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

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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.

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).

This paper is going to focus on the republic of Kalmykia situated in the south-west of Russia and specifically on one of the republic's regions - Chernye Zemli (Black Lands). Desertification in this region was caused by overstocking and plowing that was intensified in the last century. Today we observe the growing trend of livestock number - as in the previous periods. Nevertheless, agricultural techniques remain unchanged (Petrov et al, 2001). 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).

The research is based on the systems thinking approach and 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. The research model[1] covers the period between 2000 and 2050.

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, quantitative models. For that system analysis and system dynamics modeling methods were reviewed and assumptions for the systems understanding were made (O'Connor and McDermott, 1997; Jackson, 2003). Statistical data of the region (Federal Statistical Bureau, 2000; 2004) was used for the numerical model.

2. Background information

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). 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 of the republic 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). The area of the Black Lands region is 3.5 million hectares, with the population of 68 000 people, comprising 3 administrative districts.

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[1] The model was built using STELLA 8.1.1 software (iSee Systems)

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

The Black Lands 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 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 the territory of winter pastures (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.

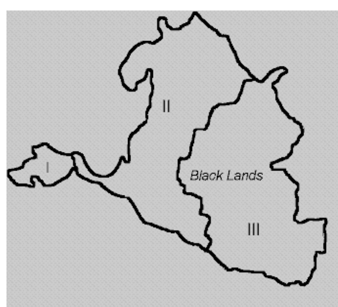


Figure 2. Agricultural regions of Kalmykia: I – Western, II – Central, III – Eastern (Borlikov, 2000a; http://kalm.ru/ru/)

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. Some of the sustainable agricultural techniques were traditional livestock composition, seasonal use of pastures and allocation of pastures and observance of individual grazing plots borders (ibid).

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 3) (Borlikov et al, 2000a). Due to collectivization farm sizes were increased and a share of private livestock was reduced (ibid).

By 1980s sheep population exceeded the carrying capacity of pastures by 2-3 times, while the share of cattle in livestock dropped from 40% to 6.7% during 70 years (Figure 3). (Bananova, 1993; Zonn, 1995). The 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). In addition land degradation in this period was exacerbated by the 35-year climatic Bruckner cycle that is believed to have been a cause of numerous droughts conditioned by changes of solar activity (ibid). Pastures degradation and enormous livestock numbers led to fodder deficits in 1986-87 when 100,000-600,000 heads of livestock starved (ibid).

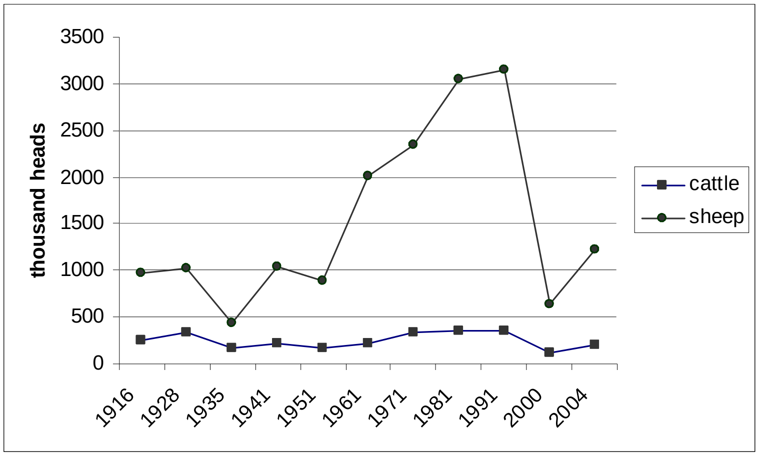


Figure 3. Dynamics of livestock population in Kalmykia in 1916-2004 (Federal Statistical Bureau, 2000; 2004)

Better pasture conditions due to decreased grazing and increased precipitation up to 320 mm annually (Borlikov et al, 2000b), and the process of economical revival after crisis of the 1990s have created favourable conditions for agricultural production and from 2000-2004 the livestock number doubled (Figure 3). Merino sheep continues to dominate livestock and grazing is year-round (Petrov et al, 2001).

