Lund University Master's Programme in International Environmental Science

Preventing desertification and achieving sustainability in the Black Lands, Republic of Kalmykia, Russia: a system analysis approach

Oxana Dordzhieva
Tunavägen 39 G: 418
22363 Lund, Sweden
oksana.dordzhieva.934@student.lu.se

Submitted in partial fulfillment of the requirements for Master's degree in International Environmental Science, Lund, Sweden

Supervised by:
Mats Svensson
Lund University Center for Sustainability Studies
P.O. Box 170, SE-221 00 LUND, Sweden
mats.svensson@lucsus.lu.se

November 21, 2005

Acknowledgements

First and foremost, I have been extremely lucky to have had Mats Svensson as my thesis supervisor and I am immensely grateful to him for his interest in my work, valuable timely advice, criticism, sense of humour and optimism.
I would also like to thank Maxim Burdaev at the Kalmyk Land Use Research Institute and Alexander Basanov at the Ministry of Natural Resources of Republic of Kalmykia for providing me with materials and sharing their insight into the problem.
My studies at LUMES has been the most rewarding experience not only study or skills-wise, but also because I had a chance to share these 1.5 years with the most bright, interesting, challenging, fun, crazy and caring Lumesians who, I am sure, will never cease to be like that even in 50 years. ☺ Thanks to the "Russian gang" for teaching me to listen!
Words are not enough to let my family know how much I love and appreciate them for everything they are.
Finally, this work is owed to Danny whose love, faith in me and encouragement are invaluable and I am tremendously grateful for every single moment we are together.

Abstract

Black Lands is an agricultural area in the Republic of Kalmykia (Russia). Previous agricultural practices under administrative planning economy during 1960s-1980s resulted in land desertification, loss of agricultural productivity, and lowered biodiversity in the area. Saiga antelope as an element of biodiversity in the area has been affected by land use management and poaching.

Transition to market economy followed by livestock starvation due to fodder shortages, had a positive impact on Black Lands pastures and saiga population. It resulted in revival of livestock numbers while agricultural practices remained unchanged and poaching intensified. The aim of the paper is to investigate existing agricultural practices and trends to forecast the region's future under different scenarios using systems analysis methods. The research showed that the desire to maximize economic benefits leads to overgrazing and pastures destruction and hence, loss of agricultural productivity. Sustainability can be achieved by changed land uses; limiting livestock population and preserving pastures, implementing effective mechanisms against saiga poaching and providing the local population with diverse economic activities to contribute to their incomes.

Keywords: desertification, sustainability, systems analysis, saiga antelope, agriculture.

Table of contents

List of figures and tables

1. Introduction

Desertification is defined as irreversible land degradation that is caused by human activity and leads to deterioration of human well-being (Mainguet, 1991).
One cannot underestimate the significance of sustainable land-use practices to prevent desertification and to preserve ecosystem equilibrium. After all, land is the source of food, while desertification has already affected around 100 countries world-wide (ibid).

Ecosystem equilibrium determines long-term land productivity, and thus well-being of those dependent on land resources. Therefore, preventing desertification is a condition of sustainable development – "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987, p.8).

This paper is going to focus on the republic of Kalmykia situated in the south-west of Russia. Desertification in this region was caused by overstocking and plowing that was intensified in the last century. Deterioration of pastures and economic crisis of the 1990s resulted in significant reduction of livestock number which was a positive factor in consequent pastures and biodiversity revival. However, reduction of livestock intensified saiga antelope poaching and its population is near extinction now.

Today we observe the growing trend of livestock number - as in the previous periods. Nevertheless, agricultural techniques remain unchanged (Petrov et al, 2001). Therefore, it is likely that despite environmental improvements, existing land-use practices will lead to desertification and, consequently, saiga extinction. Agriculture being the main source of living, desertification will lead to deterioration of people's well-being. Finding solution to these problems requires a comprehensive research of factors that contribute to desertification, whereas, many of the existing studies on the problem of desertification in Kalmykia limit their research to ecological and economic dimensions of desertification failing to establish links with social system (Borlikov et al, 2000a; Borlikov et al, 2000b; Petrov et al, 2001).

1.1. Scope and objectives

The paper will focus on one region in the republic of Kalmykia - Chernye Zemli (Black Lands). The area of the region is 3.5 million hectares, with the population of 68 000 people, comprising 3 administrative districts. The research model covers the period between 2000 and 2050.

The research is aimed at studying the ecological, social and economic systems of the defined area in order to identify the key elements contributing to land degradation and desertification. Further on, the paper will discuss the conditions for achieving sustainable development in the region.

1.2. Research questions and structure

The research questions are:

1. What are the ecological, social and economic factors that cause desertification in Black Lands?
2. What are the conditions for sustainability of these systems?

Description of methods and materials of the study is followed by background on desertification issue. Further on, the paper provides general information on Kalmykia, periods of desertification in the Black Lands and its impact on saiga population. After that a conceptual model of the system components is analyzed and further each subsystem is parameterized and numerical model is described. Then unmanaged and managed scenarios are presented together with evaluation of their results. Further on, the model serves as a framework in order to identify system sustainability indicators and to assess conditions for sustainability in the Black Lands.

2. Methods and materials

The research of the current study is based on the systems thinking approach. Under the methods of systems thinking, or holistic thinking, causalities and relations of complex systems are studied (Jackson, 2003). This interconnectedness is believed to make up a whole which has more meaning than just the sum of its parts (ibid).

System analysis models facilitate the research by revealing the dynamics of real systems being representations of reality based on our understanding (O'Connor and McDermott, 1997). Besides, systems analysis approach allows perceiving the systems in their dynamics which is an important aspect in finding solutions to existing problems as in reality systems are never static (ibid). Therefore, system analysis is an appropriate approach in understanding and analyzing the problem of desertification in Kalmykia. Not only it allows investigating what and how ecological, social and economic factors contribute to desertification, it also gives a larger-scale picture of the sustainability of the system. Understanding of systems and their interactions is a basis of effective decision making.

Detailed understanding of the system by literature review and field work was followed by building of the conceptual (using Causal Loop Diagrams – further on referred to as CLD) and later, numerical[1], quantitative models. For that system analysis and system dynamics modeling methods were reviewed and assumptions for the systems understanding were made[2] (O'Connor and McDermott, 1997; Jackson, 2003). The conceptual model of the system was further iterated several times during and after the development of quantitative models when additional insight was brought into the problem[3]. Statistical data of the region (Federal Statistical Bureau, 2000; 2004) was used for the numerical model.

[1] The model was built using STELLA 8.1.1 software (iSee Systems)
[2] Assumptions are indicated in the text in italics as *"assumption 1, 2, 3..."*
[3] The concept of the "Learning loop" (O'Connor and McDermott, 1997)

The model provided a methodological framework to identify sustainability indicators and to assess sustainability conditions using the concept of sustainability indicators (Bell and Morse, 1999; Spangenberg and Bonniot, 1998; Zhen and Routray, 2003).

Literature review on desertification causes and consequences in different countries was the first step of research process. Among them are “Desertification of arid lands” by Dregne (1983), “Desertification: natural background and human mismanagement” by Mainguet (1991) and “Desertification: causes and consequences” (UNCOD, 1977). It provided a certain base knowledge and understanding of the main patterns.
Further on, field research was carried out in Kalmykia. It involved study of works on desertification in Kalmykia by Borlikov et al (2000a; 2000b), Zonn (1995), Petrov et al (2001), and Gabunshina (2000). Interviews were carried out with several researchers and officials who work with the issue.

3. Theoretical background on desertification

Desertification is a global environmental problem that can be observed in around 100 countries all over the world (Mainguet, 1991). Disturbance of fragile dry-lands ecosystem equilibrium by human activities underlies the problem of desertification. Apart from destruction of ecosystems, desertification leads to deterioration of people’s life quality due to loss of natural resources they depend on. This adds a social dimension to desertification issue (ibid).

Semi-arid, arid and sub-humid areas are the most vulnerable to desertification processes as harsh climate conditions limit natural regeneration processes if natural ecosystems had been disturbed by human activity (ibid). According to Dregne (1983), these desertification processes are vegetation destruction, soil compaction and erosion that are mainly caused by overgrazing, while irrigation leads to salinisation and waterlogging.

The world first drew attention to the problem in 1951 under the initiative of United Nations Educational, Scientific, and Cultural Organization’s (UNESCO) to carry out the Major Project on Scientific Research on Arid Lands (Dregne, 1983). Further on, United Nations General Assembly organized an international conference on desertification in Kenya in 1977 after the drought in African Sahel of 1968-1973 that resulted in great human losses due to famine (estimated 100,000-250,000 people) (ibid).
At that time improved health services increased the population of Sahel which led to overstocking and overgrazing of the Sahelian pastures (ibid). Drilling additional wells also contributed to livestock number growth as it eliminated the limiting factor to livestock number growth. The droughts exacerbated the condition and led to the collapse of the system (ibid). In the equilibrium system droughts was a regulative mechanism that kept livestock and human populations within the carrying capacity of the land (UNCOD, 1977).

There are many definitions of desertification, yet the one that encompasses causes, mechanisms and results of this phenomenon and can be related to this study has been articulated by Mainguet (1991, p.4): “Desertification, revealed by drought, is *caused* by human activities in which the carrying capacity of land is exceeded; it proceeds by exacerbated natural or man-induced *mechanisms*, and is

made manifest by intricate steps of vegetation and soil deterioration, which *result*, in human terms, in an irreversible decrease of destruction of the biological potential of the land and its ability to support population."
In Kalmykia agricultural land has been subject to intense exploitation over the last century that resulted in overgrazing, salinization, water-logging and wind erosion (Borlikov et al, 2000a). It led to significant reduction of agricultural production and as a result deterioration of social well-being. This aspect of desertification has been identified by Nelson (1988): "It [desertification]… reduces productive potential [of the land] to an extent which can neither be readily reversed by removing the cause nor easily reclaimed without sustainable investment." Economic hardship caused by desertification leads to lower standards of life, deterioration of health, and population migration (UNCOD, 1977).

Thus, exceeding carrying capacity of land by overstocking and plowing in areas not suitable for this purpose initiated soil degradation processes and caused desertification in Kalmykia. The main reason behind agricultural intensification and exceeding of carrying capacity is argued to be growing population (Mainguet, 1991). In addition, in the former USSR countries desertification was accelerated by Soviet administrative economy oriented towards short-term increase of production and neglecting environmental conditions (Komarov, 1981). Drought is considered not a cause but a revealer and intensifier of the desertification problem (Dregne, 1983; Mainguet, 1991).

The problem of desertification in Kalmykia can also be referred to the "Tragedy of the commons" – a concept of inevitable overuse and deterioration of a commonly used resource preceded by desire to increase own well-being (Hardin, 1968). On the one hand, agricultural land "belongs to nobody" in Kalmykia, on the other – there are no effective environmental management mechanisms to protect natural resources from degradation. This way individual and state livestock herds are increasing to maximize the benefits of the owners. But long-term land productivity is not ensured and hence, everyone's well-being is put at stake. In addition, desertification leads to biodiversity loss and threatens well-being of saiga antelope.

Economic and social well-being is thus dependent on environmental conditions. This interconnectedness requires that the agricultural practices do not disturb long-term productivity of the ecosystem in order to ensure long-term sustainability of social and economic systems. The next section will discuss natural conditions and desertification processes in Kalmykia in more detail.

4. Background information on Kalmykia

4.1. General characteristics of the republic

Republic of Kalmykia is one of the regions of the Russian Federation, situated in the south-east of the European part of Russia, in the lower Volga region (Figure 1). Its territory is 76 000 square kilometers. It is characterized by semi-arid and arid climate receiving annually in average 210-420 mm of precipitation depending on the region (Borlikov et al, 2000a). The main economic activity is agriculture contributing 80% of revenues (Sengleev, 1999). Plowed areas occupy 16% of the area, while 68% of the territory is used for livestock breeding (Khulkhachiev et al, 2000).

Figure 1. Geographical position of republic of Kalmykia (marked in black) in Russian Federation. (Modified from: http://map.rin.ru/index_e.html)

The territory of the republic has been previously occupied by the Caspian Sea which determines saline soil characteristics and vegetation (Borlikov et al, 2000a). As the sea retreat occurred in various times, natural conditions throughout republic are not homogenous. Soils are varying from brown in the south and southeast to chestnut types in the west (ibid). Western part receives the most precipitation (in average 420 mm), has the most fertile erosion-resistant soils and specializes in crop growing and livestock breeding (ibid). It constitutes 5% of the republic's territory (Figure 2). Central part makes up for 52% of Kalmykia and receives 280-315 mm of precipitation annually. Its primary agricultural activity is merino sheep breeding (ibid). Eastern part is the driest agricultural region of the republic as the annual precipitation is 210 mm in average with merino sheep breeding being the main agricultural activity. Solonetz, light loamy and loamy sand are the dominant types of soils in this area (ibid). It is also referred as the Black Lands region due to the fact the in the winter the pastures stay relatively snow-free (Petrov et al, 2001). Historically it had been a territory of winter pastures (ibid). The following study will be focused on the ecological, social and economic conditions of this part of the republic.

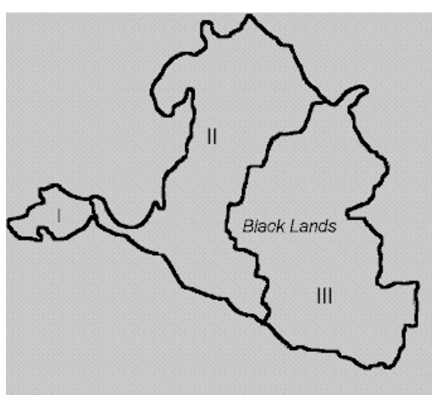


Figure 2. Agricultural regions of Kalmykia: I – Western, II – Central, III – Eastern (Borlikov, 2000a; http://kalm.ru/ru/)

The population of the republic has been steadily declining starting 1991 from 328,000 people to around 290,000 people in 2004, with 56% being rural population (Federal Statistical Bureau, 2000; 2004). Population dynamic are represented in Figure 3.

