started in the late 1950s but that the research on desertification started after the participation of a Chinese delegation in the UN conference on Desertification in Nairobi in 1977. The leading researcher on desertification in China – Zhu Zhenda - strongly influenced the direction of work as well as definitions on desertification. The first definitions presented were formed by the problems found in local Chinese experiences and were focusing on the processes of wind erosion resulting and encroachments of dunes onto other types of land "sand blown". According to Ding et al. (1998), the definition was widened by Zhu in 1991: "desertification is an environmental degradation process created as a result of the influence of excessive human activities that, owing to the emergence of desert like landscapes, leads to the decline of productive land." In 1996 the definition again was enlarged and salinization and water erosion was included. As discussed in section 2.1 no dramatic changes or significant trends in precipitation have been found over the last decades in the dry areas of China, as for example is the case in for the African Sahel. The Chinese definitions also place a much greater emphasis on the material than on the climatic variables (Zha and Gao 1997).

Chinese scientists generally ascribe natural factors such as increasing aridity associated with physiographic uplift of topography having had the major impact on the formation of deserts over geological times (Sheehy 1992). Desertification in recent times in semi-arid to subhumid areas such as the Keerqin area and the Mu Us Sandy Land are often ascribed to a combination of natural background factors or "potential factors" as a dry and windy climate and sandy soils vulnerable to erosion, while "unreasonable economic activities" by humans, such as cultivation, overgrazing and tree cutting are considered to be triggering factors (Zhu et al. 1988). These factors are sometimes descried in remarkable detail (Zhu 1990, Nianfeng et al. 1998). For example Nianfeng et al. (1998) claim that 5.00 million ha have been desertified over the most recent 20 years of which overgrazing constitutes 34.55 per cent, excessive reclamation 7.45 per cent and firewood cutting 38 per cent. The estimated figures diverge significantly between surveys, as some studies are including actual deserts. This, according to Zha and Gao (1997), is due to lack of agreement in defining desertification, originating in part from inappropriate translation from the international concept.

Report, journals and news media regularly describe the alarming rates of soil erosion and the development of desert like landscapes in the arid, semiarid and subhumid environments of Chinas' northern regions. Other natural hazards leading to various levels of subsistence crises for the northern steppe regions of China are droughts, flooding and heavy snowfalls covering the grassland, preventing livestock from grazing sometimes casing massive animal loss and hunger. In early spring 2000 as well as 2001 dust storms swept much of northern China and deforestation and cultivation of marginal land use is often blamed (BBC Web News 2000-02-27, China daily 2000-05-15, Lin 2001, Brown 2001, Cyranoski 2003). Williams (1997) discusses desertification in China and how the phenomenon has been described over time, including social considerations that condition the way environmental change is defined. Williams concludes that commonly officials have deflected responsibility for environmental disasters away from anyone associated with the current regime or reformers. One strategy is to blame local land-users, in the Mongolian example usually Mongol herders, who both officials and scholars often portray as ignorant, irrational, backward and uncooperative. The other is to make previous governmental regimes, especially the Qing, the Nationalist and the Maoist to blame for ruthless overuse of the land and creating environmental disaster.

In trying to reverse the situation research stations have been established in Yanchi, Shapotou and Naiman for investigation of various techniques of desert reclamation and sustainable resource management. Engineering work such as straw checkerboards have been developed along example rail way lines and roads leading to oil wells which are particularly important and very vulnerable to sand drift (Fullen and Mitchell 1994). Planting of shrubs and trees is an important part of the rehabilitation actions taken in China, which has the potential of bringing both ecological and economic benefits to the planted areas. An attempt to mobilize both resources and people on a national scale to

address desertification in northern China has been the planting of the 7000 km green wall from eastern Inner Mongolia to the Xinjinag Autonomous Region (Zhao and Gao 1997). Through this programme, countermeasures to control and halt desertification in the northern provinces include increasing the vegetation cover through aerial seeding, direct planting, sand dune stabilization, fencing, and by constructing shelterbelts for farmland and pastures (Li et al. 1999). The goal of the project was to plant 10000 ha of trees per year from 1978 to 2000 but because of low survival rates the success of the project has been seriously questioned. Wang and Zhou (2003) mean that the Three North Project, as it is also called, has increased vegetation cover and evapotranspiration, and reduced the surface wind speed and water moisture diffusion. Runnström (2000), analysing vegetation trends and climatic impacts of the Ordos Plateau (the area around the great Bend of the Yellow River), found no significant trends for the period 1982-1983, and hence concludes that a slight increase in production of these grasslands may be a result of increasing vegetation cover through various re-vegetation projects. In the Keerqin steppe area a sub project of the Three North Project, called the 009 Project, is jointly financed by the governments of Belgium and China and by the Food and Agricultural Organisation of the UN. Within the project plantations and shelterbelts are created using both poplars and hybrids of local species. Besides reducing wind and water erosion the planting of trees is also increasing percolation of rainwater into the soil, a way of trying to reverse the trend of lowering ground water tables in the area (FAO 2003).

4. The Chinese rural reforms

Beginning in the 1940s, a land reform program was implemented in the areas under the control of the Communist Party. The landlords' land was confiscated without compensation, and redistributed to the tenants. In order to promote agriculture the Chinese central government encouraged collectivisation and peasants joined small agricultural collectives on a voluntarily basis starting 1952. In 1958, however, the party leadership formed the peoples' communes with an average size of 5000 households and 10 000 acres of cultivated land now forcing farming population into collective agriculture. The system of people's communes faced a severe crisis in 1959-61, when 30 million people were estimated to have died of starvation and malnutrition. After the "great leap" crisis small production teams consisting of 20-30 households were formed, where land was owned collectively, and each worker's income depended on his or her contribution to the production. Greater emphasis was also given to modern inputs and irrigated land area gradually increased after 1962, mostly as a result of expanded powered irrigation. Also the use of chemical fertilizers increased with the promotion of fertilizer responsive high-yielding varieties (HYV) (Yu and Buckwell 1991).

With the post-Mao ”pragmatic” period, beginning in 1978, attention shifted to decollectivization, the dismantling of the commune system in the rural areas, and a mode towards market economy. Collective production was by many seen as stagnant and a return to household and individually based systems was thought to be the best solution. The most significant shift was from planned economy to the decisiveness of market forces. Before 1979, Chinas’ agricultural prices were controlled centrally and had been frozen for almost three decades. Prices did not reflect the value of economic activity and agriculture became the weakest sector, which in turn seriously hindered the development of the whole economy (Li 1996). The evolution of Chinas’ system of agricultural output since 1979 can be divided into three stages. The first was dominated by upward adjustments of state prices by an average of 25 per cent, the second stage included a partial price liberalisation, while the third has involved transformation of the price setting mechanism towards reliance on markets (Li 1996). Simultaneously there has been shift from collective production to household and individual production– an immense and historically important transfer of control over resources and production (Muldavin 1996). Changes within the rural sector included an expansion of free markets, a rise in government procurement prices, a diversification of the rural economy, and product specialisation and crop selection in accordance with rural comparative advantages (Prosterman and Hanstad 1990). The implementation of the Household Production Responsibility System (HPRS), included the contracting land to each family according to household size or labour force in return for tax payment and contribution to welfare funds and the households share of state procurement requirements (Fan 1997). In the pastoral regions the double HPRS refers to the two contracts that hearers can sign, one for rights to animals and the other to be allocated an individual area of grassland (Thwaites et al. 1998). The new system has increased the number of livestock and improved household economy, at the same time in many places also increased herders concern for an environmentally sustainable management of the land (Longworth and Willimasson 1993).

But China’s rural sector still faces considerable challenges in achieving further development. The majority of farmers have supported the reform, but Hill (1994), means that a serious deficiency with the HPRS was the initial short time length of the contract. This initial time periods were to short for many perennial tree-crops and very little long-term investments are done because farmers do not feel adequately assured that they will remain on their present land long enough to recover their investments. Other negative impacts of rapid agrarian change since 1978 have been discussed by a series of authors. These include a general shift towards the maximization of short- term output at the expense of long-term agricultural production, social polarisation, increased vulnerability and risk for individual households, land fragmentation, changes in cropping pattern to more intense and soil-taxing practices, over-use of chemical fertilisers causing immense production through organic matter decline and water pollution and increased use of steep slopes for cropping and overgrazing of grasslands (Hinton 1992, Muldavin 1996, Hu 1997). Longworth and Williamson (1993) in their comprehensive investigation published as “China’s pastoral region” concluded that

these areas have been affected by three sets of policy related issues – population pressure, market distortions, and institutional uncertainties. Such factors have interacted with the adoption of new technologies that may further increase stocking numbers to produce rangeland degradation. It has been suggested that the distribution of grassland to households and the following fencing of grassland in the pastoral areas of China has not been successful as in practice many areas can still been characterized by "open access", or no control at all, often leading to grassland destruction despite fencing. Poor farmers cannot afford to enclose their land as wire is costly, and those who can afford graze their herds on areas still used as public range as long as forage is still available (Ho 1998 and Williams 1996). Some rangelands in China are still managed in common despite household contracts and such tenure arrangement can be more cost-effective and also ecological sustainable for poor regions with marginal and highly variable resources (Banks 2001).