Saiga antelope (*Saiga tatarica tatarica* L.) 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.

Its population number was greatly affected by deteriorating pasture conditions and reduction of its habitat area due to agricultural intensification (Figure 4). In addition, saiga horns are used in traditional Chinese medicine and 1 kg of horns costs up to 100 US dollars (Lushchekina and Struchkov, 2001). 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, despite such conservation measures as creating a protected reserve (Arylov et al, 2004). Achieving sustainability would require stabilizing saiga population and creating such agricultural practices that do not interfere with saiga well-being.

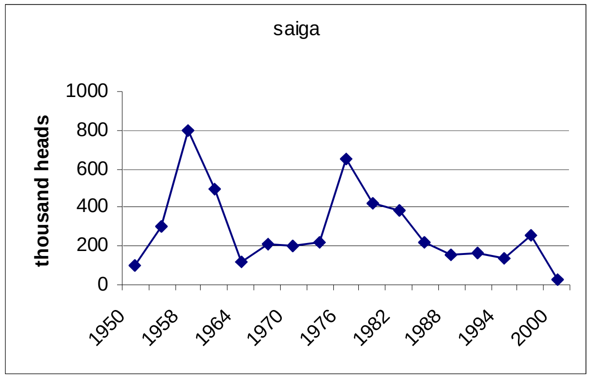


Figure 4. European saiga population dynamics in 1950-2000 (Lushchekina and Struchkov, 2001).

3. Conceptual model

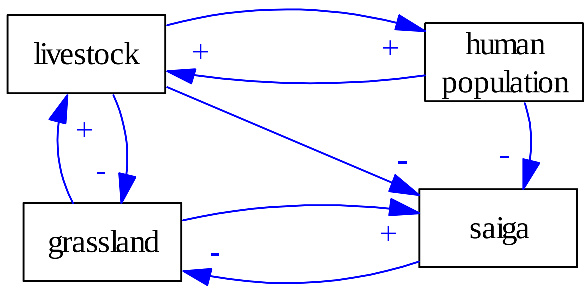


Figure 5. A basic representation of the system under study. The chart shows the influence of the livestock, human population, saiga and grassland subsystems on each other. Arrows with “+” indicate the same direction of change, while arrows with “-” identify opposite direction.

Figure 5 illustrates the basic understanding of the subsystem interactions in the studied system. 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.