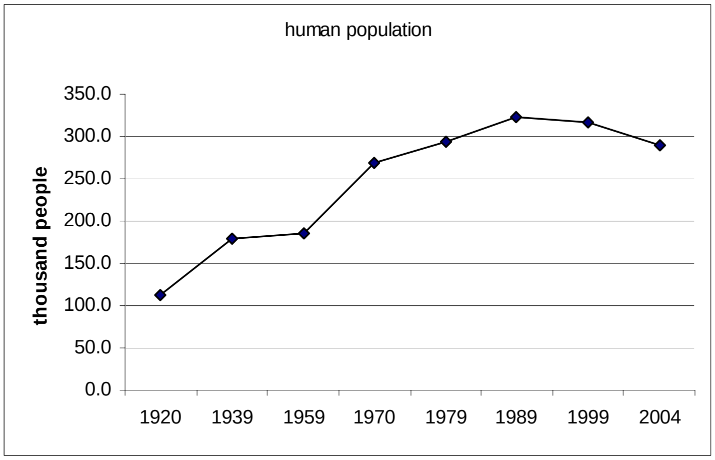


Figure 3. Kalmyk republic human population dynamics in 1920-2004 (Federal Statistical Bureau, 2000; 2004)

53% of the population are Kalmyks, 33% - Russians, and 14% are other nationalities (Chechens, Kazakhs, Germans, Ukranians, etc) (ibid). Originally Kalmyks descend from Mongolia, belonging to the Western Mongolian tribe under the name of Oirat. Kalmyk people officially joined the Russian Empire in the 17th century, and since then have traditionally used the present territory of republic for livestock herding. In the 20th century there has been severe land degradation, particularly in the Eastern part of the republic – the Black Lands.

4.2. Periods of desertification

The history of Kalmyk land-use practices can be divided into three periods according to various socio-economic conditions. These practices in turn determine the level of land degradation.

4.2.1. Traditional agricultural practices

A period before 1920 can be characterized by traditional nomadic livestock husbandry. Pastures were common; however, overgrazing did not occur as the people were aware of the vulnerability of the ecosystems that supported their well-being. They practiced sustainable herding without damaging ecosystem equilibrium. One of the sustainable agricultural techniques was traditional livestock composition: livestock consisted of 1 million heads traditional fat-tail sheep, 300,000 cattle, 200,000 horses and 20,000 camels (Zonn, 1995). Besides, the nomads used pastures seasonally. So for example, Black Lands were used as winter pastures only and sheep grazing was forbidden (ibid). Moreover, there existed allocation of pastures and control of observance of individual grazing plots borders on Black Lands (ibid).

Yet, the ecosystem equilibrium was already being disturbed at that period by migrants from other, more humid areas of Russia and Ukraine in the 18th and 19th centuries (Borlikov et al, 2000a). They started applying such agricultural techniques as plowing that is not suitable for most of the semi-arid territory of Kalmykia and accelerated wind erosion while the pasture areas were reduced which increased livestock concentration (ibid). But still the areas of plowing were kept relatively small at 110,000 hectares in 1913 and mostly in the more humid Western part of the republic (Zonn, 1995).

In this period the number of merino sheep grows (Borlikov et al, 2000a). Its sharp hooves and slow grazing in big herds are more damaging to the grassland than the traditional fat-tail sheep (ibid). At the same time droughts is a recurring phenomenon in 1890-1920 which significantly decreases agricultural productivity and steppe resilience and causes famine (ibid).

4.2.2. Intensification of agriculture

During 1920s under Soviet rule Kalmyk population was forced to change the nomadic way of life and settle. It resulted in disruption of seasonal pasture use while the share of sheep in the herds was increasing (Figure 4) (Borlikov et al, 2000a). Due to collectivization farm sizes were increased and a share of private livestock was reduced (ibid).
In 1943 during World War II Kalmyks were exiled to Siberia accused of cooperation with the enemy, where they had to remain until 1958. It accelerated the loss of traditional Kalmyk cattle and sheep breeds, moreover, the remaining Russian population extended areas of irrigated and non-irrigated agriculture and increased the number of sharp-hoofed fine-fleece sheep (Zonn, 1995; Borlikov et al, 2000a).

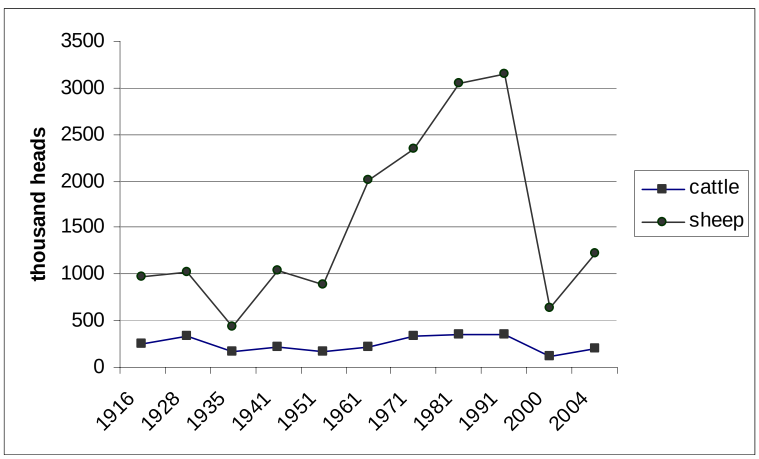


Figure 4. Dynamics of livestock population in Kalmykia in 1916-2004 (Federal Statistical Bureau, 2000; 2004)

Campaign for intensification of agricultural production began in the 1960. Sheep population grew to 2.2 million heads (Figure 4) and shortage of natural fodder was compensated by growing crops including in the areas not suitable for plowing like Black Lands which caused soil erosion and salinisation (Borlikov et al, 2000a). The period is characterized by decision makers' neglect of ecological peculiarities of the land and application of uniform agricultural techniques with a goal of increasing agricultural production at any expense (Zonn, 1995). This is argued to be the peculiarity of land degradation and desertification in the former USSR (Komarov, 1981).

In addition land degradation in this period was exacerbated by 35-year climatic Bruckner cycle that is believed to have been a cause of numerous droughts conditioned by changes of solar activity (Borlikov et al, 2000a).

By 1980s sheep population increased up to 5 million heads[4] while the share of cattle in livestock dropped from 40% to 6.7% during 70 years (Bananova, 1993; Zonn, 1995). The animal load on pastures was 2-3 times higher than carrying capacity whereas animal productivity dropped 3.5 times (ibid).
Simultaneously more land was allocated for irrigated agriculture. In the Black Lands melon and fodder crops growing led to severe erosion and formation of open sand areas. Irrigation and faulty drainage systems resulted in formation of solonchaks. Thus, more than 600,000 hectares of degraded lands in Black Lands area were excluded from agricultural use.
Pastures degradation and enormous livestock numbers led to fodder deficits in 1986-87 when 100,000-600,000 heads of livestock starved (ibid).

This time, desertification problem was acknowledged by the authorities and resulted in “General Scheme of Desertification Control” for the Black Lands region. According to the scheme, 560 thousand hectares of open sands were to be reclaimed through planting brushwood and sand-fixing crops (phytomelioration) aiming at stabilizing sands and increasing pasture area in 1993-2000 (ibid). In addition, the entire region’s water supplies were to be improved (ibid).
The measures were successful for pastures reclamation, however reduced financing at the end of the scheme period limited their implementation (Borlikov et al, 2000a). Kalmykia has also received support for the same measures from United Nations Environmental Programme (UNEP) under National Action Plan to combat desertification followed by the declaration of the state of emergency in Kalmykia by the republic’s president (Gabunshina, 2000). Combined efforts helped to reduce the area of moving sands to 110 thousand hectares (ibid).

4.2.3. Present situation

Transition to market economy in the beginning of the 1990s brought economic decline to all sectors of Russian economy including agriculture. As a result, livestock numbers were significantly reduced (Figure 4). So, by 2000 livestock load on pastures was 1.5 times lower than pasture’s capacity at around 600,000 heads (Borlikov et al, 2000a). Decreased grazing pressure contributed to pastures’ revival while continued phytomelioration helped to lessen wind erosion effect.

Revival of pastures is also believed to be a consequence of the arid climatic cycle change to a humid one which is expressed in increased precipitation up to 320 mm annually and reduced number of dust storms (Borlikov et al, 2000b).

1990s also saw a rise of the Caspian Sea level which is believed to be a historical trend rather than an ecological disaster (Mikhailov et al, 1998). Through flooding of the shore areas it is a natural cause of desertification (Borlikov et al, 2000b). Although, this area belongs to the Black Lands territory, the study does not include the sea level rise as one of the land degradation causes due to uncertainty in the

[4] Official record of 3.5 million does not include privately and illegally owned livestock that amounts to 2-2.5 million heads (Zonn, 1995).

forecast of the next rise (Mikhailov et al, 1998). Instead, the grassland system of the study excludes already flooded territories.

Better pasture conditions and the process of economical revival after the crisis of the 1990s have created favourable conditions for agricultural production and from 2000-2004 the livestock number doubled (Figure 4). Merino sheep continues to dominate livestock and grazing is year-round (Petrov et al, 2001). Private livestock now constitutes around 50% of all livestock while pastures remain common.

Several recommendations to preserve pastures and increase agricultural production have been proposed by the government. They require changing livestock composition to traditional structure with equal ratios of sheep, cattle and horses and a minor share of camels in order to reduce trampling and increase pastures' efficiency (ibid). Another recommendation is reducing grazing to 80% of livestock needs to preserve steppe vegetation (ibid). Yet, these measures are not implemented due to lack of money. Therefore, there is a risk that further increase of livestock as it was the case in 1960s-1980s will lead to severe land degradation despite several improvements during 1990s.

4.3. Saiga population

Saiga antelope has been included in the study as a part of the natural ecosystem of Kalmykia whose existence has been threatened by desertification processes and as an indicator species of biodiversity. There are several populations of saiga in Mongolia and Central Asia and Europe (Lushchekina and Struchkov, 2001). European population can be found on pre-Caspian pastures on the territory of Kalmykia and Dagestan. Saiga (*Saiga tatarica tatarica* L.) is referred to as "living fossil" (ibid, p.11), as it has been existing at the same time as mammoth. It is characterized by high adaptability to harsh environments, speed (reaching up to 80 km/hour), short life-span and high reproduction rate, qualities indicating adaptation for living in highly variable conditions (Arylov et al, 2004).

Historically Kalmyks valued saiga for game but kept hunting in control in order to preserve stable population numbers which was one ways to ensure people's long-term well-being (Lushchekina and Struchkov, 2001). Nevertheless, saiga experienced almost a complete extinction in the late 19th century due to intensive hunting for its valuable horns (ibid). As a result its population counted several hundred heads in the beginning of the 20th century when hunting ban was introduced (Arylov et al, 2004). By 1950 it increased to 100,000 heads and until 1960s it was primarily hunting and poaching (the ban was lifted in 1950) that caused saiga numbers fluctuations (Figure 5) (Lushchekina and Struchkov, 2001).

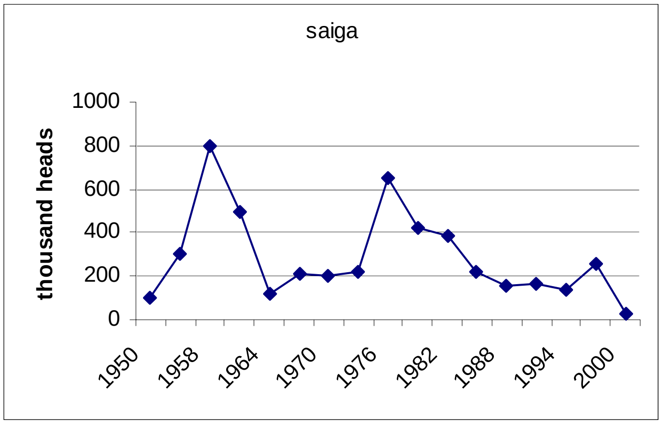


Figure 5. European saiga population dynamics in 1950-2000 (Lushchekina and Struchkov, 2001).

Further on, poaching, deteriorating pasture conditions and reduction of its habitat area due to agricultural intensification limited saiga number in 1960s and 1970s (ibid). Building irrigation canals along the migration route from breeding ground in Black Lands caused death of 14,000 new-born calves in 1977 (ibid). Besides, irrigation canals became drinking points for saiga and limited its seasonal migration which made them more vulnerable to poachers (ibid). Nevertheless, reintroducing hunting ban in 1960s allowed saiga population to recover to nearly 700,000 individuals in the 1970s.

Livestock reduction and revival of pastures proved to be a positive factor for saiga and its number was steadily increasing since the end of 1980s to around 1998 (Figure 5). In addition, a biosphere reserve Chernye Zemli was established in Kalmykia in 1993 under UNESCO's Man and Biosphere programme with an objective to conserve saiga (Badmaev and Ubushaev, 2004). Its territory in Black Lands is used by saiga as breeding ground and thus is protected against poachers during birth-giving season (ibid). Besides, saiga was included in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) treaty in 1995 (ibid).
Yet, it is argued that the reserve territory is not sufficient for saiga protection, and the main shortcoming is that while the territory of the reserve is fixed, saiga is not, which greatly reduces its chances for survival (Arylov et al, 2004)

The end of 1990s shows decline of saiga due to poaching for horns and meat (Figure 5). Saiga horns are used in traditional Chinese medicine and 1 kg of horns costs up to 100 US dollars (Lushchekina and Struchkov, 2001). Hunting for horns reduced male-ratio of adult saigas and it turn decreased antelope's reproduction ability[5] (ibid). As the livestock number dropped and economic conditions deteriorated, it caused saiga poaching for meat. As a result, in 2000 European saiga population was reduced to 25,000 heads (Arylov et al, 2004). Achieving sustainability would require stabilizing saiga population and creating such agricultural practices that do not interfere with saiga well-being.

[5] Under normal saiga herd male-female ratios, there are 12-24 females per 1 male; in 2000 adult male ratio was 0.89% and there was 1 male per 500 females or more (Lushchekina and Struchkov, 2001).

5. Conceptual model analysis

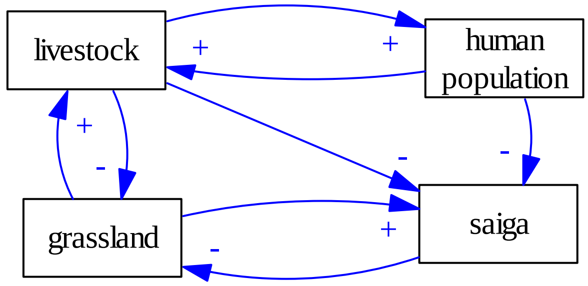


Figure 6. A basic representation of the system under study. The chart shows the influence of the livestock, human population, saiga and grassland subsystems on each other. Arrows with “+” indicate the same direction of change, while arrows with “-” identify opposite direction.

