ECONOMIC RESEARCH INSTITUTE

"Pastureland Degradation and Livestock Taxation"

Draft report

ULAANBAATAR, 2017

“Pastureland Degradation and Livestock Taxation”

Team Leader:	**Tuvshintugs Batdelger**
Members:	**Munkh-Ireedui Bayarjargal**
	Khorol-Erdenebayartsogt

ULAANBAATAR, 2017

CONTENTS

I. INTRODUCTION

Since the introduction of the last pasture fee two decades ago, there have seen dramatic socio-economic changes in Mongolia. The GDP of Mongolia has increased by a factor of 10 and there is emerging poverty and inequality in the livestock sector. Herders with a livestock count of less than 100 animals are likely to be entrenched in the poverty trap while herders with a livestock count between 100-200 animals form the low income section of the sector and are especially susceptible to economic fluctuations and natural shocks such as *zuds*.

Previously, the combination of an earlier summer drought followed by a *zud* in 1999-2002 and 2009-2010 led to large livestock losses that drastically increased poverty and encouraged the migration of herders from rural to urban areas. Since then, total livestock numbers have continued to rise, reaching around 61.5 million with a particular emphasis on goats as they are highly sought-after for their cashmere value.

Though the agriculture sector's share of GDP has been steadily declining since 2009, it still remains a vital part of the Mongolian economy. 25 percent of the total labor force is employed in this sector and about 76.6 percent of Mongolian land is used as pastureland (NSO, 2015a).

In conjunction with global warming and the desertification of certain parts of Mongolia there has been a dramatic increase in the number of livestock in the country. As a result, in recent years, the amount of pastureland has been shrinking due to overgrazing while the overall number of livestock has been rapidly growing. For example, the number of livestock, in terms of sheep unit, reached 93.8 million in 2015, an 8.3 million increase from the 2014 count. These developments are putting enormous overgrazing pressure on pasturelands and may eventually lead to a decline in the livelihoods of people living in the countryside. According to the Green Gold project, the estimated amount of pastureland impossible to be naturally recovered reached 7 percent in 2015. If the number of livestock continues to constantly grow, desertification and degradation will be a serious concern in the near future.

Fortunately, there are ways to address this issue. No cooperation leads toward a "tragedy of commons "problem. One way to tackle this problem is to address the issue in terms of solving the "tragedy of commons" scenario by creating a common interest among nomads to limit the number of animals they raise. Currently, Green Gold project by SDC has taken the initiative to support this kind of activity among herders in the western provinces of the country.

Another way to limit the number of livestock and to improve the productivity of the sector while sustaining pastureland can be to initiate a livestock tax. In this case, the degradation rate of the pastureland, the composition of livestock and the livelihoods of herders all have to be carefully considered in order to calculate the optimal rate of the livestock tax.

On the other hand, climate change is increasingly becoming a critical variable for the sustainability of the pastoral ecosystem. The Sustainable Development Goals and the Green

Development Policy of Mongolia have set new targets for sustainability, including issues such as poverty eradication and inequality reduction.

These new economic, social and ecological conditions demand new measurements for the calculation of pasture use fees and livestock taxation. The newly calculated and introduced pasture use fee and livestock taxation could be one of the critical means towards promoting and preserving the sustainability of the pastoral socio-ecological system.

Literature review

At the international level, pasture carrying capacity can refer to either ecological carrying capacity or to economic carrying capacity. In reality, ecological carrying capacity is usually less than economic carrying capacity. Utilizing a livestock taxation can bridge the difference between the ecological and economic carrying capacities.

Whereas ecological carrying capacity refers to the maximum number of livestock not detrimental to the sustainability of pastureland, economic carrying capacity depends on the herder's livestock quantity decision based on expected income, welfare and profit.