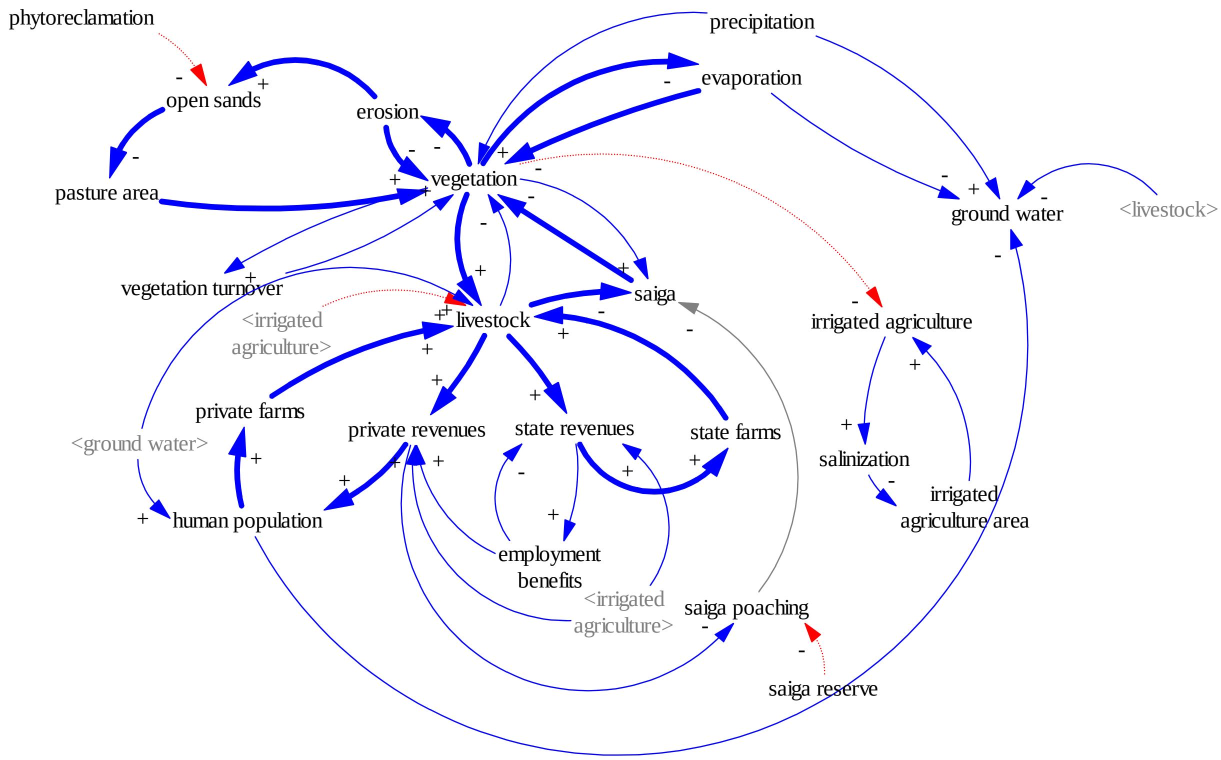


Figure 6. The Causal Loop Diagram of the system. It illustrates the understanding of the system: interaction of the subsystems and the way it affects the system. Thick arrows represent driving loops of the system. Broken arrows indicate management decisions.

The Causal Loop Diagram illustrates the following subsystems and their behaviour: the grassland, livestock, saiga and human population (Figure 6).

The driving forces of the 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.

4. Analysis of the subsystems and parameterization

4.1. The grassland system

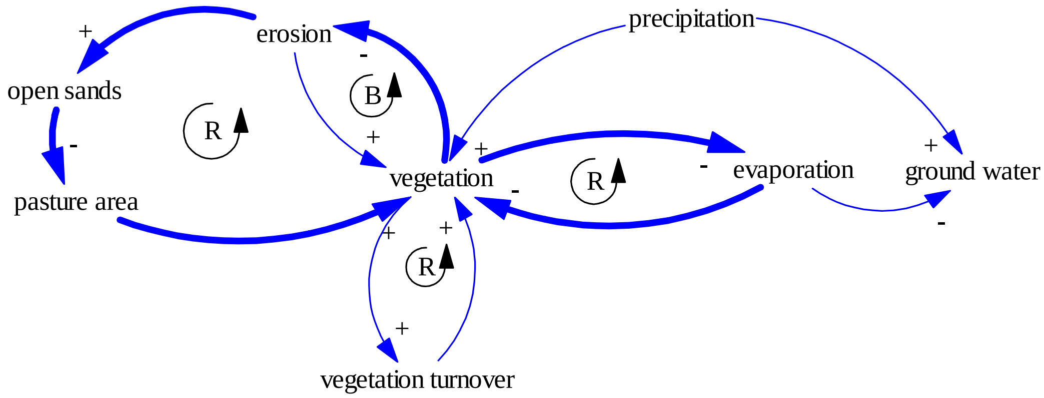


Figure 7. The CLD of the grassland system. It is a simplified representation of the main physical and biological mechanisms affecting grassland ecosystem regulation. Reinforcing loops are marked as R, balancing ones - B , driving loops as the main forces for grassland productivity (thick arrows).

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 7.

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.