5. Methodology

Section 5.1 and 5.2 summarizes the methodologies used in paper 1 and paper 2, while section 5.3 presents the methodological background and applications for paper 3 and 4.

5.1 Farmers' perception of land use change

The perceptions and attitudes of the land users form the basis for the human activities affecting the land. Different people make different demands on the same environment. When the opinion of the state, or other institution, contradicts that of the land users, conflicts may arise that make it difficult to implement conservation strategies or land use polices (Biot et al. 1995). Dalberg (1996), demonstrates that studies lacking the local perceptions have a tendency to describe all changes in the environment as negative, ignoring the fact that people are still living off the land. As the 1980 rural reforms in China drastically changed farmers' prerequisites for agriculture, their perspective as land users was a natural starting point of the study, and few studies of this kind in the agro-pastoral zone of China have been carried out. To gain information on a range of issues in relation to the reform introduction the interviews were based on the following themes: (1) changes in land use rights (2) changes in management practices related to cultivated land and grassland (3) attitudes towards soil conservation and long-term management (4) household food security and equity. The response from the household food security and equity issues are mainly discussed in Paper 2, while the other issues are discussed in Paper 1.

The respondents were selected from nine villages in the surroundings of the Daqinggou nature reserve, within the Mando and Chaohai Townships. A basic stratification according to income was made to ensure that households interviewed represented a variety of income levels. My experience was that farmers did not express themselves

when village or township cadres were present during the interview, and we therefore made our own selection of households based on prosperity indicators such as the building material of the houses. To get a more comprehensive picture of the development of the study area the interviews were also complemented by interviews with (a) a key informant consisting of an elder person who has particularly good insight into land use changes in the village (b) village leaders were interviewed focusing on the development of the village as a whole (c) interviews were also done with local officials from agricultural and forestry bureaus to get the picture of the main policy changes over time. To complement the local picture, about ten interviews were done with farmers in other parts of the prefecture.

Doing interviews in a different cultural setting, not speaking the same language as the respondent and discussing subjects sometimes economically and politically sensitive is not an easy task. However, I got the impression that the respondent often spoke openly about the different topics, perhaps based on the fact that the interviewers were strangers in the village but still had insights in the land use system and living conditions of the area. The interview topics sometimes required a mixture of quantitative answers, ranked answers or multiple choice questions, or more open answers. This was achieved by following a questioner on issues such as land holdings and new management practices, leaving the answers open for side tracking in the more complex issues such as perceptions of landscape changes, food security issues, etc. in a semi-structured manner (McCracken et al. 1988). Village leader interviews were designed for open answers. The interviews were translated interactively during the interviews, which made it possible to return to unclear points as well as follow up interesting findings. Respondents of Mongolian background usually speak both Mongolian and Mandarin, but on a few occasions an additional translation between Mongolian and Mandarin was done. An issue that may influence the perceptions and attitudes surveyed in the study could be the ethnical background of the respondents, related to the Mongolian traditional nomadic background. In order to enable a comparison between the two groups the ethnicity of the interviewed households was noted. On the basis of the themes discussed during interviews no systematic differences could be distinguished between Mongolians and Han Chinese, which could be related to the fact that the influx of Han agriculturalists in this region has been a relatively gradual process. Further research would be needed to gain a better understanding of Han and Mongolian differences in the study area.

5.2 Agricultural performance

Conway (1986) defines four system properties that together describe the essential nature of agro-ecosystems. These can be used to evaluate the effects of the introduction of new techniques in an agricultural system. Although relatively easy to define they may be less easy to actually measure. Together with cultivated land area these system

properties have been used in Paper 2 to analyse the pre- and post-reform development of agriculture, and discuss the sustainability of the agro-ecological system. A 50-year series of statistics and household surveys in nine villages in part of the area (se section 2.3 and 5.1) have been the main sources of information.

The first system-property analysed is the change in cultivated land area/grain cultivated area that is of major importance from both an economic point of view as well as an environmental sustainability factor in these marginal environments. The second property, productivity, is defined as net increment in valued product per unit of resource such as land, labour, energy or capital and which in this study has been is commonly measured as annual yield per hectare. Yield data was available for the full period only for the case-area county. To understand to which degree the total grain production from the eight counties has been developing these figures were analysed. The third property, stability, measures to which degree productivity remains constant in spite of normal fluctuations in lies within the zone of large variability in precipitation, as well as close to the long term mean of 400 mm which is a critical level for rain-fed agriculture, the stability aspect is particularly important in terms of household or regional grain vulnerability. Fourth, equitability is a measure of how evenly the productivity of the agro-ecosystem is distributed among the land users. The more the agricultural products, the food or the income, is shared among the population of the farm or region, the more equitable the system is. Since a statistical distribution of income for the counties was not available, indications of equitability from interviews in the case study have been discussed. Also related issues such as changes in household food self-sufficiency as well as changes in food patterns are discussed here. The final section of the paper is in large devoted to discuss the over all sustainability of the agro-ecosystem, and is based on the previous sections of the paper.

Chinese statistics have been collected has been collected in a detailed system and most data in terms of population and of agricultural output can be found. However, the quality of this data is inferior in the case of some items, in particular during some periods such as The Great Leap Forward or during the Cultural Revolution (Yu and Buckwell 1991). Although the State Statistical Bureau is responsible for supervising all the data compilation, in principle two different ministries are involved: the Ministry of Agriculture and Ministry of Land and Resources, and different concept used by these two influences the data compilation. In this study, where nothing else is stated, statistical data compiled by various yearbooks and publications by the Ministry of Agriculture have been used. Intentional alterations have been introduced in the figures on cultivated land to obscure the actual amount of land available through under reporting data (Yang and Li 2000, Verburg et al. 2000). The data on arable land resources have been adapted to new and more accurate figures starting since the year 1997 (U.S. Embassy September Report 1998). Within the grain production statistics, the output is considered more accurate than that of cultivated area or yield, and figures for grain and major cash crops are of better quality than those of vegetables, fruit and livestock production (Yu and Buckwell 1991). In this study quality checks of the data

has been made by using observations by farmers to cross check figures such as yields and changes of cultivated area of cultivated land.

5.3 Modelling vegetation by remote sensing

This methodology section describes the methods used to analyse the broad-scale spatio-temporal dynamics of biological productivity for the whole of the IMAR, which forms the second part of the thesis. First a general introduction to the Light Use Efficiency model (LUE) and how this approach is used in combination with remotely sensed data is given. The section then shortly presents the LUE model by Seaquist and Olsson (2003) that has been applied in this study, followed by a section on the specific adaptations and improvements of to the Seaquist-Olsson model to north China temperate conditions.

5.3.1 The light use efficiency model

The primary productivity is the amount of biomass produced through photosynthesis per unit area and time by plants, the primary producers. Primary productivity is usually expressed in units of energy (e.g., joules m -2 day -1) or in units of dry organic matter (e.g., g m -2 year -1). The net flux of carbon between the atmosphere and terrestrial vegetation can be expressed on an annual basis in terms of net biomass accumulation, or Net Primary Production (NPP). Net primary production in turn is the Gross Primary Production (GPP), i.e. the total energy fixed by plants in a community through photosynthesis, minus the respiration that provides the plant with the energy needed for plant physiological and morphological activities. Several methods of estimating NPP over large areas have been established. Some are based on complex eco-physiology models that link carbon and nutrient cycles (Parton et al. 1987, Tian et al. 1999, Kucharik et al. 2000) while others use remotely sensed data to provide information on vegetation condition and to monitor changes in leaf area index or canopy light absorption through time (Running and Hunt 1993, Potter et al. 1993, Goetz et al. 1999).

The time integral of satellite-derived vegetation indices is one of the most important biophysical information that can be quantitatively assessed by remote sensing. Empirical correlations with primary production was first reported in studies such as those by Tucker et al. (1984) and Goward et al. (1985) and later confirmed as particularly useful for studying natural semi-arid grasslands. The relationship is based on the normalized Difference Index (NDVI) or similar relative measures of reflected radiation such as Ratio Vegetation Index (RVI), Difference Vegetation Index (DVI) or the Soil Adjusted Vegetation Index (SAVI). These indexes are based on combinations of several bands from the electromagnetic spectrum whose values are added, divided, or multiplied or in any way adjusted to yield a single value. NDVI, the most commonly

applied of these indices, is based on the ratio between the near infrared (NIR) and the red (RED) reflectance proportions (Eq. 1).

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \qquad \text{(Eq. 1)}$$

An extensive body of work shows that NDVI can be related to a number of plant growth parameters, such as Leaf Area Index (LAI), fractional vegetation cover and standing biomass. The index has also shown to be related to radiation absorption characteristics such as the fraction of absorbed photosynthetic radiation and absorbed photosynthetically active radiation, and biophysical rates such as net canopy CO_2 exchange as well as primary productivity (summarized by Seaquist 2001). Other applications of the NDVI are in the study of vegetation phenology (Olson and Eklundh 1994, Eklundh 1996) as well as spatial and temporal rainfall pattern in dryland ecosystems. NDVI has been used in long-term studies as an indicator of relative biomass amount (Tucker et al., 1994, Runnström 2000; Ostwald 2000, Eklundh and Olsson 2003) and has in this way provided a picture of trends and variability of the photosynthetic activity, but does not enable an absolute estimation of primary production.