When estimating ecological carrying capacity, harvest efficiency is one of the most significant parameters. More specifically, ecological carrying capacity fluctuates depending on harvest efficiency. Harvest efficiency in turn, varies among nations based on their ecological characteristics such as the nation's location, soil quality, amount of precipitation, and average temperature. For instance, harvest efficiency is 45 percent in Kenya (Wijngaarden, 1985); 30 percent in South Ethiopia (Cossins & Upton, 1987); and 50 percent in Inner Mongolia (Wang, et al., 2011). In Mongolia's case, based on an analysis of the southern desert region of the country, a value of 35 percent or less would be appropriate. If the current year's harvest efficiency is more that 35 percent, it will negatively affect the following year's biomass growth. If the value rises to 40-50 percent, future pasture biomass is in danger of being reduced by around 80 percent (Retzer, Nadrowski, & Miehe, 2006).

It is not necessary for economic carrying capacity to be equivalent to ecological carrying capacity because their information and data are distinct (Wetzel & Wetzel, 1995). and because in most nations, pastureland is public asset without any usage charge or fee.

System dynamic modelling can be used to estimate the economic and ecological capacities simultaneously because it makes complex systems easier to solve (Grant, Pedersen, & Marin, 1997). For example, Allington et al. applied system dynamic models at multiple scales in the Inner Mongolia region(Allington, Li, & Brown, 2015). The model was made up of 3 separate sections comprising of human, natural, and land-use systems. These sections and factors are linked via a feedback loop and often exhibit not-linear relationships. Based on the model's prediction results there is cause to be somewhat hopeful in terms of the future resilience of the rangelands.

Based on the model's prediction results, there is a somewhat hopeful outlook of the future resilience of the rangelands. The main results are reliant on the continuation of rural-urban migration and grassland protection policies (Allington, Li, & Brown, 2015).

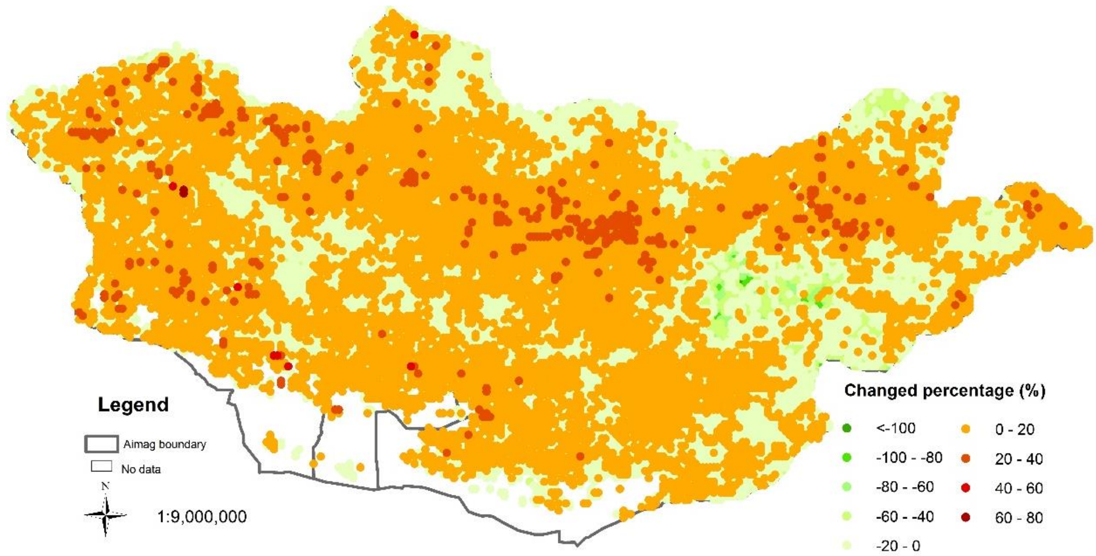
There have been several research studies based on Mongolian data, though they have not referred to the profit maximization decision of herder families. The currently available research has only focused on ecological carrying capacity rather than economic carrying capacity. For instance, in the research titled 'Defining the Ecological Site Descriptions and its Use as a Rangeland Management Tool in Mongolia', the researchers used 500 separate points within the Mongolian land region to approximate and assess nationwide pasture regrowth rates and soil conditions. Based on the study, the Mongolian pastureland was classified into around 20 ecological zones based on its productivity and capacity to endure different intensities of use while still being able to recover and regrow after being used. Although the Mongolian rangeland has a considerably high capacity and productivity, the consumption usage of pastureland is higher in comparison to its ecological capacity (Densambuu, et al., 2015). According to research done based on the entire landmass of Mongolia, a harvest efficiency of 50 percent in Mongolia is optimal and suitable (Ministry of Food and Agriculture; Swiss agency for Development and Cooperation SDC, 2015).