4.2. The grazing system

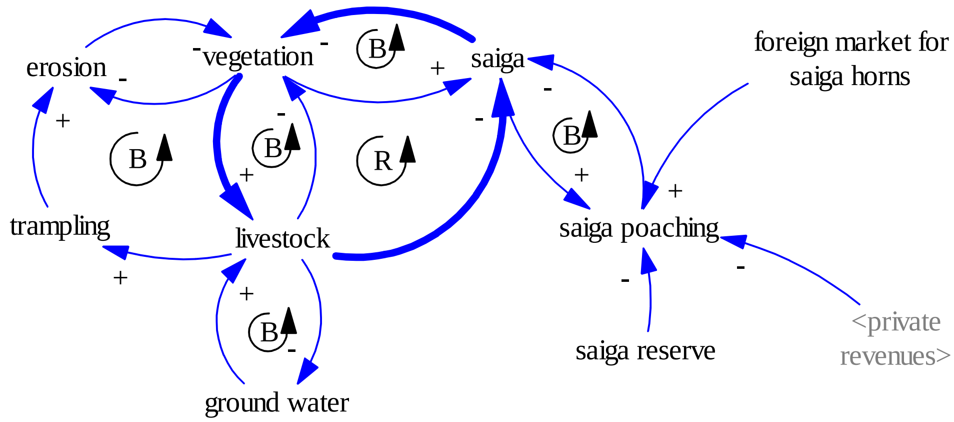


Figure 8. The CLD of the grazing system. Thick arrows indicate reinforcing effect of saiga elimination on livestock through more vegetation availability. Foreign market for saiga horns and saiga reserve are external factors that impact saiga number, along with poaching.

The grazing system is driven by external factor – vegetation productivity which in turn is dependent on other factors (see Section 4.1). 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 8). 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).
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") and meat.

4.3. The human population system

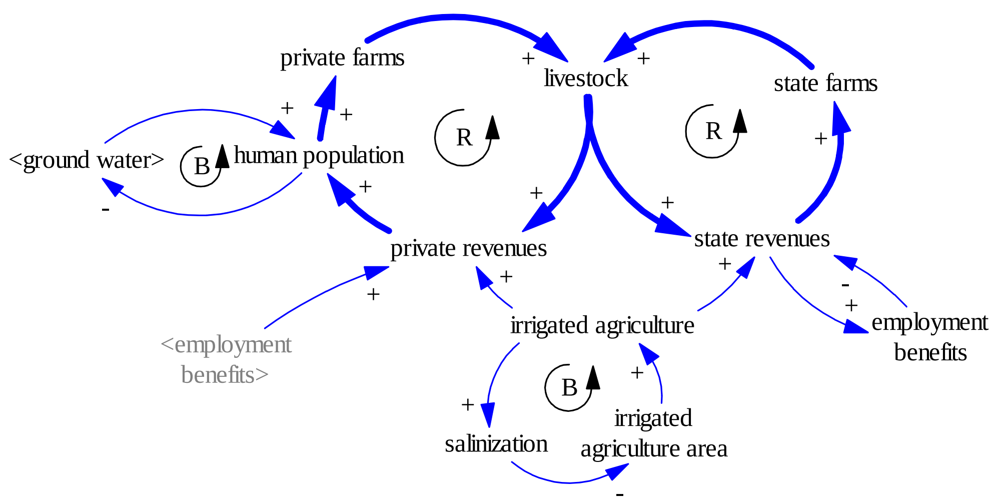


Figure 9. The CLD of the human population system. Economic system is a part of human population system as it determines people's well-being and thus, population number. The reinforcing mechanism is increasing revenues leading to population growth and increasing livestock (thick arrows).

The basic dynamics of the human population system are following: its growth is dependent on economic revenues (Figure 9). Population grows under favorable financial conditions and this in turn, increases livestock number. 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. Hence, migration is the main cause of population decline.

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.