Figure 6 illustrates the basic understanding of the subsystem interactions in the studied system where arrows with ‘+’ indicate the same direction of change between the variables while ‘-’ show opposite direction. A more detailed and elaborate graphic representation of system’s mental understanding has been created using Causal Loop Diagram (CLD). Thick arrows are used to point out the system’s driving loops.

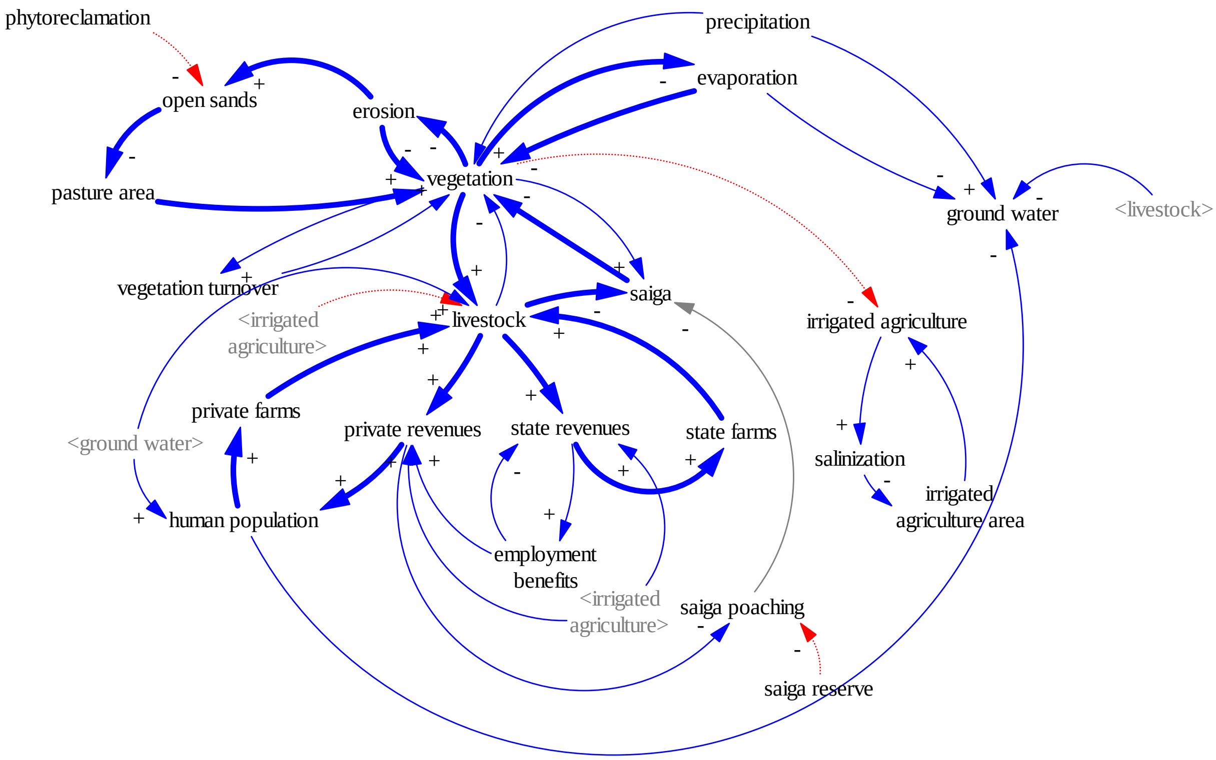


Figure 7. The Causal Loop Diagram of the system. It illustrates the understanding of the system: interaction of the subsystems and the way it affects the system. Thick arrows represent driving loops of the system. Broken arrows indicate management decisions.

The Causal Loop Diagram illustrates the following subsystems and their behaviour: the grassland, livestock, saiga and human population (Figure 7).

Vegetation is the main variable of the grassland system. It is represented by annual and perennial grasses that are characteristic of the area. Its productivity is positively affected by the amount of precipitation increasing soil moisture. The soil moisture is dependent on the rate of evaporation which increases if the density of vegetation declines and exposes the soil surface (UNCOD, 1977). Likewise, wind erosion effect is enhanced with the decline of the density of grass which protects the fertile top soil layer from being eroded (Dregne, 1983). Therefore, wind erosion reduces vegetation productivity. Due to the type of soil in the region, eroded areas turn into barren open sands and reduce the pasture area, thus reducing the total amount of vegetation. Other factor which affects vegetation productivity is its turnover rate that contributes to soil fertility.

The livestock is composed of sheep and cattle and its source of fodder is vegetation. Grass availability determines the number of animals through their reproduction and death rates. Consequently, the vegetation is decreased by its consumption and trampling. Cattle and sheep have different grazing behaviour – the latter destroys the vegetation by grazing down to the root of the plant while the former grazes the top off and covers bigger pasture areas leaving more chances for the grass to regenerate (*assumption 1*) (Yusunbaev et al., 2003). This difference is disclosed in the numerical model and will be further discussed.

The grazing of saiga is limited by the number of livestock in the area because both have the same source of fodder. However, saiga is a highly mobile animal, therefore, we assume that it only gets a part of its fodder needs in the Black Lands and thus, its reproduction and death rates are not affected entirely by the vegetation availability in the region (*assumption 2*).
A saiga reserve of 91 thousands ha was created to protect the birth-giving females from illegal hunting and to revive the European saiga population in 1993. It is also a source of fodder for saiga only and is not included into the pasture area (*assumption 3*).

The human population is dependent in turn on the revenues it gets from its share of livestock. The revenues from the state livestock also contribute to economic well-being of the people through employment benefits – 30% of the region's population is employed at the state farms (Federal Statistical Bureau, 2004). Therefore, the population growth dynamics are determined by the private revenues. Since 1995 when the livestock number decreased drastically because of fodder shortages there has been a steady decline of the population due to migration caused by poverty (Borlikov et al., 2000a).
People start poaching saiga when they face economic hardship (Luschekina, Struchkov, 2001). It is argued that the killing is done mainly for the sake of valuable horns but also for meat (Arylov et al., 2004). In the CLD we assume that saiga poaching does not bring economic revenues to the public as it is only a few individuals who prosper from it while the rest rely on it as a source of cheap meat (*assumption 4*).

Irrigated agriculture is the third source of revenues of the state and private farms. There is a limited amount of land available for plowing. It is separate from the pasture area and constitutes around 1.5 % of the total area. The same area is designated for fodder crops growing. However, the soils are not suitable for irrigation and salinization occurs within 3-7 years leaving the fields infertile and excluded from the agricultural use (*assumption 5*).

Irrigation canals provide water for saiga and for irrigated agriculture (Arylov et al., 2004; Kalmyk Environmental Programme, 2002). This water originates from the rivers that are situated outside of the geographical area in discussion, and therefore, it is not a part of the system.
Humans and livestock are sustained by the groundwater which is available in artesian wells (ibid). Because these reserves have not been assessed, we assume that if the water extraction exceeds the average inflow rate into the wells, the water ceases being suitable for drinking purposes (*assumption 6*) since the water from the deeper levels of the aquifer is highly mineralized (10-12 g/l) (ibid). The rate at which the groundwater resources are replenished is dependent on the amount of precipitation and on the infiltration rate which is negatively affected by the evaporation rate.

The measures that have been attempted in the past to stop desertification processes are aimed at reducing the advance of open sands by growing grasses (phytoreclamation) at a higher rate than the rate of their formation (Borlikov et al., 2000a). Phytoreclamation thus restores the pasture size at the original vegetation productivity (*assumption 7*). In order to prevent overgrazing, it has been recommended to limit grazing on natural pastures and provide livestock with supplementary fodder. Limiting sheep and increasing cattle, horses and camels in the livestock have also been proposed to ensure more efficient use of pastures (ibid).

Thus, the driving forces of the above-described CLD are human dependence on livestock as the main source of economic revenues and livestock grazing as the destructive factor of the semi-arid grassland ecosystem (arrows in bold). Based on the CLD, reference behaviour patterns (RBP) of these subsystems were developed in order to predict the basic dynamics of the system, and further used to construct a quantitative model. The paper will further investigate the interactions of subsystems, behaviour of the main driving forces and the impact of the management decisions on the whole system using numerical model.

6. Analysis of the subsystems and parameterization

6.1. The grassland system

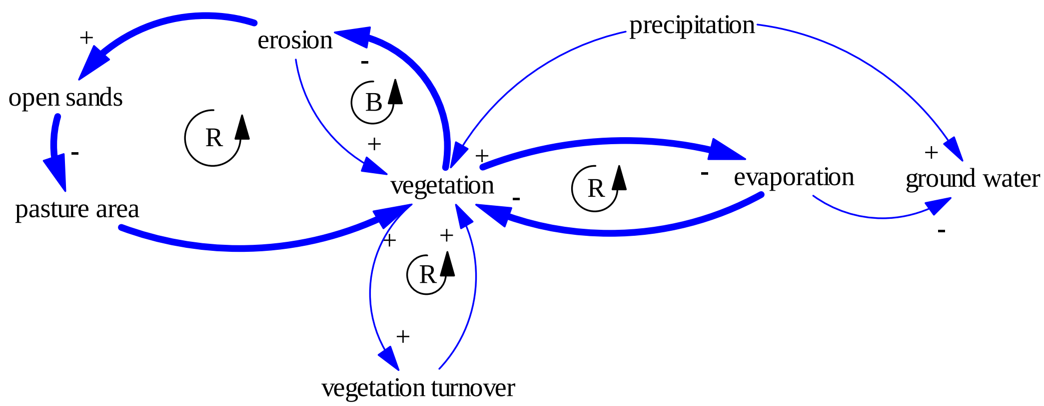


Figure 8. The CLD of the grassland system. It is a simplified representation of the main physical and biological mechanisms affecting grassland ecosystem regulation. Reinforcing loops are marked as R, balancing ones - B, driving loops as the main forces for grassland productivity (thick arrows).

In reality the physical and biological processes involved in grassland ecosystem are more complicated and involve a great number of processes and factors. Because of the lack of the necessary geochemical, physical and meteorological data, the model is validated through the parameters that have been recorded and are available in the literature, e.g. vegetation yield, sand dune formation rate, amount of rainfall, etc. The basic dynamics of the grassland system are presented in Figure 8.

Soil moisture is an important factor which determines the ability of plants to reproduce (UNCOD, 1977). However, too much moisture deprives the plant from air and it dies, as well as not enough moisture will result in the plants death (Sverdrup et al., 2005). In the model we assume that the vegetation productivity increases linearly with the increase of the soil moisture and do not provide the threshold value at which too much moisture occurs (*assumption 8*). Soil moisture in turn is determined by the amount of precipitation. Based on the available data on vegetation yields and mean annual precipitation, we assume that the average amount of precipitation in Black Lands – 210 mm – is an optimal amount for the successful regeneration of vegetation in a balanced ecosystem but not a maximum value[6] (*assumption 9*). We create a function of soil moisture and vegetation productivity in ecosystem equilibrium so that at 210 mm of precipitation the vegetation yields to 250 kg of biomass per hectare (see Appendix 1 for vegetation regeneration equation) (Vinogradov, 1993).

Vegetation prevents rainfall from evaporation. Fine-textured sandy soils of Black Lands efficiently infiltrate the water that was not intercepted by the plants to groundwater levels. Since the total annual underground runoff in the area does not exceed 25 mm it is set as the maximum value for infiltration rate, which is also the rate for groundwater recharge (*assumption 10*) (Koronkevitch, 2002).

Annually artesian wells supply 231,000 cubic meters of water, out of which 208,000 cubic meters have mineralization rate of 3-10 g/l. Remaining 23,000 cubic meters (1-3 g/l) are considered suitable for human and livestock use (Kalmyk Environmental Programme, 2002).

Both the soil moisture and infiltration rate are dependent on the rate of evaporation which increases when the density of vegetation declines. Studying vegetation productivity rate dependence on amount of precipitation on the most degraded pasture areas combined with an effect of wind erosion caused by reduction of vegetation cover, we can make an assumption that at its maximum evaporation reduces soil moisture and infiltration rate by 50%.

Vegetation turnover represents a rate at which vegetation turns into organic matter. It is a source of nutrients and therefore it contributes to vegetation reproduction rate. In a grazing environment the turnover is disturbed.

Under wind or water erosion the more fertile top soil layer is being removed while less productive subsoil is uncovered (Dregne, 1983). It occurs when vegetation cover is destroyed due to cultivation or by grazing animals exposing soil surface (ibid). In Black Lands wind velocity is at 15-20 m/sec during 52 days a year in average while precipitation is at around 210 mm/year and the relief lacks slopes

[6] One of the factors that is held accounted for the recent restoration of Black Lands' pastures is increase in annual rainfall up to 320 mm (Borlikov et al., 2000b).

(Borlikov et al., 2000a). This makes wind erosion a greater factor in land degradation in the area. When amount of vegetation in the area declines, it initiates the process of erosion decreasing the overall fertility of the area.
Under natural conditions soil erosion is balanced by soil formation processes (Zonn, 1995).

The model is using the natural vegetation yield as an indicator of erosion rate. As it is known that the current vegetation cover is 100 kg/ha and around 30-35%, we can assume that the undisturbed grassland was covered by vegetation by 100% and produced 300 kg/ha of vegetation (maximum vegetation productivity rate – *assumption 11*). The change occurred over 30 years. The annual vegetation loss is then 2.3%. In this conditions wind erosion forms areas of open sand at 50,000 hectares per year (Gabunshina, 2000). Sand area lacks vegetation and thus the pasture area is reduced by the area of sands (*assumption 12*).

The initial total productive pasture area is 2,700 thousands hectares while the total area of the Black Lands is 3,500 thousands hectares (Khulkhachiev et al., 2000). The pasture area excludes already existing salinized and open sand areas that are not included into the agricultural production.

Therefore, vegetation is the central variable in the grassland system which is externally affected by precipitation amount. Wind erosion increases the area of open sands and thus decreases vegetation cover which exacerbates erosion rate. Eroded area is more subject to evaporation and less fertile which prevents vegetation from regeneration. This is the driving mechanism of the grassland system.