Ian, 1993 attempted to estimate ecological and economic carrying capacities simultaneously and agreed with the fact that the herder's decision played a key role in determining ecological sustainability in the long-term. Until now, there has been no research done in Mongolia in terms of estimating economic carrying capacity, and this research paper aims to calculate both economic and ecological carrying capacity and evaluate the impact of introducing a livestock tax using system dynamic models.

II. METHODOLOGY

This research will focus on some provinces where degradation and desertification of pasturelands have been a salient problem. Our essential information is the amount of biomass per meter square from 1982 to 2012, and the team calculated the averages of two periods; 1982-1996 and 1997-2012. The following map illustrates how the amount of biomass per meter square has changed over time.

Figure 1. Changes in the average biomass per hectare from 1982-1996 to 1997-2012



Source: the research team's calculation

Generally, the amount of biomass has declined in most of the territory. Pastureland providing more than 550 grams of grass per meter square, the maximum value, has shrunk. The amount of biomass has, however, grown slight in a few soums in the east and northern (khangai) areas. How the amount of biomass per meter square over Mongolia's territory changed can be observed from Figure A.1 and Figure A.2 included in the Appendix.

When determining these provinces for which degradation and desertification has been a noticeable concern, the research team will refer to a pasture use index showing the ratio between consumed forage and produced forage (Joly, Sabatier, Hubert, & Munkhtuya, 2017). For a given year, we defined PU as the ratio of biomass consumed to biomass available.

$$PU = BC/BS_{\phi}$$

Where PU is the pasture use we want to estimate, BC the consumed biomass, BS the available standing biomass, insect intake and trampling (Smart, et al., 2010).

This composite index depends on forage consumption, climatic factors such as rainfall, and pasture health. If the consumed forage is more than a half of the produced forage, the ratio will have a value larger than 0.5. Generally, a ratio larger than 0.5 leads to pasture and soil degradation that in turn leads to lower ecological carrying capacity.

Based on the pasture use index, the research team will choose the provinces to include in the analysis. Broadly, the index shows pasture stress which also negatively affects the livestock's ability to adapt to weather conditions such as zuds and droughts, decreasing overall livestock income. In order to better understand this complex system, researchers use "System Dynamic Analysis" methodology and modeling to estimate economic and ecological carrying capacity as well as to evaluate the impact of livestock taxation.

Threshold levels for the poverty trap and vulnerability to zuds in terms of livestock numbers will be evaluated by social scientist groups in order to waive poor and vulnerable herders from the livestock taxation. Another topic for consideration would be to research the possibility of a progressive livestock taxation depending on livestock numbers.

Data

The ecological carrying capacity can be estimated using remote sensing technology, currently the most effective approach to biomass estimation. Grassland biomass has been successfully estimated based on the normalized difference vegetation index (NDVI), a very widely used indicator. Piao et al. estimated the distribution of carbon stocks in China's grasslands between 1982 and 1999 and established a satellite-based statistical model using national grassland resource inventory data and AVHRR-NDVI data (Piao, Fang, & Liming Zhou, 2007). The data was originally constructed using measurements from the Advanced Very High Resolution Radiometer (AVHRR) on board the USA's NOAA polar orbiting meteorological satellites and was corrected for calibration; view geometry, volcanic aerosols, and other effects not related to actual vegetation change (Tucker, et al., 2005). The collected long-term NDVI data is a 15-day maximum value composite (MVC) in an 8 km range collected from 1982 to 2012. We will then apply developed regression models for the above grand biomass versus NDVI (Gao, et al., 2013).