4.4. Management decisions

The government of Kalmykia is 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 at the rate of 50 000 hectares per year, limiting livestock grazing to 80% of their needs, and changing the composition of the livestock to traditional: 30% of fat-tail sheep, 30% of cattle, 30% of horses and 10% of camels, due to different grazing behaviour (Yusunbaev et al, 2003).

5. Scenarios – analyzing future under different conditions

Based on the analysis of the system and its numerical representation the following future scenarios can be elaborated.

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

5.1. Business-as-usual

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 (Figure 10). Hence, this forecast enables us to predict the unsustainability of the system under study.

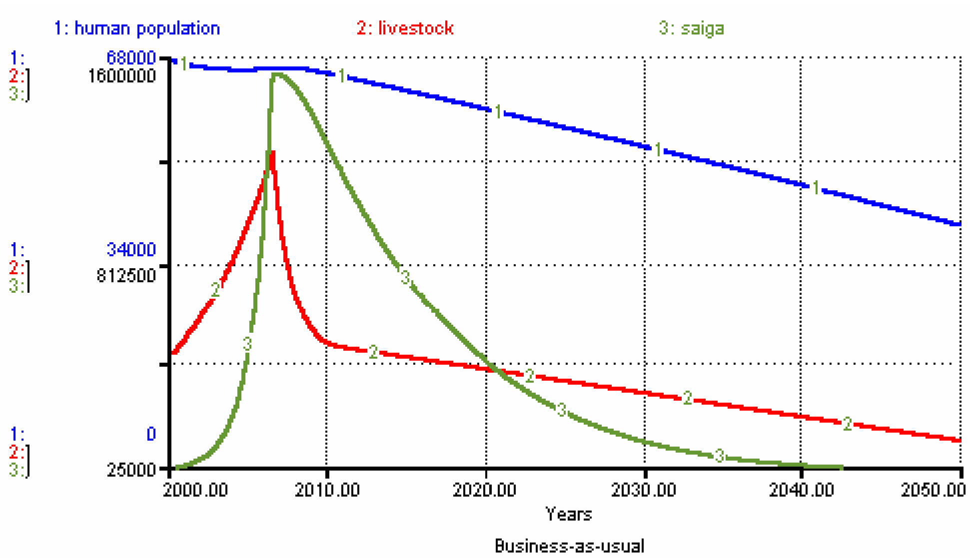


Figure 10. System dynamics of human population, livestock and saiga under business-as-usual scenario. Human population range scale is from 0- 68,000; livestock and saiga 25,000-1.6 million heads[2].

5.2. Management in force

5.2.1. Phytoreclamation

The purpose of phytoreclamation is twofold: to stop the open sands advance and to restore pastures. Modeling revealed that 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, but it does not provide long-term sustainability (Figure 11).

[2] Note that the scale for livestock and saiga populations in Figures 10-14 has been adjusted for each scenario and varies in order to enable better representation of population dynamics over time.