In the papers by Monteith (1972 and 1977) the basis was laid for the parametric type of model termed the Light Use Efficiency model (LUE). The LUE approach proposes that biological production is directly proportional to the amount of photosynthetically active radiation (PAR) absorbed by the vegetation canopy (APAR) (Eq 1.). The conversion of Photosynthetic active radiation (PAR) into biomass depends on access to water and nutrients, further regulated by vegetation stresses, temperature, diseases etc.

$$GPP = \varepsilon \bullet APAR \qquad \text{(Eq. 2)}$$

Where:
ε = photosynthetic efficiency (gMJ-1)

$$APAR = PAR * FPAR \qquad \text{(Eq. 3)}$$

$$FPAR = a \bullet NDVI + b \qquad \text{(Eq. 4)}$$

APAR is the product of FPAR (Fraction of absorbed Photosynthetically active radiation) and PAR (Eq. 3). *a* and *b* are regression coefficients for deriving the fraction of plant canopy absorbed photosynthetic radiation (FPAR) through the NDVI (Eq.4). Substituting APAR in Eq.2 then gives:

$$GPP = \varepsilon \ (a \bullet NDVI + b) * PAR \qquad \text{(Eq. 5)}$$

Light use efficiency models have been widely used to map primary production for terrestrial biomes as they reduce the fundamental rules of plant physiology and ecology to a limited number of parameters (Seaquist 2001, Novellon et al. 2000, Rasmussen 1998, Paruelo et al. 1997, Law and Warring 1994, Ruimy and Saugier 1994). The LUE model also makes it possible to absolute values of primary production.

When experimenting on crops in Britain, Monteith observed that ε did not vary appreciably and could therefore easily be included in a remote sensing model as a constant. In uniform annual vegetation under non-stressed conditions (Sellers et al. 1992), or in natural vegetation on a global or continental scale (Tucker et al. 1986) the relationships between NDVI, canopy structure, photosynthetic fluxes, and NPP seem to be constant. This supported the view that stress reduces the capacity of the canopy to absorb PAR, and thus reducing NDVI, while leaving e relatively constant. If ε is assumed to be stable then there would be no difference between the statistical approach for estimating primary production and the LUE method (Rassmussen 1998).

Later studies, however have suggested that environmental stress may cause a reduction in growth either through a decrease in leaf area or through reduction in ε, or through both acting together in a sequence, suggesting that the photosynthetic performance of stressed vegetation cannot be predicted from NDVI alone. (Hunt and Running 1992, Running and Hunt 1993, Potter et al. 1994, Runyon et al. 1994). Vegetation indexes are rather a measure of integrated past photosynthetic activity (and resulting canopy structure) (Gamon et al. 1995). ε has shown to vary, not only between biomes, but also between species and between plants of a particular species and over time, which may be attributed to short-term environmental stress (Goetz and Prince, 1999). This would mean that stress initially is manifested through a reduction in the efficiency coefficient while during prolonged stress through decrease in leaf area and, hence in interception of radiation resulting in lower NDVI. Hence the quantification biological productivity using NDVI require a method that considers stress-induced changes in vegetation indices in combination with environmental and physiological variables (Running 1990, Gamon et al. 1995). The new expression for ε evolving from this consists of the potential efficiency value (εp) defining the maximum biological efficiency of the PAR conversion to dry matter multiplied by one or several environmental stress scalars. The stress factors included in developed models are dependent on the regional characteristics of the studied ecosystems and the complexity of the model.

5.3.2 The LUE model applied in this study

The Seaquist-Olsson model (Seaquist 2001, Seaquist et al 2003) is a light use efficiency model using the NOAA NASA 8 km Pathfinder Land Data Set (PAL) together with climate and soil information to map the growing season GPP originally developed for the West African Sahel. In the model PAR at the ground is computed by

using the Ångström equation, adapted to regional West African conditions through calibrating the three cloud classes from PAL´s Clouds from AVHRR (CLAVR) with ground-measured data (Seaquist and Olsson 1999). In the hydrological component of the model, potential evaporation (PET) is partitioned into potential soil evaporation and potential transpiration through an estimation of vegetation fraction derived from NDVI. Evaporation from bare soil and potential transpiration are treated separately by a two-layer bucket model that gives an estimate of the impact of soil water stress on plant growth. The ratio between actual to potential transpiration then yields the water stress term. The maximum photosynthetic efficiency value was set to a constant value over the area, $5gMj^{-1}$, reflecting the prevailing proportion of C3/C4 ratio of the area. The model resembles some of to other LUE models to the extent that it is embedded in the LU framework. At a more detailed level the approach is unique as it considers only the water used by plants (actual transpiration) to index water stress, an approach assumed to be more biophysically realistic, and enhance the precision in the water stress term, especially across vegetation gradients. This parameterisation is particularly important for applications to partially vegetated landscapes where the fate of precipitation is to a great extent controlled by relative amounts of vegetation.

The model was tested for sensitivity of input parameter errors, for the parameters NDVI, PAR, water stress and εp through Monte Carlo simulations (Seaquist 2001). As a general rule the higher the GPP the robuster the production is. Among estimated terms PAR lends the least error, the NDVI term error was relatively low determining the GPP of savannah and cropland mosaic, but contributes to over 90 per cent of the total error variance in the desert fringe. εp rarely exceeds 30 per cent of the error variance, while the model is most sensitive to the water stress scalar.

5.3.3 Modifying and adapting the model

Since the original model was developed for the African Sahel it has been partly improved and adjusted to the continental type of climate prevailing in northern China and to run the model in longer time series. These changes, together with a description of input data, are presented in the following section and highlighted in grey boxes in Fig. 4.

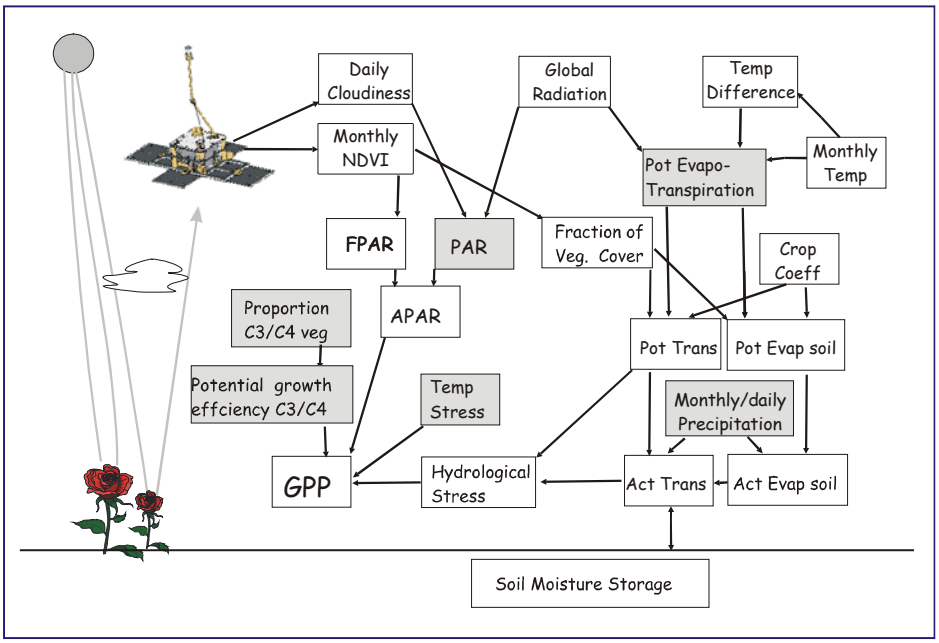

Fig. 4. Overview of the GPP model. Components that have been modified or added in the course of this work are highlighted in grey.

Data sets

The satellite data come from the Pathfinder Land (PAL) data set, a product derived from the NOAA AVHRR sensors (James and Kalluri, 1994). NDVI at monthly intervals and daily classifications of cloud cover from the CLouds AVHRR (CLAVR) at a spatial resolution of 8x8 km, were used for the period 1982 to 1999. In addition climate data from 40 stations with monthly observations of precipitation and mean maximum and minimum temperatures, were used to drive the hydrological component of the LUE model. Daily data from two stations (e.g. solar radiation, sunshine hours, and precipitation) were used for calibration purposes. Maximum soil moisture storage (SM_{max} – computed from topsoil texture and soil depth) was taken from version 3.5 of the FAO Digital Soil Map of the World (DSMW, version 3.5 1995).