6.2. The grazing system

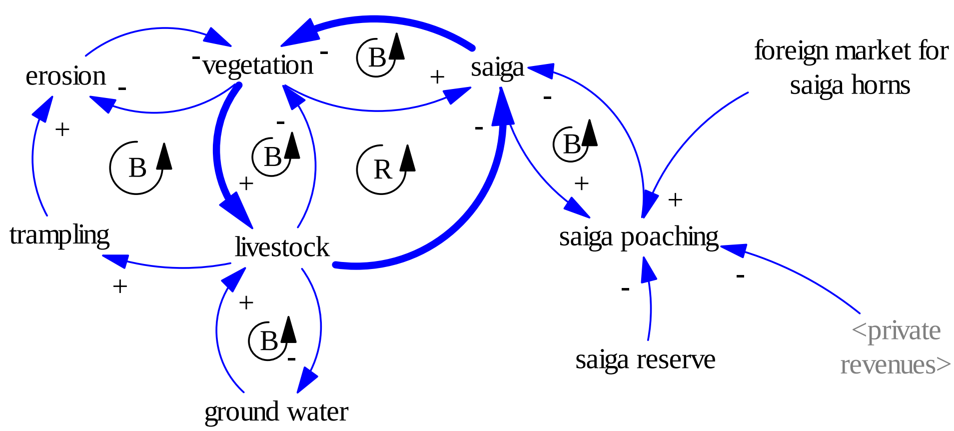


Figure 9. The CLD of the grazing system. Thick arrows indicate reinforcing effect of saiga elimination on livestock through more vegetation availability. Foreign market for saiga horns and saiga reserve are external factors that impact saiga number, along with poaching.

The Black Lands' livestock consists of 317,000 heads of sheep (91%) and 28,000 heads (9%) of cattle. The fodder needs per one ovine equivalent (1 head of cattle is equivalent to 5 heads of sheep) is 2.4 kg per day (Petrov et al., 2001). The grazing period is year around (ibid). Water needs are 3 liters a day per ovine equivalent (ibid). Under satisfactory fodder and water conditions, the reproduction rate is 45% while the death rate is 1% (ibid). After a dramatic decline of livestock in 1990s, there has been nearly doubling of livestock size from 2000-2004 due to improved pasture conditions and regional economic revival (Figure 10).

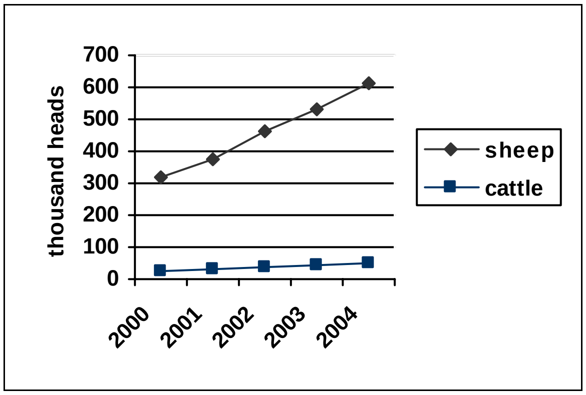


Figure 10. Livestock population growth in Kalmykia in 2000-2004 (Federal Statistical Bureau, 2004).

The grazing of sheep and cattle has a different impact on vegetation: the sheep graze down to the root of the plant and its sharp hooves trample the soil inducing soil erosion, while the cattle are less destructive, browsing over large pasture areas and leaving more chances for the plants to regenerate (Yusunbaev et al., 2003). In the model this important exception is reflected by allowing 20% of vegetation grazed by cattle to return into the fodder system as the vegetation destruction difference between sheep and cattle is a factor of 2 under normal grazing (see Appendix 1 for equation) (ibid). In the model we assume that the proportion of sheep and cattle stays the same as of 2000 (*assumption 13*).

The grazing system is driven by external factor – vegetation productivity which in turn is dependent on other factors (see Section 6.1). Besides, the competition for the single source of fodder and livestock's domination in grazing which limits saiga's survival is the driving mechanism of saiga's elimination and livestock's increase (arrows in bold in Figure 9). Yet, saiga is less dependent on the vegetation in the area. It is a nomadic animal and uses the Black Lands as its winter pastures (Lushchekina, Struchkov, 2001).The estimate saiga fodder needs are 2 kg of vegetation per day per head during 4 months period.

The reproduction rate is high: females reach sexual maturity by the age of 1 year having 2-3 calves in a year while twinning is 20-70% (ibid). Yet, over the past decade the number of males had been drastically reduced by poachers. In 1999-2000 there was 1 male per 500 females representing 0.89% of all saiga population, while in normal conditions it is 1 male per 20 females (ibid). Not only it decreases the chances of females to get pregnant, but also the population is reduced by the death of males who are too exhausted to migrate and also increases inbreeding (Soule, 1986). The saiga reproduction rate is thus estimated at 50% of its reproduction rate under favourable conditions – 100%.

Saiga poaching is triggered by decreasing private revenues from farming because of saiga's valuable horns that are used in traditional Chinese medicine ("foreign market for saiga horns"). The model is built with the assumption that most of the population is not involved in illegal hunting and consequently not profiting from it based on conversations with locals. Poaching requires necessary equipment and use of cars which is not available to the main public. However, falling incomes create a demand for saiga meat which is cheaper than sheep or cattle meat. The rate of poaching is thus dependent on the revenues from agriculture: whenever they are lower than 50% of the minimum living expenditures (agriculture constitutes 50% of incomes – see Section 6.3), poaching starts. The maximum hunting rate of 25% is based on the census of saiga population during 1990s (Lushchekina and Struchkov, 2001).

A saiga reserve was created by UNESCO on the territory of the Black Lands in 1993. Its area is 91,000 hectares, 25,000 of them are sands or salinized lands (Badmaev and Ubushaev, 2004). The main purpose of it is protection and preservation of biodiversity of the region. It is the breeding ground for saiga and here it receives its protection from poachers for that period (ibid). In the model we assume that the vegetation intake in the reserve by saiga is not significant due to their short duration of stay. On the other hand, the role of the reserve in protection of birth giving females is represented by the relatively high birth rate without zero value. It is lower than the rate under favourable conditions only due to declining number of males.

6.3. The human population system

The basic dynamics of the human population system are following: its growth is dependent on economic revenues (Figure 11). Economic revenues that are formed within the scope of the system are received from livestock, employment at state farms and irrigated agriculture. The main focus of the paper is private farms and private revenues.

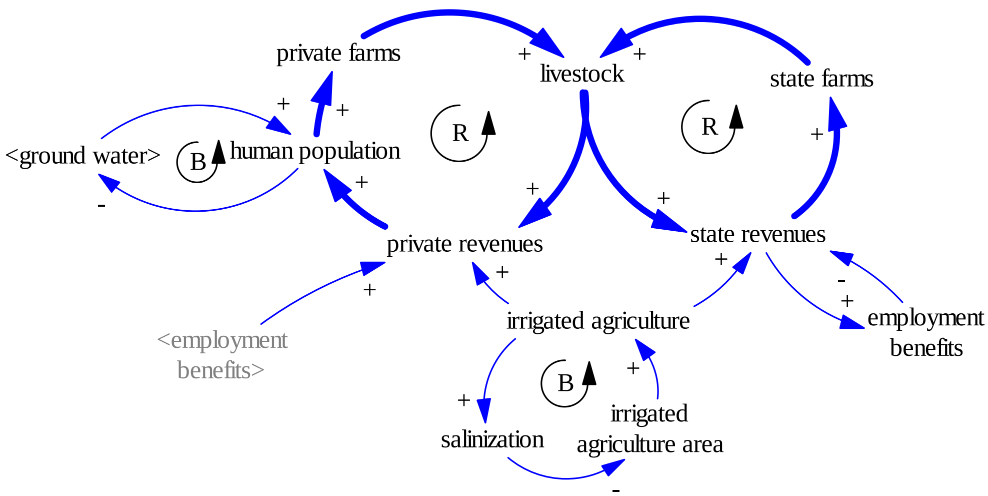


Figure 11. The CLD of the human population system. Economic system is a part of human population system as it determines people's well-being and thus, population number. The reinforcing mechanism is increasing revenues leading to population growth and increasing livestock (thick arrows).

According to Federal Statistical Bureau, in average 50% of all household income in the region of Black Lands is formed by agricultural practices (Federal Statistical Bureau, 2004). Other sources of income are employment in other fields than agriculture, various social welfare allowances, including retirement pensions, and external money transfers from migrants to other parts of the region or country.

In order to derive the minimum value of annual income per household ("private farm") we use the official monthly living expenditures minimum[7] for the year of 2000 assuming that it does not change over time in the model (*assumption 14*) (ibid).

In 2000 45% of all livestock belonged to private owners and 55% to the state ("state farms") (ibid). Annually, each private farm sells 40% of its livestock, while the state – 20% (ibid). In the model we assume that neither of the livestock owners sells more than this percentage of their livestock.

30% of all population is employed at state farms (ibid, p.48). Thus we assume that at least one member of each household receives a monthly salary of 590 rubles in 2000 which is raised to 1300 rubles in 2001 (*assumption 15*) (ibid).

Irrigated agriculture consists of growing vegetables on specially designated for irrigation fields out of which 40% belongs to the state and 60% is rented by the private farms (ibid). The area of such crops growing was 3600 hectares in 2000 (ibid, p.183-184). Each hectare yields in average 5000 kg of crops which is sold at the price of 5 rubles/kg (see Appendix 1 for equation of private and state revenues formation) (ibid).
However, the fields become salinized and lose productivity within 3-7 years (Borlikov, 1998). We assume that no additional area is permitted for crop growing when the area of available fields is degraded (*assumption 16*).

When revenues from agriculture are less than 50% of the official minimum living expenditures, it raises migration rate forcing people to look for economic opportunities elsewhere. In 1995 during the aftereffects of economic transition and previous livestock reduction due to starvation, the migration rate was at its highest at 4.5% (3281 people) (Federal Statistical Bureau, 2004). In 2000 the migration rate stabilized at 2.5% (ibid).
Hence, migration is the main cause of population decline, the birth rate being 1.4% in favorable economic conditions and equal to death rate, while the death rate stays stable at 1% (ibid). Nativity and mortality have been excluded from the CLD for simplification purposes.

Water availability of a satisfactory quality is an important factor of population system. 70 liters per day per person have been identified as a minimum requirement in the area (Kalmyk Environmental Programme, 2002). Shortage of water leads to increased migration rate. In the model it is assumed that the daily water requirement remains the same (*assumption 17*). The reserves of the groundwater are not unlimited, but there are no reserve assessments and it poses a limitation to the model. Instead, we use the rate of recharge of the wells (see *assumption 6*).
Hence, the driving mechanism of the human population system is its dependence on revenues from farming: population grows under favorable financial conditions and this in turn, increases livestock number. Irrigated crop growing is also a source of revenues. Yet, it is not a reinforcing mechanism due to the fact that the irrigated area is limited.

---

[7] Monthly living expenditures minimum is an official value derived from minimum amount of nutrition needs, non-food goods and services, required for person's health and well-being, and necessary monthly payments and fees according to prices at a certain period of time (Federal Statistical Bureau, 2004).

6.4. Management decisions

The government of Kalmykia is concerned with the desertification problem that had been especially acute in the end of 1980s and beginning of 1990s. Therefore, the government has issued a number of policies and recommendations to prevent the environmental disaster and to ensure economic and social sustainability. They are phytoreclamation of open sands, limiting livestock grazing to 80% of their needs, and changing the composition of the livestock.

Phytoreclamation is only successful if it is done at a higher rate than the advance of sands. It is an important measure to restore the pasture area and to prevent it from shrinking when the grassland is overgrazed and eroded. In 1992-1995 the area of recultivated sands was 100,000 hectares annually (Gabunshina, 2000). However, in 2000 it was 50,000 hectares per year due to reduced financing from the federal government (Borlikov, 2000a). The fodder yield of the restored pastures is assumed to be the same as of non-disturbed pastures.

The recommendation of limiting livestock grazing to 80% of their needs aims at reducing the impact of livestock on pastures and preserving them from overgrazing (Petrov et al, 2001). 20% of the fodder has to be supplied from “self-produced reserves” (ibid). It also ensures animal productivity during non-grazing weather conditions in the winter and spring. We will assume that 100% of farmers follow the recommendation. Currently it is 25,000 hectares that are used for fodder crops growing with an annual yield of 650 kg of grain/ha (Khulkhachiev et al, 2001). However, the existing plowing area cannot be increased due to high risk of soil erosion and salinization. Therefore, we assume that the rest of needed fodder crops are imported from other regions at a price of 1.6 rubles/kg (Federal Statistical Bureau, 2004).

Traditional livestock composition of 30% of traditional fat-tail sheep, 30% of cattle, 30% of horses and 10% of camels is believed to be optimal for Black Lands’ pastures (Petrov et al., 2001). At this ratio the use of pastures is argued to be the most effective (ibid). It can be explained by different grazing behaviour of these farm animals, horses and camels being the least destructive and differing with sheep by vegetation destruction factor 3, i.e. leaving 30% more vegetation than sheep (see Appendix 1 for equation) (ibid; Yusunbaev et al., 2003).

7. Scenarios – analyzing future under different conditions

Based on the analysis of the system and its numerical representation described in the previous chapter future scenarios can be elaborated.

The first scenario provides prediction of the systems behaviour assuming stable rainfall at 210 mm per year while other factors and conditions correspond to the described trends of the grassland, grazing and human population systems. Thereafter, the model is run under different government management decisions to combat desertification and to ensure livestock productivity.

Thus, Sections 7.1-7.2 investigate the system dynamics under following scenarios:

- Business-as-usual
- Phytoreclamation
- Limited grazing
- Traditional livestock composition
- Combined measures

7.1. Business-as-usual

Figure 12 illustrates the human population, livestock and saiga system behaviour from year 2000-2050. Both saiga and livestock increase exponentially following the pasture revival after the intense overgrazing and resultant livestock reduction of 1990s.