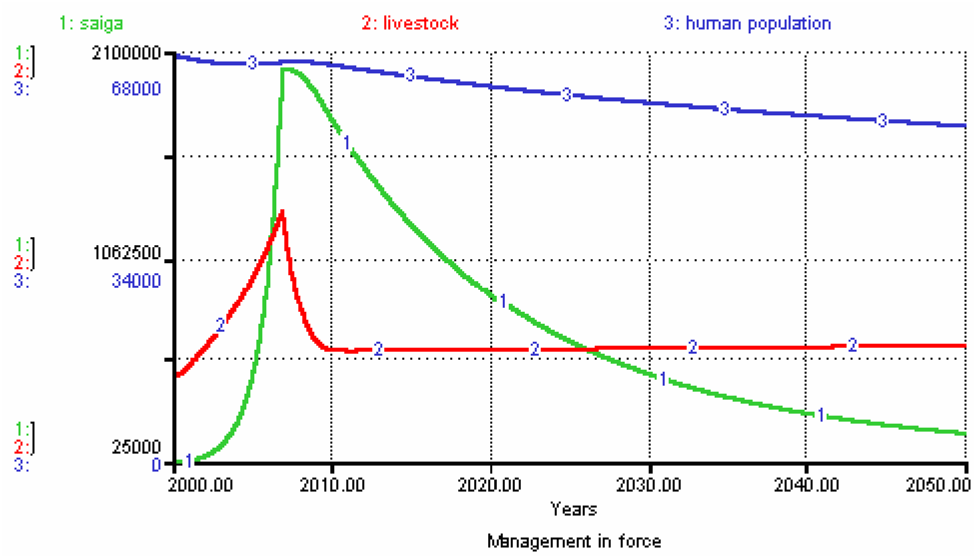


Figure 11. Effect of phytoreclamation on livestock, saiga and human population. Scale range for livestock and saiga is 25,000-2.1 million heads; human population 0-68,000 people.

5.2.2. Limited grazing

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. As a result, the observed trend of population decline (Figure 12).

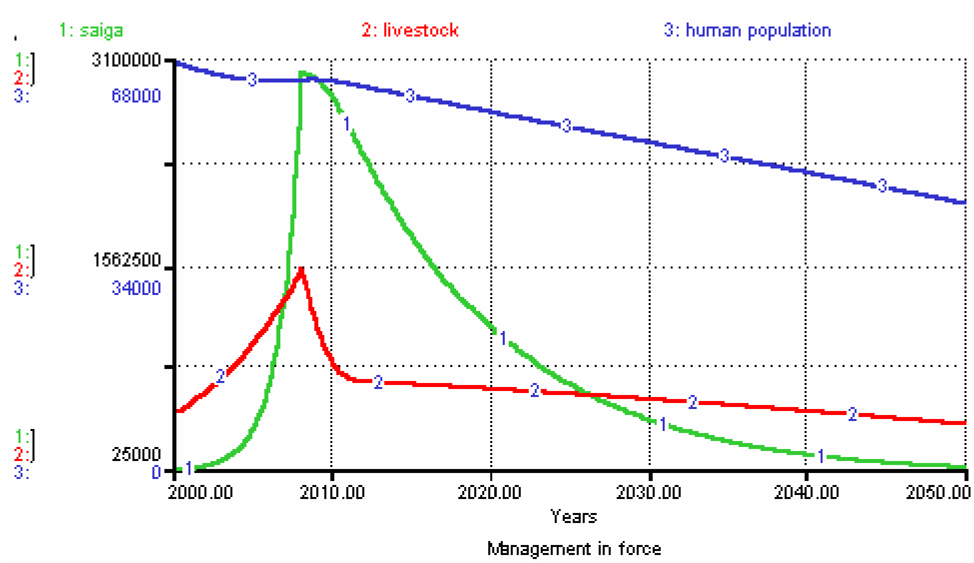


Figure 12. Systems response under limited grazing management decision. Scale range for livestock and saiga is 25,000-3.1 million heads; human population 0-68,000 people.

5.2.3. Traditional livestock composition

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 (Figure 13).

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.