Estimation of PAR

Direct measurements of PAR are scarce, particularly in the vast and sparsely populated drylands of the world. Instead point based observations of sunshine hours and remotely sensed methods based on satellites have been used. Seaquist and Olsson (1999) used the NOAA CLAVR data set and regional on Ångström coefficients to adjust daily theoretical radiation calculations on a pixel-by-pixel basis. The CLAVR data set vas tested over the study area in terms of long-term time-consistency, the classification precision of the three classes, and the possibility of using an instantaneous satellite overpass to characterize the full day's cloud feature. This evaluation made us aware of

the inclusion of diffuse radiation in the clear sky CLAVR class so that it was impossible to use the Ångström equation. Instead, a direct empirical relationship between CLAVR and top of the atmosphere radiation values for each CLAVR class was developed. Top of the atmosphere Global Radiation (GR) was calculated with a model where daily estimates of incoming radiation were derived trigonometrically and total incoming PAR was approximated to 48 percent of the short-wave flux (SW) (Frouin and Pinker 1995). Daily measurements of SW radiation for the year 1989 from Tongliao were used to empirically determine the fraction of penetrated SW radiation for each CLAVR class.

Changes in the hydrological component of the model

Potential evapotranspiration was estimated with the Hargreaves method (Shuttleworth, 1993) and the results agreeing well with measured monthly data at the two control stations (Ganjig and Wushen). To obtain daily precipitation data for the computation of actual transpiration and bare soil evaporation monthly interpolated rainfall was temporally scaled down to simulate daily rainfall. Based on a total of 15 years of daily data from 2 climate stations 3 magnitude categories of rainfall events were identified; small, medium and large, and the monthly frequency of these events was determined. The days that should receive rainfall were determined through a random-number generator grid cell by grid cell.

New stress factor term and computation of photosynthetic efficiency

To allow for the effects of temperature stress on C3 vegetation (C4 vegetation is not affected by temperature) two temperature stress terms (after Potter et al., 1993) suppressing ε have been applied. The first term (ts_1) serves to suppress ε at very high and at very low temperatures and the second term (ts_2) to suppress ε when the temperature is above or below the optimum temperature (t_{opt}). t_{opt} is defined as the mean monthly temperature when NDVI reaches its maximum.

In the original model an estimation of the mixture of C3 and C4 photosynthetic pathway was taken into account through the fixed photosynthetic efficiency value. Lacking data spatially distributed data on photosynthetic pathway for the IMAR the observed relationship between the proportion of C4 grasses and temperature was used (Teeri and Stowe, 1976). For C4 vegetation Photosynthetic efficiency *(εp)* is not dependent on temperature and has a value of 6.1 g DM/MJ (equal to 2.76 gC/MJ if the conversion factor for dry matter yield is assumed to be 0.45^{-1}). The gross ε for C3 plants is temperature-dependent and was calculated according to Collatz et al. (1991).
Including these above additional functions and changes into equation 2 yields equation 6. The GPP results are presented in gm^{-2} of dry matter (DM) and represent both above and belowground production.

$$GPP_{total} = \sum_{i=1}^{n} [(propC3 \times \varepsilon pC3 \times ws \times ts_1 \times ts_2 \times APAR) + (propC4 \times \varepsilon pC4 \times ws \times ts_1 \times ts_2 \times APAR)]$$

(5)

Uncertainty and LUE-controversy

The PAL NDVI data set was found to be stable through time as investigated by Eklundh and Olsson (2003) for the African Sahel until the year 2000 when a rapid drop in NDVI is evident, possibly a result of a delayed overpass time for NOAA-14. This was further tested by Lindström (2003) but no relationship between NDVI and solar zenith angle for the period 1982-2000 was found. The data set was tested for North China dryland conditions by Runnström (2000) between 1982-1993, and was found to be reasonably stable.

Despite the widespread applications of the LUE model, its biophysical basis has been challenged. Alexandrov and Oikawa (1997) argue that in satellite based LUE models FPAR should rather be used to estimate the growing period. In LUE models FPAR is related to LAI, yet theoretical investigations show that FPAR remains constant over a wide range of LAI thus undermining fundamental assumptions of the model. Another weakness consists of the danger of deriving multiple variables from the same source, i.e. very many biophysical variables may be related to the NDVI. Alexadrov and Oikoa also emphasize the in equivalence between the satellite derived macro-parameters and modelled micro-scale variables in an ecological sense.

6. Results and conclusions

In this section the results and conclusions of the four papers included in the study are brought together and discussed.

With the introduction of the HPRS in the villages in the Daqinggou area cropland was first contracted to households in 1979 or early 1980. The length of the contracts as well as the number of land re distributions varied between villages. Normally the land is divided into at least two land quality types, black soil of high organic content, *heishadi*, and white sandy soil, *baishadi*. The average landholding varies from 0.3 to 0.9 ha per person and all villages have restrictions on the total area of cultivated land; 80 per cent of the respondents indicated they had preferred to increase their cultivated land but were hindered by village restrictions. According to farmers', the introduction of new varieties of maize in combination with an increase in the use of fertilizers has improved yields, though yield variability persists due to erratic rainfall. Further increases in crop production today were considered to be hindered by low soil fertility, lack of money (mainly for improving soil fertility or digging a well), as well as irregular rainfall that has only partly been compensated for through increased irrigation, followed by lack of land for expansion of cultivation and soil erosion which were equal ranked. Other factors referred to were lack of knowledge of agriculture practices, the poor quality of seeds and lack of farm machinery. Farmers used on an average between 10 to 45 kg mu^{-1} equal to 150 to 675 kg ha^{-1} averaged over the total area cultivated, and they emphasized that even in a year with abundant rain, yields are

low if inorganic fertilizers are not applied, and lack of money to buy fertilizer being a major problem for poor households. According to researchers at the Naiman ecological station the fact that more fertilizer is needed each year to maintain yields, as pointed out by several farmers, can be ascribed to lack of phosphorous or lack of micro-nutrients.

In the agro-pastoral areas of IMAR, unlike in the pastorals areas, the process of contracting grassland to individual families did not begin until 1999 and the expectations of farmers are high. The main obstacles to raising more livestock were found to be lack of money, and the availability of grazing land. Apart from the necessary capital for fodder and veterinary care of the livestock, taxes on livestock and money for building shelters are needed. The farmers stressed the negative impact of grazing and cultivation on soil erosion and emphasized that fact that differences in vegetation composition and cover between the nature reserve and the surrounding land are due to the human pressure. The prevailing view was that the vegetation cover had decreased and the formation of bare sand patches had accelerated over the last 20 years, but that the situation over the last 5 to 10 years had improved as a result of afforestation in enclosed areas and along roads. However, major differences in opinion between the villages surveyed in terms of post-1978 land development were revealed during the study. A possible explanation for this could be an increasing importance of the village leader in environmental resource management parallel to increasing economic influence of the village leaders on the economic situation. The fact that certain land management regulations and land-use policies issued by higher administrative levels, as for example the Prefecture Agricultural Bureau, were not followed, or even known about, at village levels is not a new phenomenon and constitutes a major problem for the central government when enforcing policy decisions.

Investigating land-users' and village leaders' perspectives on post reform land use gave essential insights into the land-use system that to a certain extent could be generalized to a regional level using time series of agro-statistics from the Tongliao City Prefecture (previously Zhelimu League) in Paper 2. The study shows that grain production has not only kept pace with population growth during the post reform years but that the output per capita has considerably increased. This has been achieved mainly through intensification and with expansion limited to two of the pastoral counties, even though data adjustment since 1997 makes the interpretation of the later part of the time-series difficult. The increase in total grain production of the post-reform period has occurred later than in the rest of China, partly as a result of that the rise in maize yields in China occurred later than that for wheat and rice and also due to the later response to the reforms in remote and marginal areas (Yang 1999).

Through the household surveys presented in Paper 1 it was concluded that the farmers acknowledge the importance of the 30-year contract on cultivated land introduced in 1997 to their investment in long-term management such as tree planting and enclosing

cultivated land. However, they also emphasize the increasing importance of chemical fertilizers for short-term economic subsistence. As regards the farmers in the Dagingou area the differences in access to agro-chemicals and other means of agricultural intensification such as water pumps, as well as knowledge about the new agriculture practices are important factors behind the increasing differences in household income. A continuous trend of more applied fertilizers per hectare is found among the counties in the Tongliao City Prefecture and the increase is steeper in the semi-pastoral the counties than in the pastoral counties. Through the study presented in Paper 2, also several other differences between the pastoral and semi-pastoral counties were discerned; only in the pastoral counties a marked increase in cultivated land area in the post reform period was found, and the variability in output is also higher. In general interannual output variability has increased, in spite of the more intensive use of the land in terms of high yield varieties, fertilisers etc. A maintained variability of total grain output was found only in the two counties, Kailu and Tongliao, which can be explained in part by their considerably higher proportion of irrigated cropland. Farmers confirm these findings, and as they only cultivate a few hectares per household, they experience larger variability than any of the aggregated area statistics show. However, having land located both in the moister depressions and on the dunes, can moderate the effect.

Generally speaking, in the less developed northern and western areas of China, there are fewer possibilities of off-farm income, and hence the effort put into land may be larger, than in other parts of China where a process known as discontinuous farming is increasing (Li and Wang 2003). It can be concluded that the intensification process has brought increased wealth to the farmers in the area, but also widened the gap in household income and living standard. The long-term sustainability of the rapid increase in use of agro-chemicals use can be questioned and the study points to a need for information on more sustainable fertilization practices. The farming systems in this area of the IMAR are generally based on a combination of crop cultivation and animal husbandry complementing each other to give maximum economic and environmental sustainability. As a way of minimizing the damage by trampling and grazing, and hence making a further return to denser vegetation cover possible, it has been suggested that livestock should be kept in enclosures and instead cutting grass to feed them. Another suggestion is to increase the proportion of biomass from cultivation, i.e. mainly corn stalks, to be used as supplementary animal feed rather than as to burn it as fuel as is often done today. Increasing the number of pigs raised and sold is another income-generating activity (Shi et al. 1998).