The economic carrying capacity can be estimated through calculating the profit maximizing decisions of herder families. The main source of data essential in estimating this is the Household Socio-economic survey compiled by the National Statistics Office. The survey covers questions pertaining to the income and cost related to raising livestock and is carried out in all 21 provinces. When income is higher than the cost, a herder family would choose to continue raising more livestock instead of cutting back and curbing the amount of livestock they raise. A livestock taxation would increase the costs associated with continuing to raise livestock and therefore could play a central role in the decision to raise or cut back on raising more livestock.

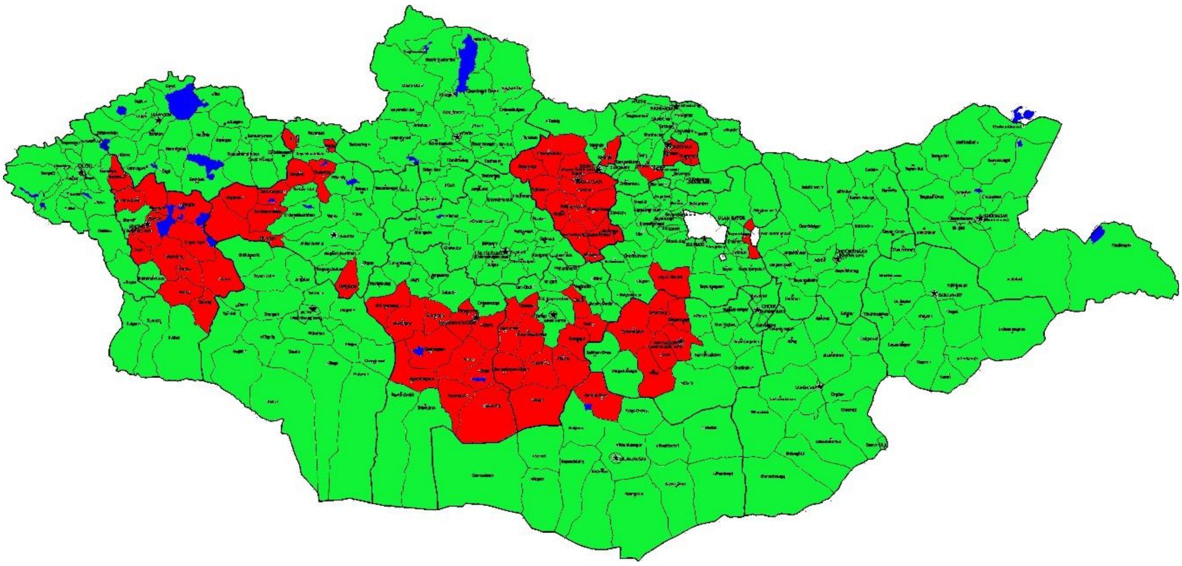
III. MODELING

Description

In this study, we looked at the soums most heavily burdened by livestock overgrazing in 2016. In order to select these soums, we calculated the pasture use index outlined above, calculating biomass using available data that takes into account climate variables such as precipitation and temperature. As biomass growth is relatively stable, we used the available data for 2012.

Based on the index, we then listen the soums with indexes above a value of 5. These soums had an annual biomass consumption, based on the number of livestock, that was 500% more than the available biomass. Of these soums, we excluded those that were province capital cities as they don't have grazing pastureland but have livestock registered to them due to the living situations of the herders. The finalized list of soums for further study consisted of 67 soums show in the figure below. Our pasture index results are in line with the grazing capacity map made by the National Agency for Meteorology and Environment Monitoring. The complete list of selected soums and the government grazing map is included in the annex.

Figure 2. Selected Soums



Source: the research team's calculation

For these soums, we will further look into their herding decisions by calculating their economic livestock income using the Household Socio-Economic survey by the National Statistics Office.