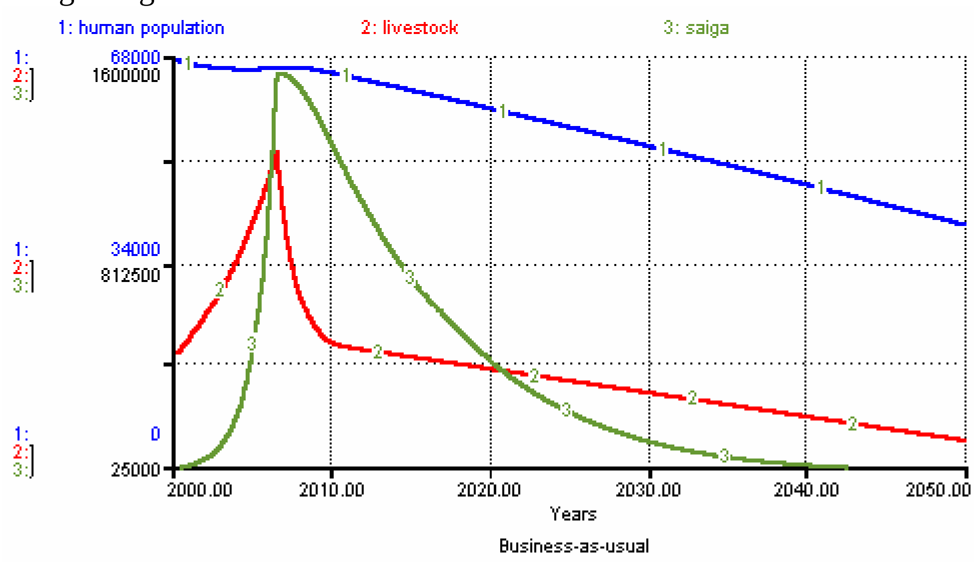


Figure 12. System dynamics of human population, livestock and saiga under business-as-usual scenario. Human population range scale is from 0- 68,000; livestock and saiga 25,000-1.6 million heads[8].

In 2000 their population numbers are still within the carrying capacity of the land. By 2007 livestock reaches the size of around 1,230,000 heads of ovine equivalent. At the same time saiga grows up to about 1,600,000 heads. It creates shortage of fodder which livestock is more vulnerable to than saiga since the latter is a nomadic grazing animal. That is why the number of livestock decreases exponentially between 2006 and 2009 and continues to decline more gradually down to 120,000 heads by 2050. Saiga population faces more gradual but more severe decline at 5,000 heads in 2050.

Intense overgrazing induces wind erosion which causes open sand formation and results in loss of pasture area (Figure 13). By 2050 the pasture area is decreased by around 2.1 million hectares, or by 75% of the territory. Despite the decreased pressure on the grassland that happens over time, the productivity of the vegetation does not go back to its initial value partly due to still present grazing and partly – to erosion processes that decrease soil fertility and thus its ability to regenerate.

[8] Note that the scale for livestock and saiga populations in Figures 12, 16-19 has been adjusted for each scenario and varies in order to enable better representation of population dynamics over time.

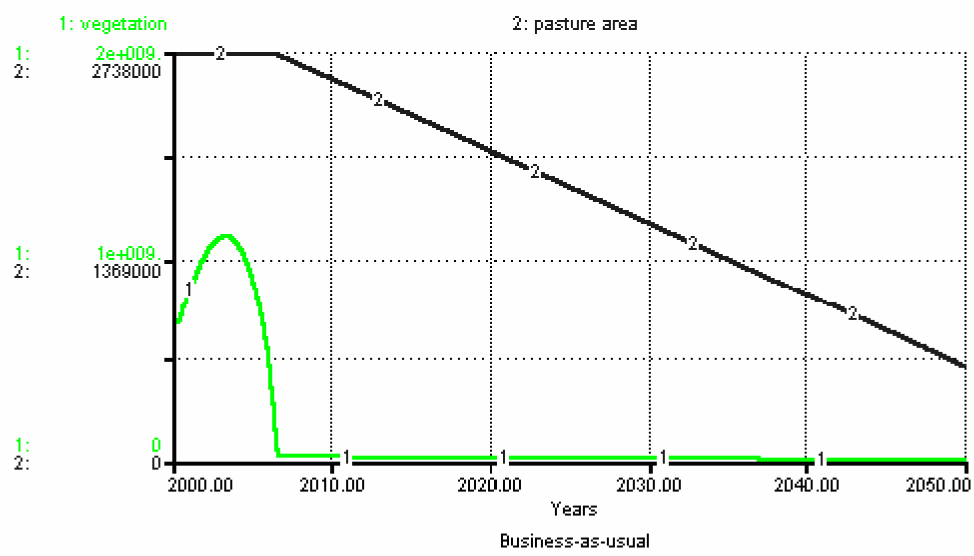


Figure 13. Changes in vegetation and pasture area under business-as-usual scenario. Vegetation is expressed as a total amount of biomass (range 0 – 1.1 billion kg). It increases exponentially due to relatively low number of livestock and saiga and exponential decrease follows when the latter exceed the carrying capacity of the pastures. Maximum pasture area is 2.7 million ha.

Human population decreases initially, however, by the time livestock population reaches its peak, it grows again, and faces a gradual decline following the pattern of saiga and livestock populations. The decrease can be explained by the dropping income of the population when the number of livestock falls (Figure 14).

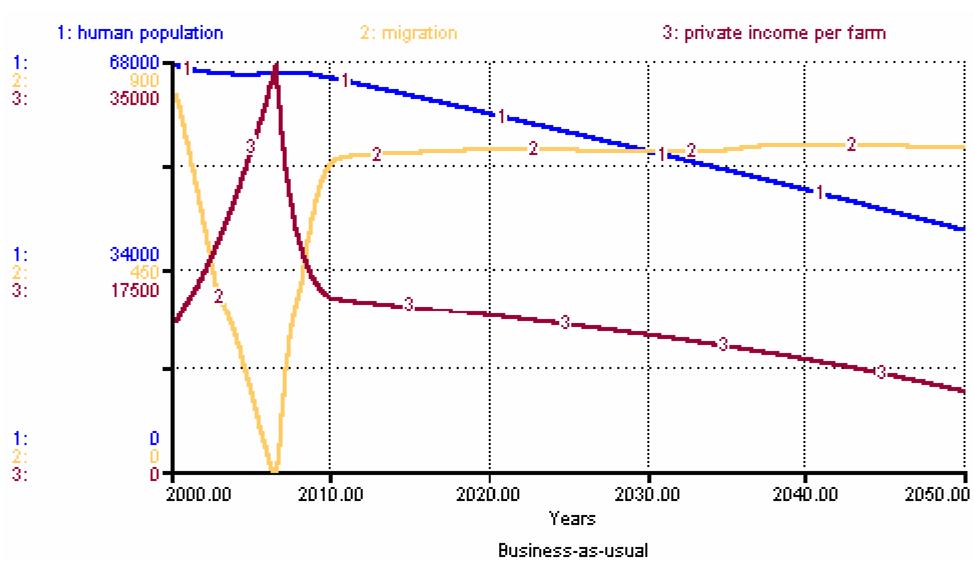


Figure 14. Human population, income per farm and migration patterns under business-as-usual scenario. Graph scale for migration is 0-900 people, private income per farm ranges 0-35,000 rubles, and human population 0-68,000.

Migration is high at the start of 2000 and falls when the income per farm grows. Thus human population declines from 68,000 people in 2000 to 41,000, or by 40%, in 2050.

Similarly, falling incomes create poverty which intensifies saiga poaching (Figure 15). Poaching decreases in absolute numbers when saiga herds decline, however, hunting rate remains high in accordance with poverty.

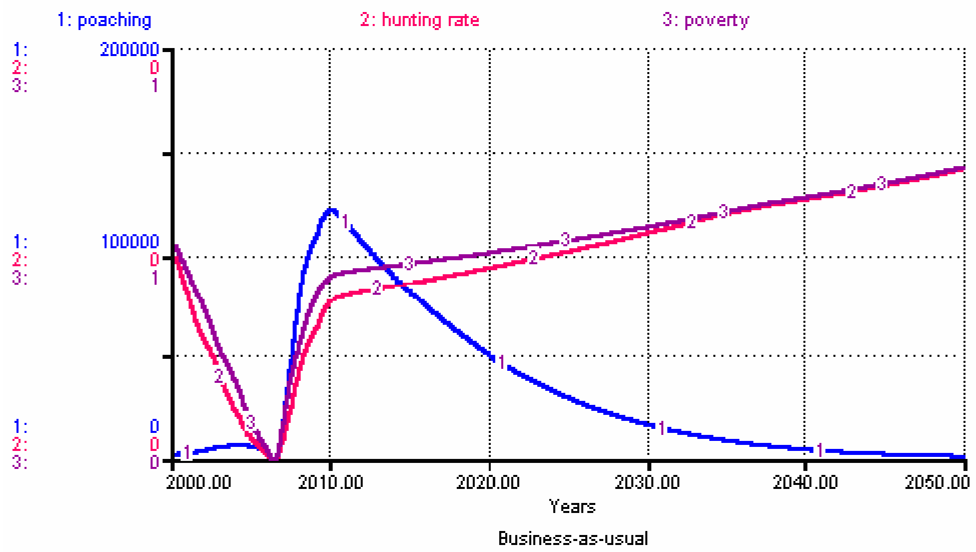


Figure 15.Poverty, hunting rate and poaching under business-as-usual scenario. Poaching is represented in absolute numbers – heads of saiga, while poverty is a rate ranging from 0-1. Hunting rate maximum is 0.25 (per cent of saiga population).

The driving factors for the system change are the human population and livestock dynamics. Human population increases the latter to gain economic benefit from it; however, livestock's exponential growth inevitably leads to the collapse of the ecological system endangering saiga population as a representative of area's biodiversity, while poaching remains the main cause of saiga elimination. Hence, this forecast enables us to predict the unsustainability of the system under study.

7.2. Management in force

The following scenarios predict systems behaviour under government proposed management decisions to combat desertification and to retain high livestock productivity.
These measures include phytoreclamation of open sands area, limiting livestock grazing to 80% of its needs and providing 20% by own grown and imported fodder crops, and changing the composition of livestock (see section 6.4). First, the decisions are modeled separately; the last scenario forecasts systems changes under combined measures.

7.2.1. Phytoreclamation

Soil erosion occurs under intense grazing as a result of combination of vegetation removal and trampling. As the soil layer is shallow (3.5 cm), soil erosion leads to formation of open sand areas (Petrov et al., 2001).

Phytoreclamation defined as re-vegetation of degraded areas by planting grasses has been taken up by the decision-makers as one of the desertification management strategies (Borlikov et al., 2000a). The purpose of phytoreclamation is twofold: to stop the open sands advance and to restore pastures.

In order for this measure to be effective re-vegetation has to be implemented at a rate that matches the rate of sand areas formation. We determine that this rate is then at least 50,000 hectares per year starting year 2006. Maintaining the pasture capacity enables the livestock population to stabilize at nearly 600,000 heads and start slightly growing at the end of the modeling period (Figure 16). Although, the number of saiga is higher than in business-as-usual scenario (nearly 2,000,000 at the maximum and 160,000 at the end of the modeling period), phytoreclamation measure fails to ensure its stable population dynamics as livestock still dominates in grazing and poaching has not stopped. A larger human population compared to the business-as-usual scenario (56,000 vs. 41,000) is due to five times higher livestock number as in the previous scenario. Hence, the economic revenues are higher which limits but not eliminates people's migration.

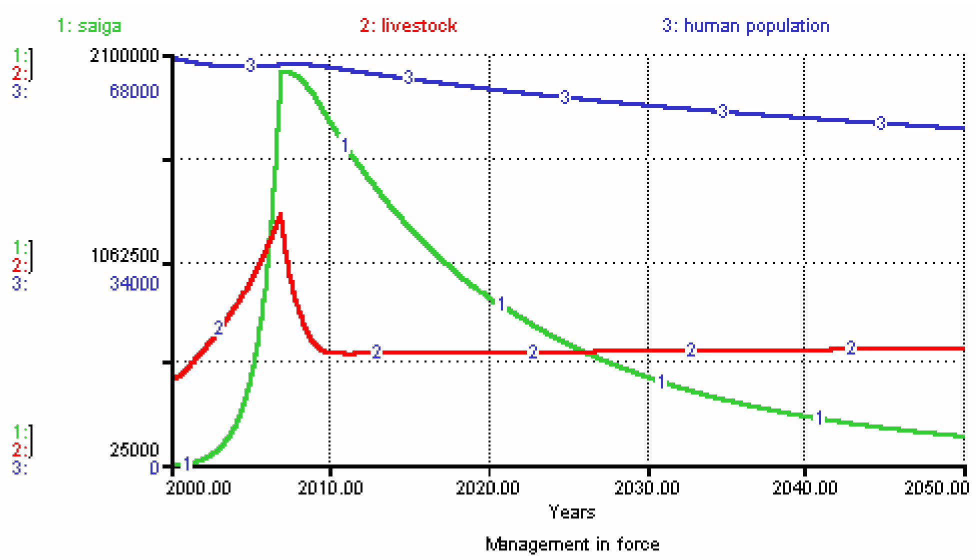


Figure 16. Effect of phytoreclamation on livestock, saiga and human population. Scale range for livestock and saiga is 25,000-2.1 million heads; human population 0-68,000 people.

7.2.2. Limited grazing

The Kalmyk Branch of Southern Land Use Institute has recommended limiting livestock grazing on natural pastures to 80% of its needs (Petrov et al, 2001). Currently 100% of livestock fodder needs are provided by pastures.

Decreased pressure on pastures results in more stable vegetation yield, which in turn, directly affects livestock and saiga populations. At maximum in 2009 their numbers reach 1,550,000 and 3,000,000 heads respectively (Figure 17). At its lowest in 2050 livestock counts 350,000 heads which is around three times more than at 100% grazing (Scenario 7.1).

Saiga experiences less competition for fodder from livestock, therefore, we observe a great increase in its number, almost double as much as without limiting livestock grazing. Nevertheless, its number declines due to poaching. Despite receiving more livestock yield, human population fails to increase its economic revenues as there is a need to purchase additional fodder for the livestock. As a result, population decline is nearly as severe as when there was three times less livestock and by 2050 population drops to 44,000 people.