Analysing provincial scale spatial and temporal dynamics of primary production for the whole of the IMAR provides yet another way of studying the impact of natural and human agents on the productivity and land cover of the agro-pastoral ecosystems. In Paper 4 GPP is modelled for the 1982 to 1999 period, which also enables, on a cell-by-cell basis, the calculation of mean GPP values, GPP variability as well as indications of trends throughout the period. When modelling aboveground primary production of

ecosystems through the light-use efficiency approach the incoming PAR is an essential variable. In order to take advantage of the higher resolution of the NOAA AVHRR CLAVR data set in comparison with PAR data based on geo-stationary satellites, the resolution, consistency, precision and bias of the CLAVR data set was first tested (Paper 3). No trends are apparent through the time series as regards the annual number of the three classifications, clear, mixed and cloudy. The quality of the data over time is improving in terms amounts of missing data, which has been decreasing considerably in the 1990s as compared with the 1980s. A coefficient of atmospheric transparency was empirically determined from ground measurements for each of the CLAVR classifications. Clear pixels corresponded to an average 61 per cent penetration of the top of the atmosphere radiation, mixed pixels to 47 per cent and cloudy pixels to 40 per cent and daily images of surface incident fluxes of SW could be estimated. Monthly fluxes modelled from the CLAVR data for the growing season were evaluated against ground data and found acceptable (NRMSE = 6.6 per cent).

Running the revised and adapted model for the 18-year period resulted in a mean annual GPP ranging from about 100 g/m^2 in desert regions in the west (e.g. Tenger and Ulan Buh) to about 3400 g/m^2 in the northeast. Highest variability was found at the margins of the deserts in the west where rainfall is low and erratic. The fitting of linear trends throughout the 18-year period reveals that the western regions show no change, while trends are negative for the northeastern part where rainfall has decreased. The central part of the IMAR shows a noticeable increase in GPP that coincides with increasing precipitation. Despite the rapid increase in the number of grazing animals on the steppes of the IMAR for the 1982-1999 period, our model estimates do not indicate any general trend towards declining biological production. However, the high interannual variability of primary production for this region makes it difficult to identify long-term trends, despite the 18-year record.

For the two reference sites representing typical steppe vegetation of the Keerqin steppe (Naiman) and the Mu Us (Eutoke), the controls on production have been analysed. For both sites the mean water stress and NDVI show statistically significant Pearson r-squared values against seasonally summed GPP, while potential ε for C3 vegetation was statistically significant for the Naiman site, and temperature stress for the Eutoke site. Disaggregating seasonal precipitation and water stress into a monthly time-step clearly reveals a time-lag effect. High rainfall events carry over to the following month while prolonged drought, expressed though high water stress, i.e. the relationship between actual and potential transpiration, aggravates the water availability situation in each successive month (Fig 5).

Validations of the results are difficult to obtain because of the lack of corresponding ground-based data for grassland primary production representative for the 8-km pixel resolution. By comparing modelled results of annual primary production with aboveground destructive measurements from the Xilingol biosphere reserve (0.4 percent of the pixel), and with CENTURY-modelled primary production at the Eutoke

reference site, it is clear that the results are realistic. They are lower than the measured but higher than those modelled by CENTURY. It can be shown that our model detects annual variability within the same range as the measured results. However a further evaluation of the results by comparison with other regionally applied productivity models is desirable.

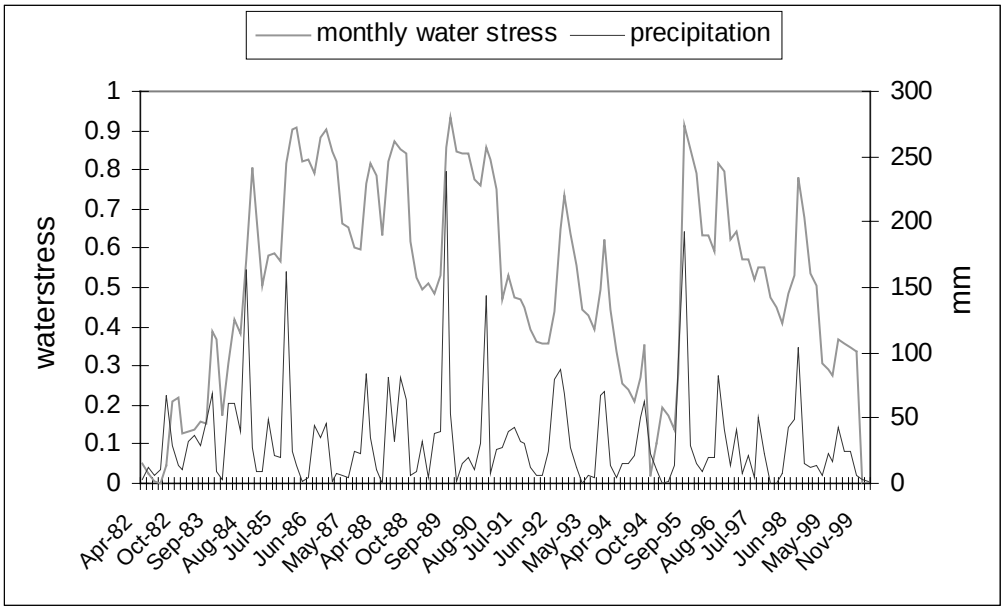

Fig 5. Monthly values of precipitation and water stress for the growing season at the Eutoke site. Note that the water stress parameter is the fraction of actual to transpiration to potential transpiration, hence higher values denote less stress.

Fig 6 presents the trends in GPP for the Tongliao City Prefecture. Based on the calculated liner trends a general increase in primary production in the southern and eastern parts of the study area is found. Some of the increase is probably a result of the increasing biomass of cropland, but it is also an indication of a general increase of the biological productivity in the area since the dryer years of 1982 and 1983. In the Zhalute County the findings are either no change or a slightly negative trend, where the latter indicates a decrease in vegetation. Part of the explanation of the this pattern in the northern area of the Tongliao City Prefecture may be due to the spatial expansion of cultivated land, accompanied by a relatively lower input level as shown in Paper 2. As summarized by Oksen (2003) expansion of cropland unaccompanied by anti-erosion measures, and improper fertility management makes environmental degradation more likely.

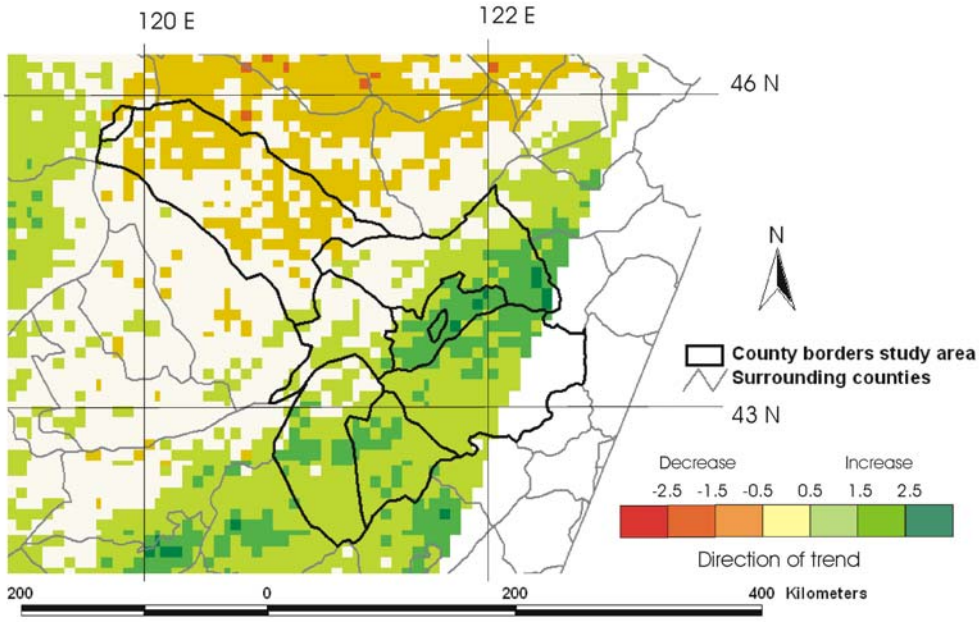

Fig 6. Trends in GPP over the growing season in the Tongliao City Prefecture.

Although the cultivated land area constitutes only a small proportion of the total land area of the IMAR region, the findings of the primary productivity trends may be influenced by the increasing productivity of agricultural land. Other important factors contributing are the regional pattern of increasing precipitation over the 18-year period, as well as the *Green Wall* afforestation project and other vegetation cover improvement activities. To disclose the mosaic of explanatory factors of the primary production pattern more research based on high-resolution remote sensing data (e.g Brogaard and Prieler 1998, Runnström 2003), analysis of precipitation and temperature patterns, as well as more livestock and land use data are needed.