The main model will be made up of three separate sections comprising of ecology, the mechanical change in the number of livestock, and profit maximization (to see the whole model, please refer to Diamond 1 in the Appendix). The ecological section will calculate the ecological carrying capacity using precipitation, and other pertinent data while the economic carrying capacity is calculated using both the mechanical change in the number of livestock and the profit maximization sections. We calculated the livestock consumption in each soum by converting the number of livestock in each soum into a unified sheep unit using comparable eating coefficients. According to the eating units, the biomass consumed by each type of livestock is the following, 1 goat-2 sheep, 1 camel-3 sheep, 1 cow-4 sheep, 1 horse-8 sheep (Enkh-Amgalan, 2013). We then use the daily estimated sheep intake calculated in a study by the Japanese International Research Center for Agricultural Sciences to calculate the annual biomass consumption per soum. This allows us to determine the pasture use index (Uehara, Yamasaki, Shindo, A, & G, 2016).

In order to estimate the ecological carrying capacity, the model will use the following information.

- Grazing
  - Regeneration
    - An average temperature
    - Precipitation
  - Harvest
    - The number of livestock

The regeneration of pastureland is positively affected by the amount of precipitation and negatively influenced by average temperature.

In order to estimate the economic carrying capacity, the following information will be used:

- The mechanical change in the number of livestock
  - The number of livestock
  - The number of deaths, based on historical data including death rate and death possibility which is positively influenced by pasture stress.
  - The number of birth, based on the historical data including birth rate and birth possibility which is negatively influenced by pasture stress.
- Profit maximization
  - The amount of income pertaining to livestock
  - The amount of cost pertaining to livestock

As the mechanical change in the number of livestock is determined by aggregate historical data that fluctuates minimally from year to year, the main driver of the economic carrying capacity lies in the profit maximizing decisions to either raise or lower the amount of livestock made by herder families. The profit maximizing decisions will take into account and consider the incomes associated with either continuing to raise all the livestock for another year or reducing and slaughtering some of the livestock this year.

Continuing to raise all the livestock will benefit the herder families by providing income made up of the livestock's raw animal products such as cashmere, wool, milk and the present value of the revenue of selling meat and animal hides next year. Conversely, slaughtering some of the livestock this year will benefit the family through an income comprising only of selling meat and hides as the herder family will not gain an income from the livestock's raw animal products. Likewise, herder families will also compare the expenses associated with the two scenarios above. If slaughtered this year, the cost pertaining to livestock will be zero. If instead the herder family decides to continue to raise all their livestock, they need to provide for the livestock's continued sustenance. These costs include necessities such as medicine, vaccination, buying bales of hay to use in the winter and so forth. With the increased degradation and desertification of pasturelands, the cost of buying hay is also expected to rise. Taking these various incomes and expenses into account, herder families will choose the more profitable option when it comes to managing their amount of livestock.

Introducing a livestock taxation would increase the cost of continuing to raise livestock and would therefore lower the expected profit of maintaining more livestock. This change in the income and cost dynamic would incentivize more herder families into decreasing their supply of livestock. As a result, it will encourage a decrease in the current pasture capacity and give the pastureland a chance to recover naturally.

Simulations

According to international practices, livestock taxation is more efficient compared to a number quota on livestock when regulating livestock numbers.

Considering this, the research's aim is to define whether the tax can solve problems such as pasture and soil degradation, desertification acceleration, and so forth. In order to test this hypothesis, the research will make the two following general simulations.

1. If the government does not regulate and control the agriculture sector, especially livestock, would the sector reach the ecological and economic equilibriums simultaneously in the future?
2. If the government introduces the livestock taxation, would the sector reach the ecological and economic equilibriums simultaneously in the future?

In the first simulation, the government has no direct role in regulating the agriculture sector. To convey this, in the first simulation we assume there is no tax rate on livestock. Considering this situation, we observe the estimated forecasts of the agriculture sector and conclude whether or not the sector can achieve economic and ecological equilibrium without government interference.

In the second simulation, we observe the forecasted situation when there is direct government involvement in the agriculture sector. Based off of successful practices maintained in other nations, the livestock taxation can either be progressive depending on the number of livestock or a fixed constant rate. In this simulation, we test the results of two different type of government taxation.