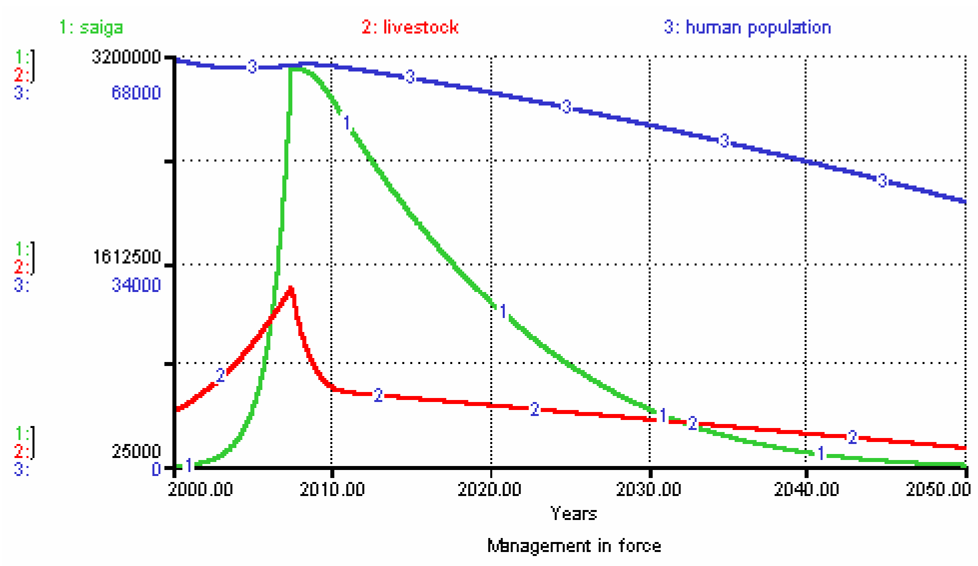


Figure 13. Saiga, livestock and human population under traditional livestock composition management decision. Scale range for livestock and saiga is 25,000-3.2 million heads; human population 0-68,000 people.

5.2.4. Combined measures

The following scenario forecasts the future of the system assuming that above-described management strategies are implemented simultaneously. The overall increase of livestock and saiga numbers by around 30% compared to business-as-usual scenario results in collapse of the vegetation system and as a result, pasture degradation is inevitable. As a consequence, there is still a steady migration out of the region, despite the seemingly stable number of livestock (Figure 14).

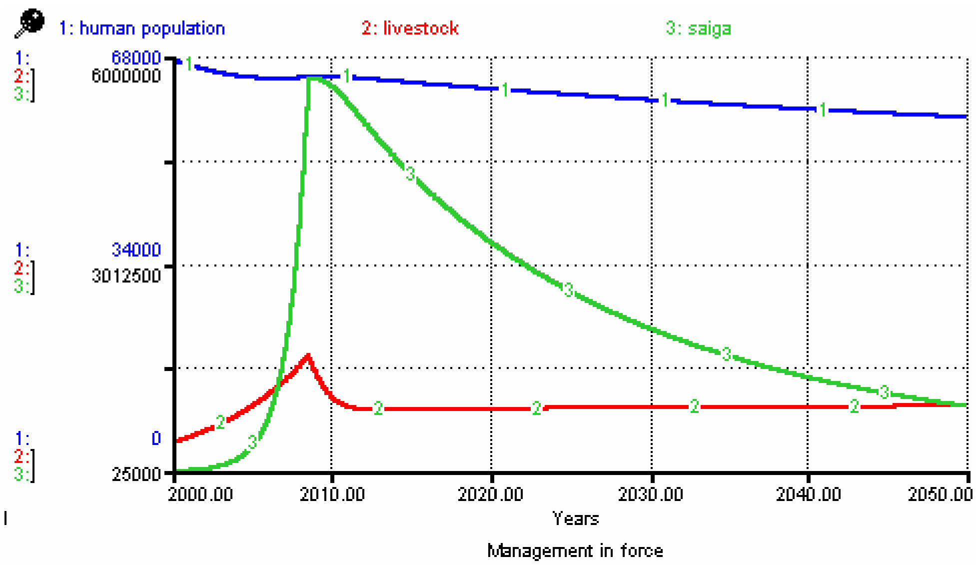


Figure 14. Dynamics of livestock, saiga and human population systems under combined management decisions. . Scale range for livestock and saiga is 25,000-6 million heads; human population 0-68,000 people.

6. 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.