Acknowledgment

First of all I would like to thank my supervisor Lennart Olsson who through these years has had an immense patience with my research ideas, optimistic time plans, and as well as my numerous *speling misstakes*. You have always been there to share your vast knowledge, and you have always inspired me when things were difficult.
I am grateful also to Ulf Helldén for introducing me to the study area and the interesting and the challenging aspects of the Chinese grasslands.
Micael Runnström, Rannveig Olafsdottir, Jonathan Seaquist, thank you for being such great friends and colleagues. I doubt that I would have managed without your cooperation, support and sense of humour. Your great personalities, hard work and interesting research approaches have inspired me in my own work.
Special thanks also goes to Bodil Elmqvist and all the others at MICLU for offering such great support during the final months of this work. Petter Pilesjö and the rest of you at the GIS Centre, I am glad that feeding bottles and baby babble did not stop you from having us around for a while. Thanks also to Ulrik Mårtensson and Lars Eklundh for your support and advice.

The cooperation and help from my Chinese colleges has been invaluable. I am very grateful to all the staff at the Naiman research station for the hospitality and friendliness. Special thanks to Zhao Xueyong for the great fieldwork memories, interesting discussions, and for sharing your knowledge about the people and land of Inner Mongolia. Li Xiubin, I am very glad that I met you at IIASA and later in Beijing, and that we could cooperate even over such great distances. An Guiqin, doing interviews and data searches with you was a pleasure; I hope we can meet again to attack the dunes of the Keerqin Steppe. Thank you also Professor Wang Changyao for the hospitality and help during my stays in Beijing. Back in Lund I had the great advantage of finding a genuine Tongliao family in Norra Fäladen; thank you, Wang Shujing for helping me translate all kinds of cryptic terms.

My stay at the IIASA LUC project helped me to place my own study into a larger perspective, and I am particularly grateful to Sylvia Prieler for encouragement and cooperation. Through you, I also was able to meet with Bettina Hamann in Urumqi where we had some great experiences.

Kajsa, Johan and Magnus – knowing that you were always around for a good party or for a serious talk during the ups and downs in life helped me to hang in there. Meeting you and the rest of the "Ariman gang" over coffee on Saturdays made life worth living, especially during the most stressful periods.
My parents and sister in Uddevalla and Västerås, I did not see you as much as I wanted to during the last years. If there wasn't fieldwork in China there was writing to do. Hopefully now we will have plenty of time to catch up on things.
Finally, Joakim and Tove, you have had to spend far too many weekends and evenings on your own during the past year. But, coming home after working long hours, the thoughts of thousands of image files and desertification definitions quickly faded. Thank you for your support. I love you.

References

Ahlcrona, E. (1989). The impact of climate and man on land transformation in central Sudan - Applications of remote sensing. Meddelande från Lunds Universitets Geografiska Institutioner Avhandlingar 103, 140 pp.

Alexandrov, G.A. and Oikawa, T. (1997). Contemporary variations of terrestrial net primary production: The use of satellite data in light of an extremal principle. Ecological Modelling, 95, 113-118.

Ash, R. F. and R. L. Edmonds (1998). "China's land resources, environment and agricultural production." The China Quarterly (156): 836-879.

Banks, T. (2001). Property rights an the environment in pastoral China: Evidence from the field. Development and change, 32, 717-740.

BBC Web News (2000). China on sandstorm alert. Web news 2002-02-27, www.news.bbc.co.uk.

Behnke, R.H. and Scoones, I. (1993). Rethinking range ecology : Implications for rangeland management in Africa. In Range ecology at Disequilibrium, Behnke, R.H., Scoones, I. and Kerven, C. (Eds). Overseas Development institute, London.

Bilik, N. (1996). Culture, the Environment and Development, p.134-146. In Culture and Environamnt in Inner Asia: 2. Society and Culture. Humphry, C. and Sneath. D. (Eds). The White Hoarse Press, Cambridge.

Biot, Y., Blaikie, P.M., Jackson, C. and Palmer-Jones, R. (1995). Rethinking research on land degradation in developing countries. World Bank discussion paper 289. The World Bank, Washington, 140 pp.

Bishop, J.K.B., and Rossow, W.B., (1991). Spatial variability of global surface solar irradiance. Journal of Geophyshical. Research, 96,16839-16858.

Blakie, P. 1985. The political economy of soil erosion in developing countries. Longman, New York.

Blakie, P. and Brookfield, H. (1987). Land degrdation and Society. Routledge, London and New York.

Boserup, E. (1965), Economic and Demographic Relationships in Development. Essays selected and introduced by T.P. Schultz. The John Hopkins University Press, Baltimore. 304 pp.

Brogaard, S. and Prieler, S. (1998). Land cover in Horqin Grassland – Detecting changes between 1975 and 1990 by means of Remote Sensing, IIASA Interim Report IR-98-044.

Brown, L.R. (2001). Bad tidings on the wind for Chinese. Guardian Weekly, June 7, p. 23.

Cao, M., Prince, S.D., Li, K. Tao, B., Small, J. and Shao, X., 2003. Response of terrestrial carbon uptake to interannual variability in China. Global Change Biology, 9, 536-546.

Cheng, C. (1993). Climate and Agriculture in China. China Meteorological Press, Beijing.China daily (2000). Sandstorm sound ecological alarm. Article 2000-05-15. http://www.chinadailiy.com.cn

China Population Information and Research Center. (1999). Province Facts – Inner Mongolia: (http://www.cpirc.org.cn/30Province1999-innermongolia.htm). Access data 2003, November,1.

Collatz, G.J., Ball, J.T., Grivet, C. and Berry, J.A. (1991). Physiological and environmental regulation of stomatal conductance, photosynthesis and transpiration: a model that includes a laminar boundary layer. Agriculture and forest meteorology, 54, 107-136.

Conway, R.G.. (1986). Agroecosystem analysis for research and development. Winrock International Institute for Agricultural Development, Bangkok.

Conway, G. R. and E. B. Barbier (1990). After the green revolution - Sustainable agriculture for development. London, Earthscan Publications Ltd.

Cyranoski, D. (2003). China plans clean sweep on dust storm. Nature, 421, 101.

Dahlberg, A.(1996). On interpretating environmental change, time, space and perceptions in the cases of Kalakamete, North East District, Botswana. In interpretations of environamntal change and diversity: A study from north East District, Botswana. Dissertation Series No 7. Stockholm University, Department of Physical Geography: Stockholm. 12

Ding, D., Bao, H. and Ma.Y. (1998). Progress in the study of desertification in China. Progress in Physical Geography, 22(4), 521-527.

Djurfeldt, G., Egerö, B. and Hammarskjöld, M. (1997). An Asian model for Africa? - Perspectives on population and food production in Sub-Saharan Africa. PROP reports No 20, Lund University, Department of Sociology.

Domrös, M. and Gongbing, P. (1988). The climate of China, Springer Verlag, Berlin, 360 pp.

Eklundh, L. (1996) AVHRR NDVI for monitoring and mapping of vegetation and drought in east African environments. Meddelande från Lunds Universitets Geografiska Institutioner. Avhandlingar 126.

Eklundh, L. and Olsson. L. (2003) Vegetation index trends for the African Sahel 1982-1999. Geophysical Research Letters, 30, No. 8.

Ellis, J.E. and Swift, D.M. (1988) Stability of African pastoral ecosystems: alternate paradigms and implications for development. Journal of range management, 41, 450-459.

Fan, S. (1997). Production and productivity growth in Chinese agriculture: new measurement and evidence. Food Policy, 22,(3),213-228.

FAO (2003). Tackling desertification in the Korqin Sandy Lands through integrated afforestation. Information from www.fao.org.

FAO/UNESCO (1995). Digital Soil Map of the World and Derived Properties. Version 3.5. Food and Agriculture Organization of the United Nations.

Frouin, R. and Pinker R.T. (1995). Estimating Photosynthetically Active Radiation (PAR) at the Earth´s Surface from Satellite Observation. Remote Sensing of Environment, 51, 98-107.

Fullen, M.A. and Mitchell, D.J. (1994) Desertification and reclamation in north central China. Ambio, 23, 131-135.

Gamon, J.A., Field, C.B., Goulden; M.L. et al. (1995). Relationships Between NDVI, Canopy Structure, and Photosynthesis in Three Californian Vegetation Types, Ecological Applications, 5 (1), 28-41.

Goetz, S.J. and Prince, S.D. (1999). Modeling terrestrial carbon exchange and storage: evidence for and implications of functional convergence in light use efficiency. Advances in Ecological Research, 28, 57-92.

Goetz, S.J., Prince, S.D., Goward, S.N., Thawely, M.M. and Small, J. (1999). Satellite remote sensing of primary production: an improved efficiency modeling approach. Ecological Modeling, 122, 239-255.

Goward, S.N.. Tucker, J.C. and Dye, D.G. (1985) North American vegetation patterns observed with NOAA-7 AVHRR. Vegetatio, 64, 3-14.

Grassland and Grassland Sciences in Northern China (1992). National research Council USA. National Academic Press. Washington.