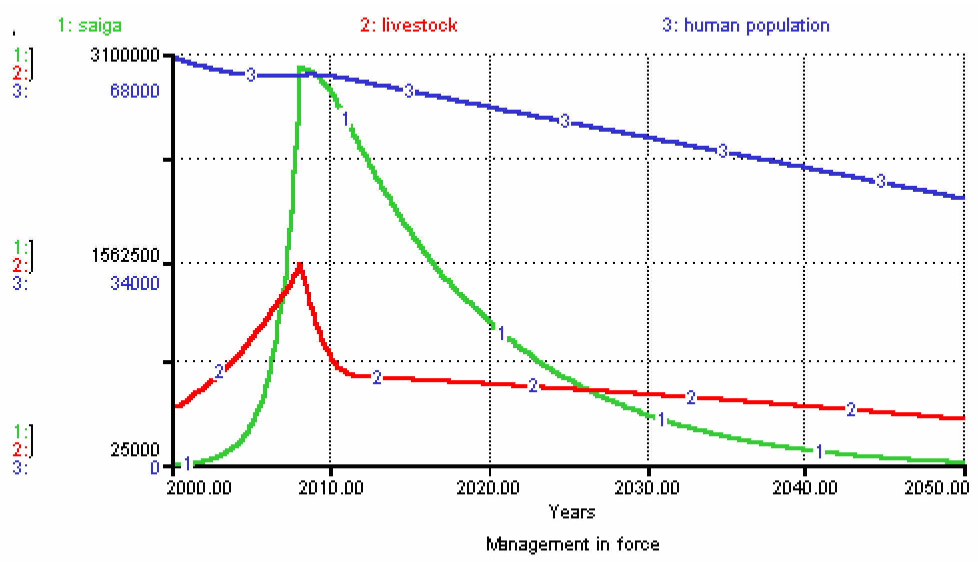


Figure 17. Systems response under limited grazing management decision. Scale range for livestock and saiga is 25,000-3.1 million heads; human population 0-68,000 people.

7.2.3. Traditional livestock composition

Traditional livestock composition is less destructive for the grassland and includes horses and camels so that the livestock composition is 3:3:3:1 (sheep, cattle, horses and camels, respectively) (Petrov et al, 2001). Under these conditions soil vegetation cover is preserved and protects the soil from erosion and consequent open sand formation. As in the previous scenario, higher pasture productivity allows saiga to outgrow the number of livestock (Figure 18). Both populations are only around 10% lower than under limited grazing conditions (Scenario 7.2.2). Yet, overstocking results in saiga and livestock population collapse as in other scenarios and as a result, we observe the same human population trend with a little difference from business-as-usual scenario. This management policy can allow the livestock and saiga to reach higher population numbers but overall results resemble those without management under business-as-usual conditions (Scenario 7.1)

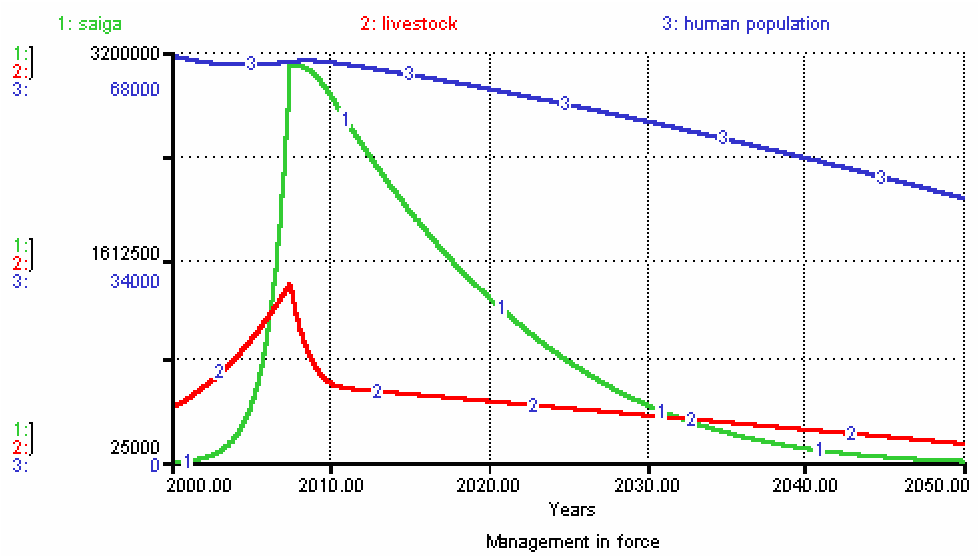


Figure 18. Saiga, livestock and human population under traditional livestock composition management decision. Scale range for livestock and saiga is 25,000-3.2 million heads; human population 0-68,000 people.

7.2.4. Combined measures

The following scenario will forecast the future of the system assuming that above-described management strategies are implemented simultaneously.

Decision to limit grazing, change livestock composition and continue phytoreclamation to fight advancing sands indicates increase in livestock yield by around 30% compared to business-as-usual scenario, while saiga population shows a dramatic difference of 3.5 times higher number than under business-as-usual conditions. Livestock reaches nearly 1,700,000 heads in 2009. However, the vegetation system cannot sustain the impact of this number of grazing animals and in 2012 the livestock stabilizes at 914,000 heads to gradually grow up to 960,000 by 2050, preceded by a rapid decline.

Saiga population initially grows exponentially following the dynamics of livestock and reaches over 5,700,000 heads by 2010. Yet, it then faces fodder shortage and decreases to 950,000 heads in 2050 unable to compete for fodder with livestock and exterminated by poverty stricken population.

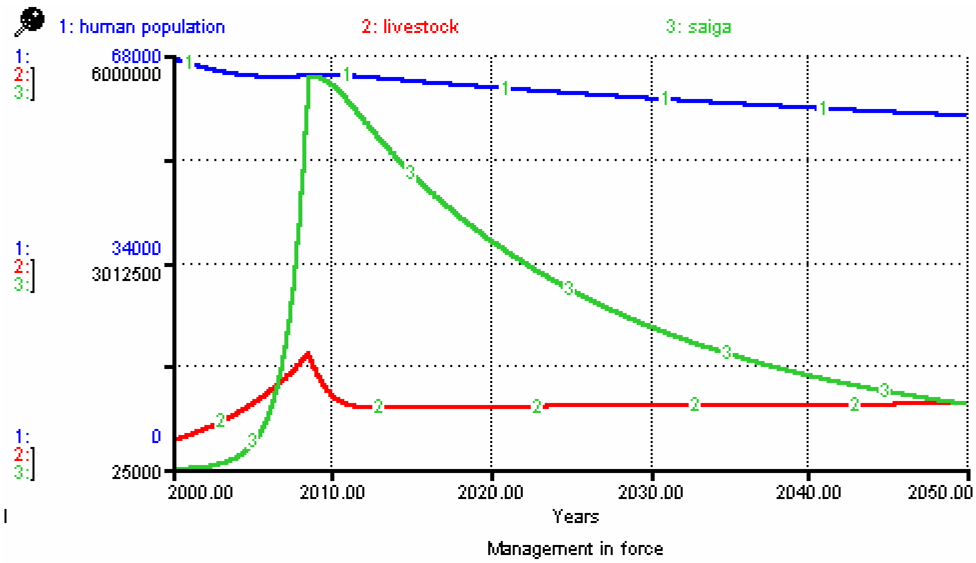


Figure 19. Dynamics of livestock, saiga and human population systems under combined management decisions. . Scale range for livestock and saiga is 25,000-6 million heads; human population 0-68,000 people.

Figure 20 illustrates the impact of management measures on human population. Despite high livestock productivity, human population is steadily declining. The cause of it is declining income of private farms and a steady migration rate. We can see that poverty rate falls significantly when the livestock population reaches its peak. But as livestock size decreases, the revenues decline. Human population falls from around 68,000 people in 2000 to 58,000 in 2050. At the end of the period, revenues are increasing due to the fact that herd size increases and at the same while population is declining, so there is more livestock per farm now.

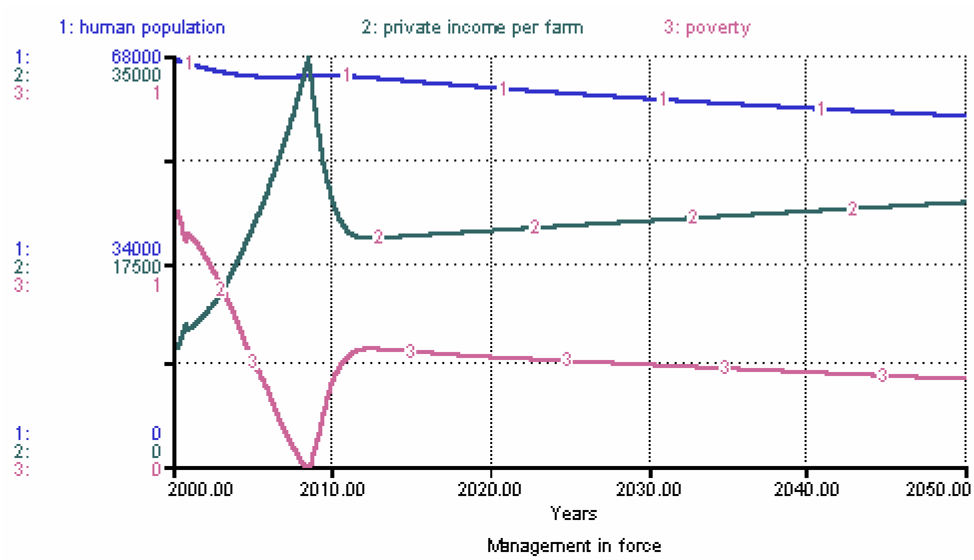


Figure 20. Human population, private income per farm and poverty under combined management decisions. Poverty rate has a range from 0-1; income per farm – 0-35,000 rubles; human population is ranging 0-68,000 people.

This scenario is based on government proposed measures that have not been implemented yet. Livestock composition change is to be carried out according to President's Programme on Revival of Traditional Husbandry in 2001-2010, while limiting livestock grazing remains a recommendation (Petrov et al, 2001).
The changes require a significant investment, yet farmers lack the state financial support (Borlikov et al., 2000a).

8. Discussion and results

8.1. Evaluation of scenarios

People's well-being in Black Lands region is determined by revenues formed by livestock productivity. Livestock in turn, disturbs grassland ecosystem balance and limits saiga. Human population too, reduces saiga number by poaching. These are the basic dynamics of the ecological, social and economic systems in Black Lands.

Modeling the systems trends as they are (Scenario 7.1) revealed that the systems are not prone to long-term sustainability. Social and economic systems rest on the natural resources capacity. When natural resources support human well-being, it is critical that their productivity is not disturbed. But according to the model, human pressure on grassland ecosystem is going to increase and it will lead to desertification and loss of agricultural productivity.

Human-induced land degradation is a rather common phenomenon of the world's arid and semi-arid areas. According to Dregne (1983), around 80% of world's agricultural land in arid lands is subject to desertification. Probably the most renowned example is desertification in Sahel which was induced by growing human and livestock populations due to improved health services and water availability and aggravated by droughts of 1968-1986 (Mainguet, 1991). A different factor behind overstocking can be observed in Australia – commercialization of farming and not the growing population caused land degradation (ibid). It is argued that in the former USSR adaptation of agricultural techniques from more humid areas to semi-arid and arid ones and overall intensification of agriculture under command economy resulted in severe land degradation (Borlikov et al, 2000a). For instance, natural fodder shortage in Black Lands in 1970s due to overstocking lead to conversion of pasture land to irrigated cropland (Zonn, 1995). It caused accelerated soil erosion, waterlogging and salinization.

Nowadays, Black Lands' social, economic and natural conditions have changed: plowing is restricted to a very limited area and market economy regulates agricultural input and output. In addition, after the reduction of agricultural production during 1990s the pastures have increased their capacity (Holzel et al., 2002). Agriculture has become vital for the population - it relies on livestock both for subsistence and income, while during the Soviet times private livestock could only constitute 15% of the state one (Petrov et al, 2001). But as long as people are guided by maximization of their economic interests that are based on common resources (pasture land), it may result in the Tragedy of the Commons – a phenomenon of overexploitation and depletion which in essence occurs to any resource owned and used commonly (Hardin, 1968).

Therefore, effective management strategies and techniques are vital. At this stage of agricultural development most of the preventative measures are only recommendations without being implemented in reality (Petrov et al, 2001). The aim of these management strategies is to ensure a long-term sustainability of the systems.

Phytoreclamation may prove to be an important measure in reviving pastures and preserving livestock productivity. Yet, it is another “end-of-pipe” solution – fixing already disturbed equilibrium (Carter, 2001). It alleviates the symptom of desertification and land degradation, and may be considered as a short-term action plan while most of the emphasis is necessary to place on preventative measures, such as limiting livestock grazing and changing livestock structure.

Limiting livestock grazing is effective in decreasing the load on the ecological system. However, there is a barrier in its implementation as it requires purchasing fodder crops which is not economically feasible for the population and is a way of importing sustainability from another, external system, which then may, in turn, increase its unsustainability. In addition, this measure may be difficult to enforce without effective grazing control.

Changing livestock composition to its traditional structure yields the most of agricultural and ecological productivity including revival of saiga population. Yet, modeling showed that without placing a limit on livestock number, the system is most likely to collapse, although the measures seem to be able to sustain a certain amount of agricultural production.

Despite several economic and ecological benefits of proposed measures, modeling revealed that they do not lead to social, economic and ecological sustainability in the area. The strategies need to be based on regional ecological, social and economic conditions encompassing the reality and providing appropriate guidelines. Moreover, land degradation management is to be linked and aimed at increasing overall ecological, social and economic sustainability in the region. Thus, systems sustainability needs to be defined and assessed. This issue will be discussed in the next section.

8.2. Assessing sustainability

The objective of this section is to investigate on what conditions the region can achieve sustainable development. The constructed model provides a framework for sustainability conditions analysis and assessment which will be done here using the concept of sustainability indicators. The analysis starts with general description of sustainability indicators and their role, further on it follows with the criteria on which they are selected and how the model can be employed for this purpose. Ecological, economic and social sustainability indicators for the system under study in the Black Lands are then identified based on these criteria, and linked to the sustainable development targets. Finally, a framework for effective decision making in order to reach the targets and achieve sustainable development is described and institutional conditions identified.

8.2.1. The role of sustainability indicators

Sustainable development is defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987, p.8). Sustainable society which is characterized by social and

economic well-being while maintaining and preserving productivity of ecosystems and their services is a goal of sustainable development.
Sustainability indicators are quantified variables that represent current state of sustainability dimensions (McCool and Stankey, 2004). It is a technique that simplifies complex systems and their interactions by selection of indicators that serve as guidelines in decision making and a measure of progress (ibid). The purpose of indicators is not only to reflect the current state of sustainability. They are also used to investigate the effect of management strategies within the dimensions of the system. In addition, indicators are helpful tools in forecasting future changes within the system (ibid).