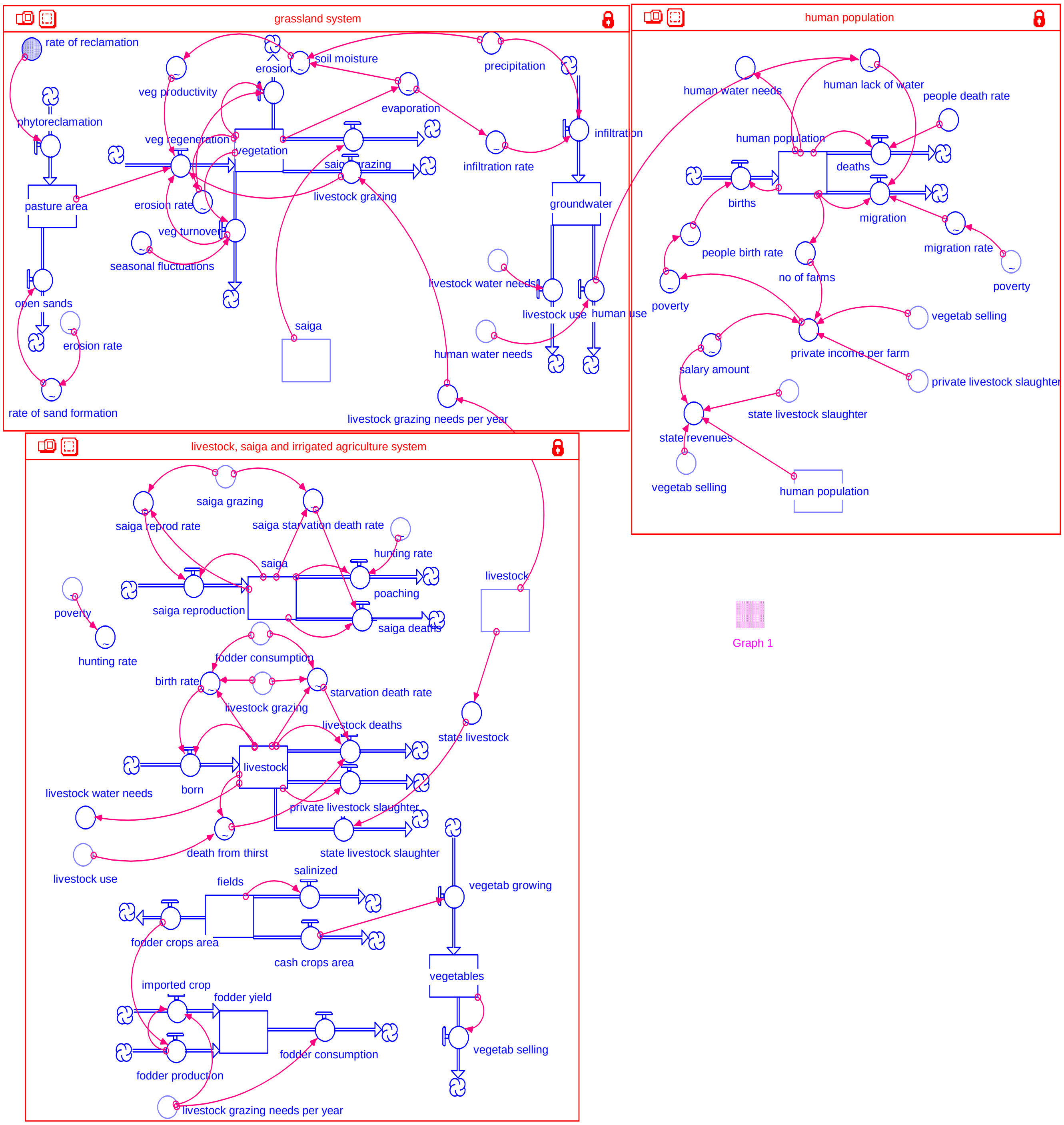
Modeling revealed that the system is highly vulnerable and will result in the increased land degradation, so by 2050 pastures will be reduced by 75% due to erosion and open sand advance. It will lead to lower numbers of livestock that the land can sustain and as a result, deterioration of human life 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.

Appendix 1. STELLA model



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