Harris. F. (1996). Lessons from the Kano Close-Settled Zone, Nigeria. International Institute for Environment and Development Gatekeepers series No. 59. 17 pp.

Heilig, G.H. (1996). Anthropogenic driving forces of land-use and change in China. IIASA Working paper. WP-96-011.

Hellden, U. (1992). Desertification- Time for an Assessment?. Ambio, 20(8),372-383.

Hill, R. D. (1994). Upland development policy in the People´s Republic of China. Land Use Policy,11(1),8-16.

Himiyama, Y. (1997). Land Use In North-East China in the 1930´s and After. IIASA Interim Report IR-97-011/March.

Hinton, W. (1992). Privatiseringen av Kina: Den Stora Kursomläggningen 1978-1991. Trana, Stockholm, 238 pp. (In Swedish).

Ho, P. (2001). Rangeland degradation in north China revisited? A preliminary statistical analysis to validate non – equilibrium range ecology, Journal of Development Studies, 37(3), 99-133.

Ho, P. (1998). Ownership and control in Chinese rangeland management since Mao - A case study of the free-rider problem in pastoral areas in Ningxia. In: Cooperative and Collectives in China's Rural Development – Between State and Private Interests. Vermeer, E.B., Pieke. F.N. and Chong W.L. (eds). Sharpe, Armonk, pp. 197-235.

Holling, C.S. (1973). Resilience and stability of ecological systems. Annual review of ecology and systematics, 4, 1-23.

Hu, W. (1997). Household land tenure reform in China: its impact on farming land use and agro-environment. Land Use Policy 14, 175-186.

Hulme, M. (2001). Climatic perspectives on Sahelian desiccation: 1973-1998, Global environmantal Change, 11,19-29.

Hunt, E.R. and Runing, S.W. 1992, Simulated dry matter yield for aspen and spruce stands in the North American boreal forest. Canadian journal of remote sensing, 18, 126-133.

James, M.E., and Kalluri, S.N.V., 1994. The Pathfinder AVHRR land data set: An improved coarse resolution data set for terrestrial monitoring. International Journal of Remote Sensing, 15, 3347-3363.

Kinlund, P. (1996). Does land degradation matter? Perspectives on environmental change in north-eastern Botswana. Stockholm studies in human geography 7, Almqvist and Wiksell International, Stockholm.

Kucharik, C.J.,Foley, J.A.,Delire, C.,Fisher, V.A.,Coe, M.T.,Lenters, J.D.,Young-Molling, C. Ramankutty, N.,Norman, J.M. and Gower, S. T. (2000). Testing the performance of a Dynamic Global Ecosystem Model: water balance, carbon balance, and vegetation structure. Global Biogeochemical Cycles, 14(3)795-825.

Law, B.E. and Warring, R.H. (1994). Combining remote sensing and climatic data to estimate NPP across Oregon. Ecological Applications, 4, 717-728.

Li, B. (1996). Price reform for agricultural products. In: The third revolution in the Chinese countryside. Garnaut, R. Guo, S. and Ma, G. (eds.) Cambridge University Press, Cambridge, pp 311.

Li, S.G., Harazonoz, Y., Oikawa, T., Zhao, H.L., He, Z.Y., and Chang, X.L., (1999). Grassland desertification by grassing, and the resulting micrometeorological changes in Inner Mongolia. Agricultural and forest meteorology, 102, 125-137.

Li, X. (1999). Change of Arable Land Area in China During the Past 20 Years and it's Policy Implications. Journal of natural resources, 14(4)329-333. (In Chinese).

Li, X. and Wang, X. (2003). Changes in agricultural land use in China: 1981-2000. (In press.)

Lin, J. Y. and F. Zhang (1998). The effect of China's rural policies on the sustainability of agriculture in China, Economy and Environment Program for Southeast Asia. 1998.

Lin, T-H. (2001). Long-range transport of yellow sand to Taiwan in spring 2000: observed evidence and simulation. Atmospheric Environment. Vol 35: 5873-5882.

Lindskog, P. and Tengberg, A. (1994). Land Degradation, natural resources and local knowledge in the Sahel zone of Burkina Faso. Geo Journal. Vol. 33, No 4, 365-375.

Lindström, J. (2003) Statistical aspects of changes in normalized difference vegetation index as an effect of changes in Solar Zenith Angle. Master Thesis, Department of Mathematical Statistics, Lund University.

Liu, C. and Zhang, S. (2002). Drying up of the yellow river: its impacts and counter-measures. Mitigation and Adaptation Strategies for Global Change, 7, 203-214.

Liu, X., Zhao, H. and Zhao, A. (1996). Vegetation and Environment of Horqin Sandy Land. Science Press, Beijing. (In Chinese).

Longworth J.W. and Williamson G.J. (1993). China's Pastoral Region: Sheep and Wool, Minority Nationalities, Rangeland Degradation and Sustainable Development. CAB International, Wallingford, 352 pp.

Mertz, O. and Reenberg, Anette (1999). Building on diversity: pathways to agricultural intensification in Burkina Faso. Danish Journal of Geography (Special issue 2), 125-138.

Luk, S-H. (1983). Recent trends of desertification in the Maowusu Desert, China. Environmental Conservation 10(3)213-223.

McCracken, J. A., Pretty, J.N. and Conway, G.R. (1988). An Introduction to Rapid Rural Appraisel for Agricultural Development. International Institute for Environment and Development, London 1988, 94 pp.

Mei, A.X. (1985). A study of grassland utilization conditions in the eastern parts of Inner Mongolia by analysing Landsat MSS imagery, p723-724. In Proc.XV int. Grassland Congress, Kyoto, Japan.

Monteith, J.L. (1972). Solar radiation and productivity in tropical ecosystems. Journal of Applied Ecology, 9, 747-766.

Monteith, J.L. (1977). Climate and the Efficiency of Crop Production in Britain. Philosophical Transactions of the Royal Society of London, 281, 277-294.

Mortimore, M. (1993). Population growth and land degradation.Geo Journal 31(1)15-21.

Mortimore, M. and Tiffen, M. (1994). Population growth and sustainable Environment: The Machakos Story. Environment, 36(8)10-20 and 28-32.

Muldavin. J. (1996). The political ecology of agrarian reform in China – The case of Heilongjiang Province. In: Liberation Ecologies – Environment, Development, Social Movements. Peet. R. and Watts, M. (eds). Routledge, London and New York, pp 227-269.

Nianfeng, L., Jie, T. and Dianfa, Z. (1998). The problem of the Quaternary, geological environment and desertification. Environmantal Geology, 38(1) June 1999, 7-12.

Nouvellon, Y., Seen, D.L., Rambal, S., Begue, A., Mora, M.S., Kerr Y. and Qi, J. (2000). Time Course of Radiation Use Efficiency in a Shortgrass Ecosystem: Consequences for Remotely Sensed Estimation of Primary Production, Remote Sensing of Environment, 71, 43-55.

Oksen, P. (2003). Agricultural expansion and animal husbandry in a West African Savannah Environment. In: Politics, property and production in the West African Sahel. Benjaminsen, T.A. and Lund C. (eds). Nordiska Afrikainstitutet. pp 303-331.

Olsson, L. and Eklundh, L. (1994), Fourier Series for analysis of temporal sequences of satellite sensor imagery. International journal of remote sensing, 15, 3735-3741.

Olsson, L. (1993). Desertification in Africa, A critique and alternative approach, 31(1)23-31.

Ostwald M, Jusoff K och Lindqvist S. (2000). Indicating local protection efforts in forest vegetation change in Orissa, India using NOAA AVHRR data. Journal of Forest Science, 12,778-793

Parton, W.J., Schimel, D.S., Cole, C.V. and Ojima, D.S. (1987). Analysis of factors controling soil organic matter levels in the Central Great Plains Grassland. Soil Science Society of America Journal, 51, 1173-1179

Paruelo, J.M., Epstein, H.E., Lauenroth, W.K. and Burke, I.C. (1997). ANPP estimates from NDVI for the Central Grassland Region of The United States. Ecology, 78, 953-958.

Potter, C.S., Randerson, J.T., Field,C.B., Matson, P.A.,Vitousek, P.M.,Mooney, H.A., and Klooster, S.A. (1993). Terrestrial Ecosystem Production: A Process Model Based on Global Satellite and Surface Data. Global Biogeochemical Cycles, 7, 811-841.

Prosterman, R.L. and Hanstad T.M. (1990). China: A fieldwork-based appraisal of the household production responsibility system. In: Agrarian Reform and Grassroots Development – Ten Case Studies. Prosterman, R.L., Temple, M.N. and Hanstad (eds). Rienner Publishers, London, pp103-136.

Rasmussen , M.S. (1998). Developing simple, operational, consistent NDVI-vegetation models by applying environmental and climatic information: Part 1. Assessment of net primary production. International Journal of Remote Sensing, 19, 97-117.

Rasmussen, K. (1999). Land degradation in the Sahel-Sudan: the conceptual basis. Danish Journal of Geography (Special Issue 2): 151-160.

Reenberg, A. (1995). A hierarchical approach to land use and sustainable agricultural systems in the Sahel. Working paper, Sahel-Sudan Environmental Research Initiative SEREIN, 1:1995.