The system analysis model creates a comprehensive framework for sustainability indicators measurement and identification. It is an indispensable methodology for understanding the systems behaviour and interactions which enables to derive critical factors of sustainability (Jackson, 2003; O'Connor and McDermott, 1997; Van den Belt, 2004). Thus it facilitates in selection of relevant indicators. Construction of the model ensures transparency of the indicators as the mental understanding of the system and quantifications are the required steps, while relevancy of indicators and transparency of the methodology to derive them are conditions of effective decision making (Spangenberg and Bonniot, 1998).

8.2.2. Selection of sustainability indicators

Basically, the choice of indicators is determined by *what* it is that needs to be sustained, i.e. by selecting sustainability goals (McCool and Stankey, 2004). The indicators can then be categorized into sets of ecological, economic and social ones, which together form assessment of sustainability (Farrell,1996).

Although system dynamics modeling and its way of dealing with reality complexity has been accused of reductionism, narrowness and neglect of external factors (Flood, 1999), its advantage is that when based on research it allows to see through the complexity and to determine the underlying causes of system behaviour (Jackson, 2003). A benefit of simplification through use of the model is in its further acceptability and practical use by local population and decision makers (Van den Belt, 2004). Moreover, the constructed model helps us avoid such pitfalls as overcomplication or ad-hoc choice of indicators which commonly arise when indicators are selected (McCool and Stankey, 2004). In addition, we are guided by the criteria identified for indicators selection by Zhen and Routray (2003) among which are sensitivity to stresses and known response and existence of threshold values.

Thus, in order to derive sustainability indicators for the Black Lands system, we need to determine what components of the system reflect sustainability of ecological, economic and social dimensions, i.e. what is to be sustained to achieve sustainable development.

The model allows identifying the bottlenecks, or critical variables, that determine the system dynamics. Grassland equilibrium determined by vegetation cover and saiga, as a representative of biodiversity, are critical variables of the ecological system. Economic revenues derived from agricultural productivity (in our model, mostly livestock productivity) indicate economic system sustainability. Social well-being dependent on economic revenues is measured in the people's migration rate and consequently, population number. The state of these indicators, external pressures, response and under what conditions desirable sustainability can be achieved will be discussed further.

8.2.3. Ecological system sustainability indicators

There are a number of biogeochemical and climatic variables that affect the grassland ecosystem equilibrium. Yet, the non-disturbed by external factors system is capable of coping with stress and to revive, even in the case of droughts (UNCOD, 1977). Under external pressure, such as overgrazing and trampling, destruction of vegetation cover leads to soil degradation and eventually desertification. Therefore, balanced amount of vegetation cover is an indicator of ecological sustainability. The balanced amount is then such amount under which soil erosion is balanced by soil formation processes. According to the model, it is 250 kg of biomass per hectare assuming average precipitation typical of the area (210 mm/year). Grazing is an external pressure to the system, yet, when it stays within the carrying capacity (i.e. regeneration rate of the vegetation) the system is stable.

Saiga is dependent on grassland ecosystem as vegetation is a source of its forage. So on the one hand, it places pressure on the grassland by grazing and on the other hand, vegetation availability in turn puts pressure on saiga. Thus the two variables keep each other in check and together make up a balanced system over a long-term perspective. Poaching is another and much more significant pressure which reduces saiga to unsustainable numbers and brings it close to extinction. Sustainable number of saiga is such that does not create a threat of pastures overgrazing, does not compete for forage with livestock maintaining a stable high population number to ensure survival and successful reproduction. According to Zonn (1995), sustainable saiga number in Europe is around 1.2 – 1.5 million heads.

Thus the sustainability goals of the grassland ecosystems are maintaining pastures productivity at 250 kg/hectare and saiga population at 1.2 – 1.5 million heads. Under what conditions is it possible? As overgrazing and trampling are the critical factors of vegetation reproduction under normal precipitation, livestock grazing is to be limited to the carrying capacity of pastures. But as one of the scenarios showed (Section 7.2.3) changing of livestock structure to less destructive in their grazing habits animals allows to maintain bigger herds (in ovine equivalents) and preserve pastures yield. Seasonal rotational grazing also helps to retain pastures productivity (Borlikov, 2000a). These measures are to be successfully implemented if the land-users have an economic incentive to preserve pastures productivity.

Saiga population revival is only possible if poaching is eliminated. In order to achieve it, a possibility to sell saiga horns on the black market for use in Chinese medicine is to be eradicated. On the other hand, some of the poaching is done for meat. Therefore, people's incomes need to increase as it is often the relatively low prices for saiga meat that creates demand for poaching.

8.2.4. Economic system sustainability indicator

Economic revenues from agricultural practices, which is mainly livestock breeding, indicate economic system sustainability. The target of economic sustainability is a stable amount of income that makes up for the 50% of all revenues (the share of agriculture – see Section 6.3). The sustainable limit is then estimated according to the official minimum living standard which includes all expenditures necessary to sustain a person. In our case agricultural revenues are determined by livestock numbers.

We can observe a trend of growing income when livestock numbers grow[9]. Therefore, we conclude that the livestock productivity determines economic revenues in the area. However, the number of livestock that is sufficient to raise revenues to an official minimum living standard amount exceeds the carrying capacity of pastures. Dropping livestock number due to forage availability directly results in loss of incomes. Forage availability in turn is determined by the state of grassland ecosystem. When livestock numbers are beyond sustainable, pastures are degraded and livestock starves. Falling incomes result in lowered living standards manifested in declining birth rates and life expectancy, deteriorating health and increasing migration (Dregne, 1983).

Thus it is evident that people's reliance on livestock and the increasing trend of the latter in order to maximize economic benefits can lead to the dramatic fall of incomes and hence, economic unsustainability. Currently, 60% of rural population lives below official poverty line (Federal Statistical Bureau, 2004). For that reason income sources need to be ensured and diversified so that less pressure is put on the ecosystem while economic revenues are stable and within sustainable limit.

8.2.5. Social system sustainability indicator

Low living standards determined by low revenues precondition people's migration to other (mostly urban) areas in search of better economic opportunities. Thus human population number is an indicator of social sustainability. By social sustainability we understand the level of standard of living. The quality of life can be assessed by other indicators of social sustainability, such as unemployment, access to housing, clean water, food, etc (Spangenberg and Bonniot, 1998). But in all these instances, except for access to clean water[10], it is economic revenues that basically determine the status of the others.

Throughout the modeling time we could observe the falling trend of human population except for the time when livestock number increased exponentially and caused population growth. The target of the social sustainability is stable population number at current value since the birth and death rates are nearly matching and have not changed significantly over the past decade (Federal Statistical Bureau, 2004).
Therefore, in order to achieve social sustainability the standard of living needs to be raised. It will reduce migration and population will stabilize. So it is not the number of the human population as such but the absence of migration which represents sustainability of the social system and is an indicator of social sustainability in the region.

Thus, the selected sustainability indicators are the critical variables of the driving systems and stabilizing them would result in stabilization of the entire system.

8.2.6. A framework of effective decision making

As it was discussed above, the main purpose of sustainability indicators is to serve as guidelines for decision making (McCool and Stankey, 2004). Using system dynamics models presents a variety of advantages, including a possibility to "see into" the processes which enable changes in the values, and

---

[9] Irrigated agriculture contributes less to the formation of the income and cannot be expanded (see section 4.3).
[10] According to the model, existing drinking water resources are not going to be depleted and thus it does not put a pressure on either human or animal population.

that in turn, allow us to derive simple indicators for sustainability. Table 1 summarizes the characteristics of the selected indicators of the system under study.

Normative dimension	**Sustainability indicator**	**Temporal characteristics**	**Spatial characteristics**	**Data requirements level**	**Uncertainty level**
Ecological system	Grassland vegetation biomass	short-term	regional	low-medium	low-medium
	Saiga population number	short-term	regional	low	low
Economic system	Human population revenues	short-term	regional	low-medium	low
Social system	Human population number	short-term	regional	low	low-medium

Table 1 Summary of the defined system sustainability indicators characteristics according to normative, temporal and spatial dimensions, data requirements and uncertainly levels.

Simple indicators derived from modeling do not require a high level of data in order to assess them. It has a twofold advantage: 1) higher level of acceptability by decision-makers as available data translates to low investment needs in order to acquire it 2) the lower the data demands are, the higher the certainty level which is an important condition for the effectiveness of the decisions. In this sense, composite and aggregate sustainability indicators are less certain, as they require a high amount of data which is often not available as well (Munda, 2005). A system dynamics model too can be of a different level of complexity. But increasing amount of input data and processes in the model does not necessarily result in getting more accurate results (Robinson, 2004).

Temporal and spatial dimensions of the systems sustainability indicators (Table 1) refer to how soon the stress on the system is revealed by an indicator and over what space an indicator can be used to measure sustainability - local, regional or national. The temporal dimension may also have a different meaning in conditions of weak sustainability (Zhen and Routray, 2003). In that case trade-offs are necessary to make to attain economic growth and social well-being at the expense of the environment (Bell and Morse, 1999). It then requires a different approach in measuring sustainability. In our case the indicators show a response to a change in the system in a short-term period which was one of the criteria for their selection as it allows monitoring the response and taking timely decisions accordingly in order to ensure long-term sustainability.

Thus, the system dynamics model can serve as a methodological framework to derive simple low-data demanding and high certainty yielding sustainability indicators which then can be used as guidelines for effective management.

Yet, another aspect is to be discussed in connection with effective decision making: under what institutional framework can it be achieved?

In order to achieve sustainable development in the region, decision making is to take into account vulnerability of the ecosystem. On the one hand, there is awareness of the consequences of overstocking and plowing in the area, due to the fact that the Black Lands have experienced severe land

degradation in the 1960s-1980s (Petrov et al, 2001). On the other hand, the government stresses the importance of agriculture for the republic's welfare and hence, maximization of agricultural production is still the priority (Sengleev, 1999). Yet, farmers are using the same agricultural techniques that led to desertification before, and no effective soil protection schemes have come into force recently, while the existing ones do not receive necessary financing (Borlikov et al, 2000a).
Therefore, the government needs to re-evaluate its priorities and invest into environmentally sustainable agricultural practices and would yield long-term productivity of the ecosystems.

Effective decision making is to be based on comprehensive research of ecological, social and economic systems. Thus, it requires efficient coordination and collaboration of existing government bodies, scientists and local population. The desertification problem that occurred in the past was in part due to neglect of ecological issues by decision makers (Zonn, 1995). Currently, decision makers are detached from science and local population which affects the quality of decisions and hence, the sustainability of the region (personal interview with A. Basanov, 2005). Besides, the multidimensional approach is necessary in tracking the progress of decisions.
Participation of local population is a crucial condition of effective decision making. Not only it provides decision makers with first hand experience and opinion, it also ensures that a proposed decision is accepted, which determines if it is going to be implemented successfully. In addition, involving land-users has educational value (Mainguet, 1991).

A more direct communication between local population and decision makers may also help to achieve a more transparent management. Transparency is a critical condition of sustainable development (World Summit of Sustainable Development, 2002). However, corruption remains a common problem throughout Russia.[11] It inhibits effective management which in turn, does not improve people's welfare. Furthermore, decreased accountability allows decision makers to be guided by their own interests when taking decisions. We may also assume that corruption prevents truly concerned and skilled people from being involved in decision making. As a result, absence of transparency can lead to deterioration of all systems. This is how I. S. Zonn (1994) describes conditions for decision making in Kalmykia: "Alternative decisions and ecological forecasts are often trumps in the political game of force and interests. They could be ignored in whole or in part, depending on the interests of administrators."
Finally, desertification prevention management strategies need to be incorporated into a larger-scale management so that it leads to improvement of not only environmental but also social and economic systems (Dregne, 1983). Therefore, decisions need to be comprehensive and consistent.

Thus, effective decision making in Black Lands requires:

- Prioritizing sustainable agricultural practices
- Enhanced communication between decision makers, scientists and local population
- Direct participation of local population in decision making
- Transparency of decision making and decision implementation
- Comprehensiveness of desertification prevention decisions – decisions are to be aimed at social and economic sustainability along with environmental

[11] According to Transparency International (2005), Corruption Perception Index (CPI) 2005 for Russia was 2.4 and placed the country in position no. 126. For comparison, Sweden is number 6 and its CPI is 9.2.

9. Conclusion

The driving forces of the Black Lands' grassland-livestock-human population system are human dependence on livestock as the main source of economic revenues and livestock grazing as the destructive factor of the grassland ecosystem. Overgrazing and trampling of vegetation lead to desertification and loss of agricultural productivity. At the same time, livestock dominates over saiga in grazing as they use the same pastures. It limits saiga number along with poaching.

Modeling revealed that the system is highly vulnerable and will result in the increased land degradation, so by 2050 pastures will be reduced by 75% due to erosion and open sand advance. It will lead to lower numbers of livestock that the land can sustain and as a result, deterioration of human life quality if the trend of increasing agricultural production remains as it is. Projected human population in 2050 is 40% lower than present population due to migration. At the same time pasture degradation and poaching remain the main limiting factors for saiga and by 2050 its population is nearly extinct. Modeling possible management proposals of phytoreclamation, limited grazing and traditional livestock structure indicated the same trends as the scenario under present conditions.

In order to achieve sustainable development livestock grazing is to be kept within the carrying capacity of pastures, saiga poaching control needs to become more effective by eliminating the access to the black market of saiga horns, while the population is to be provided with additional sources of income.

Institutional framework requires better intersectional communication, transparency, local population involvement, and comprehensiveness of decision making.

The research can be a basis for effective decision making in the area under study and other areas in the republic. In addition, it provides an opportunity for modeling management strategies and their outcomes in the complex of all systems involved.