Ren, G. and Zhang, L. (1998). A Preliminary Mapped Summary of Holocene Pollen Data for Northeast China. Quaternary Science Reviews 17, 669-688.

Ribot, J.C., Magalhães, A.R, Panagides, S. (1996). Climate variability, climate change, and social vulnerability in the semi-arid tropics, Cambridge, Cambridge University Press

Ruimy, A., Saugier, B. and Dedieu,G. (1994). Methodology for the estimation of Terrestrial NPP from Remotely Sensed Data. Journal of Geophysical Research, 99, 5263-5283.

Running, S.W. (1990), Estimating terrestrial primary productivity by combining remote sensing and ecosystem simulation. Pp. 65-68 in R.J. Hobbs and H.A. Mooney, Eds. Remote sensing of biosphere functioning. Springer Verlag, New York.

Running, S.W. and Hunt Jr., E.R. (1993). Generalization of a forest ecosystem process model for other biomes, BIOME-BGC, and an application for global-scale models. In: Ehleringer, J.R., and Field, C. (Eds). Scaling Processes Between Leaf and Landscape Levels. Academic Press. pp. 141-158.

Runnström, M. (2000). Is northern China Winning the battle against desertification? Ambio, 29, 468-476.

Runnström, M. (2003). Range land devlopment of the Mu Us Sandy Land in semiarid China: an analysis using Landsat and NOAA Remote Sensing data. Land degradation and Development, 14, 189-202.

Runyon, J., Warring, R.H., Goward, S.N. and Welles, J.M.(1994). Environmental limits on net primary productionand light use efficiency across the Oregon transect. Ecological Applications, 4, 226-237.

Seaquist, J.W. and Olsson, L. (1999). Rapid Estimation of Photosynthetically Active Radiation over the West African Sahel Using The Pathfinder Land Data Set. International Journal of Earth Observation and Geoinformation, 1, 205-213.

Seaquist, J. (2001). Mapping Primary Production for the West African Sahel with Satellite Data. Meddelande från Lunds universitets geografiska institutioner, Avhandlingar 140. PhD Thesis, Department of Physical Geography, Lund University, Sweden.

Seaquist, J.W., Olsson, L., and Ardö, J. (2003). A remote sensing based light use efficiency model for grassland biomes. Ecological Modeling, 169, 131-155.

Sellers, P.J., Berry, J.A., Collatz, G.J. et al. (1992). Canopy reflectance, photosynthesis, and transpiration. III. A reanalysis using improved leaf models and a new canopy integration scheme. Remote Sensing of Environment, 42, 1-20.

Sheehy, D.P. (1992). A perspective on desertification of Grazingland Ecosystems in North China. Ambio, 21(4)303-307.

Shi, M., Tanaka, Y. and Zhao, H. (1998). Land use and farming system for combating desertification in Horqin Sandy Land. pp. 79-92. Proceedings of Japan-China workshop on land evaluation of prevention and remedies for desertification. Tskuba, Japan, Feb. 24-25,1998.

Shuttleworth, W.J. (1993). Evaporation. In: D.R. Maidement (ed.), Handbook of Hydrology. McGraw-Hill Inc., New York.

Smil, V. (1987). Land degradation in China: an ancient problem getting worse. In: Land degradation and society. In: Blakie, P. and Brookfield, H. (eds). Routledge, London and New York, pp 214-222.

Statistical yearbook of Inner Mongolia (1998). Chinas Statistical Publishing House. Beijing 1999.

Sun, X. and Yu, Z. (1996). Grassland degradation in the main pastoral provinces of China. Chinese Journal of Arid Land Research, 8(4), 281-285.

Teeri, J.A. and Stowe, L.G. (1976). Climatic pattern and the distribution of C4 grasses in North America. Oecologica, 23, 1-12.

Tian, H.,Melillo, J.,Kicklighter, D.W.,McGuire, A. D.,Helfrich, J. (1999).The sensitivity of terrestrial carbon storage to historical climate variability and atmospheric CO_2 in the United States. Tellus 51b. 414-452.

Tucker, C.J., Gatlin, J.A. and Schneider, S.R. (1984). Monitoring vegetation in the Nile Delta with NOAA-6 and NOAA-7 AVHRR imagery. Photogrammetric Engineering and Remote Sensing, 50, 53-61.

Tucker, C.J. and Sellers, P.J. (1986). Satellite remote sensing of primary production. International Journal of Remote Sensing, 7, 1395-1416.

Tucker, C.J., Justice, C.O. and Prince, S.D., (1986). Monitoring the grasslands of the Sahel 1984-1985. International Journal of Remote Sensing, 7, 1571-1581.

Tucker, C.J., Dregne, H.E. and Newcomb, W.W. (1991). Expansions and contraction of the Sahara Desert from 1980 to 1990. Science, 253, 299-301.

Tucker, C.J., Newcomb, W.W. and Dregne, H.E. (1994). AVHRR data sets for determination of desert spatial extent. International Journal of Remote Sensing, 15, 3547-3565.

Thwaites, R., De Lacy, T., Hong, L.Y. and Hua, L.X. (1998). Property rights, social change, and grassland degradation in Xilingol Biosphere Reserve, Inner Mongolia, China. Society and Natural Resources, 11, 319-338.

National Research Council USA (1992). Grassland and Grassland Sciences in Northern China. National Academic Press, Washington D.C, 214 pp.

UN (1992). Agenda 21: The United Nations plan for action from Rio. New, York, United Nations.

U.S. Embassy September Report (1998). PRC Arable land jumps 40 percent. http://www.usembassy-china.org.cn/english/sandt/prcland.htm.

Wang, H. and Zhou, H. (2003). A simulation study on the eco-environmental effects of 3N shelterbelt in North. Global and Planetary Change. 37,231-246.Warren,A. and Agnew, C. (1989), An assessment of desertification and land degradation in arid and semi-arid areas. International Institute for Environment and Development, paper no. 2. London: Ecology and Conservation Unit, University College.

Verburg, P.H., Chen, Y. and Veldkamp, T. (2000). Spatial explorations of land use change and grain production in China. Agriculture, ecosystems and environment, 82, 333-354.

Warren, A. (1998). Land degradation in the Sahel: some observations, in The Sahel: Sahelian perspectives - myths and realities, Eds. Reenberg, A., Marcussen, H.S. and Nielsen, I., Proceedings of the Danish Sahel Workshop, Sandbjerg, January, SEREIN Occasional Paper, 6, Department of Geography, University of Copenhagen, 1-12.

Williams, D. M. (1996). Subjective landscapes and resource management on the Chinese grasslands of Inner Mongolia. PhD thesis: Graduate School of Arts and Sciences, Columbia University: New York. 293 pp.

Williams, D. M. (1997). The desert discourse of modern China. Modern China, 23(3)328-355.

Xu, B. Liu, X. and Zhao, X. (1996). Soil erosion and its control in the farming-pastoral transition belt in the Horqin Sandy Land, Inner Mongolia. Chinese Journal of Arid Land Research,8(4), 267-273.

Yang, H. (1999). Growth in Chinas grain production 1978-1997, A Disaggregate Analysis. World Development 27, 2137-2154.

Yang, H. and Li, X. (2000) Cultivated land and food supply in China. Land use policy, 17(2)73-88.

Yu, C. L. and Buckwell. A. (1991). Chinese grain economy and policy. CAB International, Oxford, 263 pp.

Zha, Y. and Gao, J. (1997). Characteristics of desertification and its rehabilitation in China. Journal of Arid Environments, 37,419-432.

Zhao, H., Li, S., Zhang, T. et al. (1998). The productivity changes and the evaluation of rational utilization of Horqin Sandy Grassland under different grazing Intensities. pp. 61-68. Proceedings of Japan-China workshop on land evaluation of prevention and remedies for desertification. Tskuba, Japan, Feb. 24-25, 1998.

Zhao, Z-C. (1996). Climate Change and sustainable Development in China's Semi-arid Regions, pp 92-108,. In : Ribot, J. C., Magalheas, A.R., and Panagides, S.S. (Eds.), Climate variability, Climate Change and Social Vulnurability in the Semi-arid Tropics. Cambridge, Cambridge University Press.

Zheng. D. (1994). Desertification and its management in China. Chinese Journal of Arid Land Research, 7(2) 81-95.

Zhou, X, Chen, N. and Li, W. (2000), An analysis of the climate change in the past and the future. In: China's Climate Change Study (Gan, S., Wu, Z. and Wang, W. eds), pp.72-103. Tsinghua University Press, Beijing

Zhu, Z. (1990). Desertification in the northern territory of China: present status and trend development. Journal of Chinese Geography, 1:61-70.

Zhu, Z., Liu, S., Wu, Z and Di, X. (1986). Deserts in China. Insitute of Desert Research, Academica Sincia, Lanzhou. 135 pp.

Zhu, Z., Di, X., Chen, G., Zou, B., Wang, K., and Zhang, J. (1988). Desertification and rehabilitation – Case study in Horqin Sandy Land. Institute of Desert Research. Academia Sincia, Lanzhou, 113 pp.