Appedix 1. List of equations

6.1. Grassland system

vegetation regeneration = *pasture area*vegetation productivity+ livestock grazing*0.09*0.2+vegetation turnover*

6.2. Grazing system

livestock grazing needs per year = *livestock*365*2.4*

cattle's grazing habits (reduction of impact on vegetation)=*Livestock grazing*0.09*0.2*

6.3. Human population system

private income per farm = *((private livestock slaughter*2500+vegetable selling*0.6*5)/number of farms)+salary amount*
(2500 rubles per head of ovine equivalent; 5 rubles per kg of vegetables)

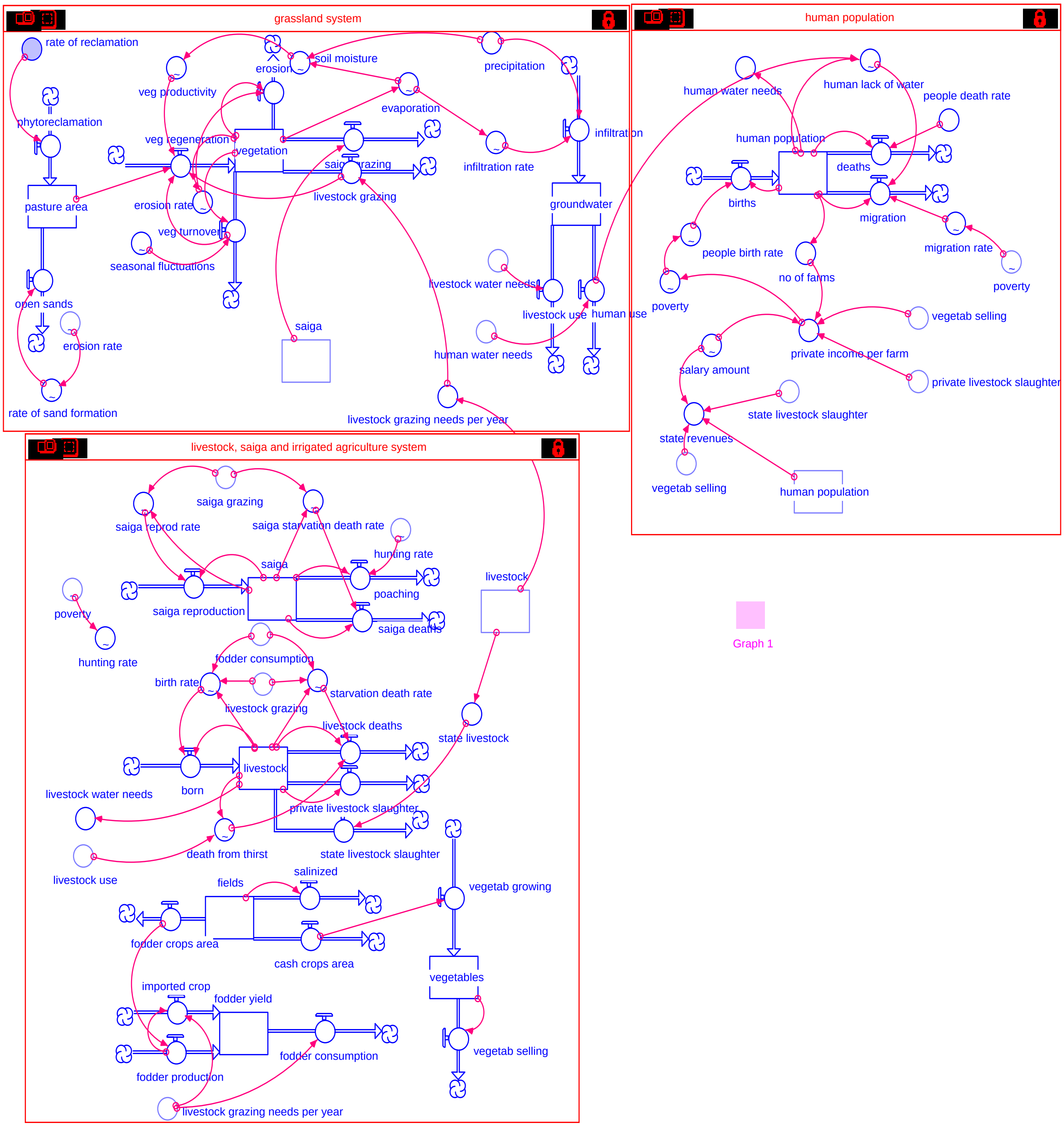
state revenues = *(state livestock slaughter*2500+vegetable selling*0.4*5)-(human population*0.33*salary amount)*

private livestock slaughter = *livestock*0.45*0.4*
state livestock slaughter = *livestock*0.2*

6.4. Management decisions

traditional livestock's grazing habits (reduction of impact on vegetation)=*Livestock grazing*0.3*0.2+ Livestock grazing*0.4*0.3*

Appendix 2. STELLA model



References

Arylov, Yu., Lushchekina, A., Neronov, V. (2004). The saiga antelope in the drylands of Russia and how to ensure its sustainable future. *Traditional knowledge and modern technology for the sustainable management of dryland ecosystem*. Proceedings of the International Workshop, Elista, Republic of Kalmykia, Russian Federation, 23–27 June. UNESCO–MAB Drylands Series, 4, 163-166.

Badmaev V., Ubushaev B. (2004). Chernyje Zemli Biosphere Reserve and its role in the conservation of biodiversity in dryland ecosystems. *Traditional knowledge and modern technology for the sustainable management of dryland ecosystem*. Proceedings of the International Workshop, Elista, Republic of Kalmykia, Russian Federation, 23–27 June. UNESCO–MAB Drylands Series, 4, 155-157.

Bananova, V. B. (1993). *Anthropogenic desertification of arid areas of Kalmykia.* Synopsis of thesis for Doctor's Degree of Geographical Sciences. Ilym, Ashgabad. In Zonn, I., S. (1995). Desertification in Russia: problems and solutions (an example in the Republic of Kalmykia – Khalmg Tangch). *Environmental Monitoring and Assessment*, *37*, 347-365.

Basanov, A. A. (2005). Personal interview. July 29.

Bell, S., Morse, S. (1999). *Sustainability indicators: measuring the immesurable?* London: Earthscan Publications, Ltd.

Borlikov, G. M. (1998). Sovremennie ekologo-geographicheskie problemi ratsionalnogo prirodopolzovania v prikaspiskom regione [Contemporary environmental problems of the sustainable land use in the Caspian]. *International conference "Caspian ecosystems – for the 21st century"*, 23-30 May. Elista: Kalmyk State University.

Borlikov, G. M., Lachko, O. A., Bakinova, T. I. (2000a). *Ekologiya I prirodopolzovanie aridnih territorii* [Environment and use of arid lands]. Rostov-on-Don: Higher Education Publishers.

Borlikov, G. M., Harin, N., G., Bananova, V., A., Tateishi, R. (2000b). *Opustinivanie zasushlivih zemel Prikaspiiskogo regiona* [Desertification of the Caspian Lowland region]. Rostov-on-Don: Higher Education Publishers.

Carter, N. (2001). *The politics of the environment*. Cambridge: Cambridge University Press.

Dregne, H. E. (1983). *Desertification of arid lands*. New York: Harwood academic publishers.

Farrell, A. (1996). Making decisions about sustainability: joining social values with technical expertise. *Technology and Society Technical Expertise and Public Decisions*. Proceedings. International Symposium,188-197.

Federal Statistical Bureau. (2000). *Kalmykiya v tsifrah. Statisticheski sbornik* [Statistics of Kalmykia 2000]. Elista: Kalmyk Statistical Bureau.

Federal Statistical Bureau. (2004). *Kalmykiya v tsifrah. Statisticheski sbornik* [Statistics of Kalmykia 2004]. Elista: Kalmyk Statistical Bureau.

Flood, R. L. (1999). *Rethinking the fifth discipline: learning within the unknowable*. London: Routledge.

Gabunshina, E. B. (Ed.) (2000). *Iz plena peskov i morskoi stihii. Sbornik proektnih predlozheni po stabilizatsii ekologicheskoi obstanovki v respublike Kalmykia* [Fighting sand and sea. Environmental stabilization projects in the Republic of Kalmykia]. Elista: Sfera Publishers.

Hardin, G. (1968). The tragedy of the commons. *Science, 162,* 1243-1248.

Holzel, N., Haub, C., Ingelfinger, M. P., Otte, A., Pilipenko, V. (2002).The return of the steppe – large-scale restoration of degraded land in southern Russia during the post-Soviet era. *Journal for Nature Conservation, 10*, 75-85.

Jackson, M. C. (2003). *Systems thinking: creative holism for managers.* Chichester: John Wiley and Sons, Ltd.

Kalmyk Environmental Programme. (2002). *Ekologiya i prirodnie resursi Kalmykii na 2002-2010 gg* [Environment and Natural Resources of Kalmykia in 2002-2010]. Elista: Jangar Publishing House.

Khulkhachiev, B., Kaminov, Yu., Sheret, A., Badmaev, V., Basanov, A. (2000). *Doklad o sostoyanii okruzhayuschei sredi Respubliki Kalmykia v 2000 godu* [State of Environment in the republic of Kalmykia in 2000]. Elista: Jangar Publishing House.

Komarov, B. (1981). Author: Komarov B. The Red and the Green: the destruction of nature in the USSR. Paris: Seuil. In Plit F., Plit, J., Zakowski, W. (1995). *Drylands development and combating desertification. Bibliorgaphic study of experiences in the countries of the CIS*. Food and Agriculture Organization. Retrieved August 12, 2005, from http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/T4410E/t4410e06.htm

Koronkevitch, N. I. (2002). Water resources. In "*Land Resources of Russia*" [CD ROM]. IIASA & RAS. Retrieved June 25, 2005, from http://www.iiasa.ac.at/Research/FOR/russia_cd/hydro_maps.htm#und.

Lushchekina, A., Struchkov, A. (2001).The saiga antelope in Europe: once again on the brink? *The open country, 3,*11-24.

Mainguet, M. (1991). *Desertification: Natural background and human mismanagement*. Berlin: Springer Verlag.

McCool, S. F., Stankey, G. H. (2004). Indicators of Sustainability: Challenges and Opportunities at the Interface of Science and Policy. *Environmental Management, 33*, 3, 294-305.

Mikhailov, V. N., Rychagov, G. I., Povalishnikova E. S. (1998). Yavlyayutsya li nedavni pod'em Kaspiiskogo morya i ego posledstviya prirodnoi katastrofoi? [Are the recent Caspian Sea level rise and its consequences a natural disaster?]. *Journal of Russian Foundation for Basic Research*. Retrieved October 5, 2005, from http://www.rfbr.ru/default.asp?doc_id=5525

Munda, G. (2005). "Measuring sustainability": a multi-criterion framework. *Environment, Development and Sustainability, 7*, 117-134.

Nelson, R. (1988). *Dryland management: the "desertification" problem*. The world bank policy planning and research staff. Environment Department, Working Paper No. 8, Washington, DC. In Mainguet, M. (1991). *Desertification: Natural background and human mismanagement*. Berlin: Springer Verlag.

O'Connor, J., McDermott, I. (1997). *The art of systems thinking: essential skills for creativity and problem solving*. London: Thorsons.

Petrov, V. I., Durdusov, S. D., Zulaev, M. S., Kulik, K. N., Khegai, V. E. (2001). *Kontseptsiya vosstanovlenia traditsionnogo zhivotnovodstva dlya adaptivnogo osvoeniya prirodnih pastbishch chernih zemel na period do 2020 goda* [The concept of revival of traditional animal husbandry for sustainable use of Black Lands pastures until 2020]. Elista: Jangar Publishing House.

Robinson, S. (2004). *Simulation - the practice of model development and use*. New York: Wiley and Sons, Ltd.

Sengleev, V. B. (1999). *Ekonomika Kalmykii: Istoriya i perspectivi* [The economy of Kalmykia: History and Perspectives]. Elista: Kalmyk Book Publishing.

Soule, M. E. (Ed.) (1986). *Conservation biology: the science of scarcity and diversity*. Sunderland: Sinauer Associates, Inc.

Spangenberg, J. H., Bonniot, O.(1998). Sustainability Indicators – A Compass on the road towards sustainability. *Wuppertal Paper*, No. 81. Wuppertal: Wuppertal-Institut für Klima, Umwelt, Energie.

Sverdrup, H., Belyazid, S., Nihlgard, B., Ericson, L. (2005). *Modelling change in ground vegetation from effects of nutrients, pollution, climate, grazing and land use*. Unpublished paper.Lund: Dep. of chemical engineering, Lund University, Umea University.

Transparency International. (2005). *TI Corruption Perceptions Index (CPI) 2005*. Retrieved November 5, 2005, from http://www.transparency.org/cpi/2005/cpi2005.sources.en.html

UNCOD (United Nations Conference on Desertification). (1977). *Desertification: its causes and consequences*. Nairobi. Frankfurt: Pergamon Press.

Van den Belt, M. (2004). *Mediated modeling: a system dynamics approach to environmental consensus building*. Washington, DC: Island Press.

Vinogradov, B. V. (1993). The present dynamics and ecological forecasting of natural environment in Kalmykia. *Problems of Desert Development, 1*, 29-37. In Zonn, I. S. (1995). Desertification in Russia: problems and solutions (an example in the Republic of Kalmykia – Khalmg Tangch). *Environmental Monitoring and Assessment, 37*, 347-365.

World Commission on Environment and Development. (1987). *Our Common Future*. Oxford: Oxford University Press.

World Summit of Sustainable Development. (2002). *Johannesburg Plan of Implementation*. Retrieved November 1, 2005, from http://www.un.org/esa/sustdev/documents/WSSD_POI_PD/English/WSSD_PlanImpl.pdf

Yusunbaev, U. B., Musina, L. B., Suyundukov, Ya. T. (2003). Dynamics of steppe vegetation under the effect of grazing by different farm animals. *Russian Journal of Ecology, 34,* 1, 43–46.

Zhen, L., Routray, J. K. (2003). Operational Indicators for Measuring Agricultural Sustainability in Developing Countries. *Environmental Management, 32*, 1, 34-46.

Zonn, I. S. (1994). *A creeping environmental phenomenon in Russia: Desertification in Kalmykia.* In M. Glantz (Ed.), Workshop Report on Creeping Environmental Phenomena, National Center for Atmospheric Research, Boulder, Colorado, 169-174. In Zonn, I., S. (1995). Desertification in Russia: problems and solutions (an example in the Republic of Kalmykia – Khalmg Tangch). *Environmental Monitoring and Assessment, 37*, 347-365.

Zonn, I., S. (1995). Desertification in Russia: problems and solutions (an example in the Republic of Kalmykia – Khalmg Tangch). *Environmental Monitoring and Assessment, 37*, 347-365.