In the first case, we look at the projection of the agriculture sector when there is a flat fixed government tax on livestock. In the second, we focus on the effects of introducing a progressive government tax on livestock that increases as the number of livestock grows. We then compare these two cases and see whether or not the agriculture sector can reach ecological and economic equilibrium simultaneously in either case.

By comparing this first and second simulations, we hope to capture the effect of government involvement in the agriculture sector and determine whether livestock taxation is necessary in guiding the agriculture sector towards a more ecologically sustainable future.

IV. PRELIMINARY CONCLUSION

The estimated amount of pastureland impossible to be naturally recovered reached 7 percent in 2015. If the number of livestock continues to constantly grow, desertification and degradation will be a serious concern in the near future. Therefore, the research will play a central role in solving and overcoming these challenges.

After completing the research, the optimal number of livestock will be defined by simulations with and without the livestock taxation. It will also reveal how the livestock taxation influences the ecological and economic carrying capacity. These findings are useful to policy and decision makers.

V. APPENDIX

Figure A.1 An average of biomass per meter square from 1982-1996

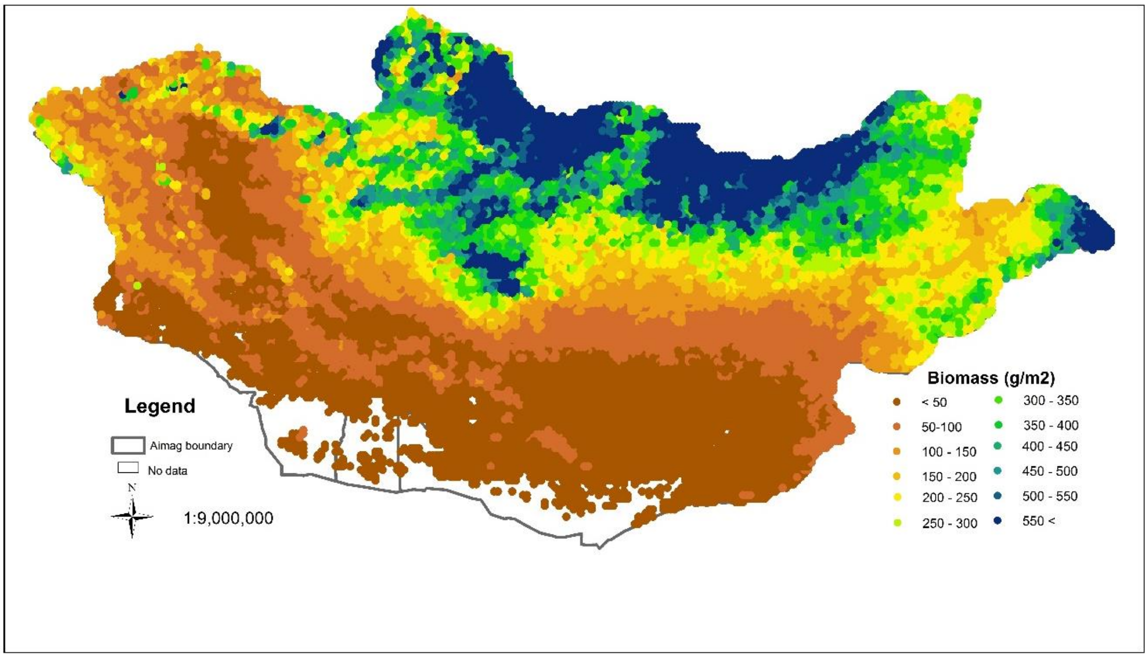


Figure A.2 An average of biomass per meter square from 1997-2012

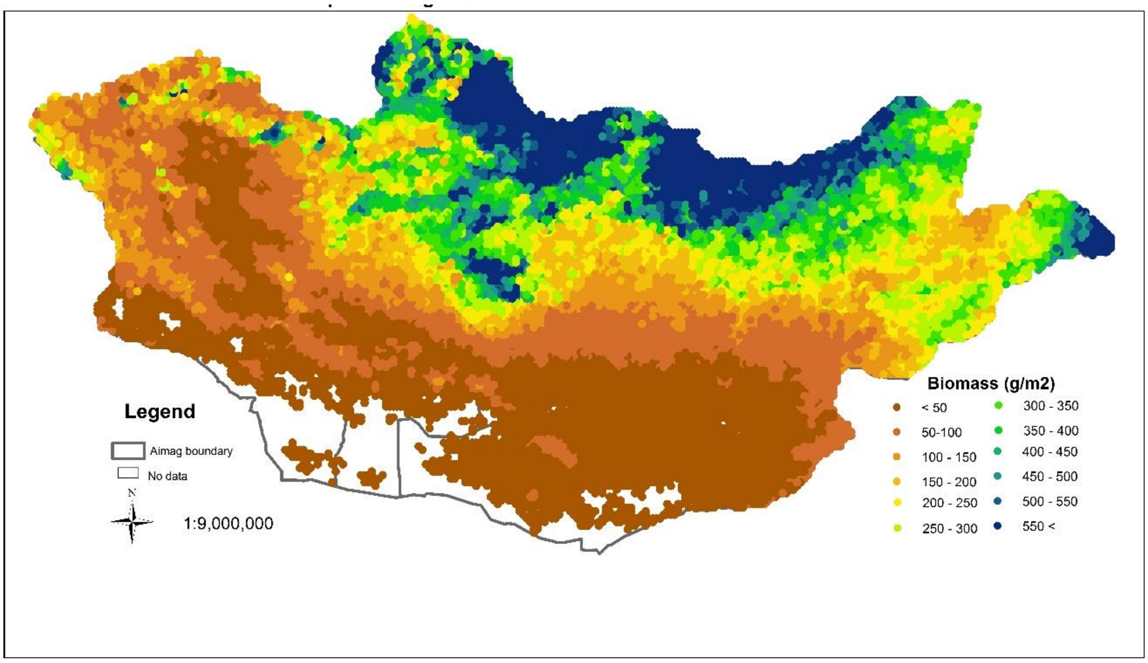
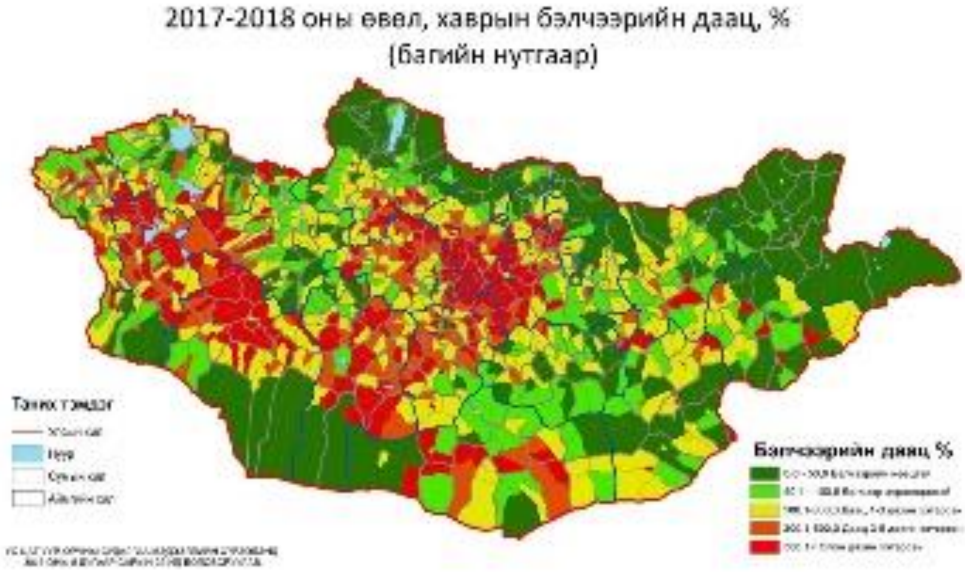


Table A. 1. Selected Soums with Pasture Use Index over 5

Province	Soum	Pasture Use Index
Darkhan	Sharingol	61.50
Bulgan	Bayan Nuur	60.91
Bulgan	Rashaant	54.68
Darkhan	Orkhon	39.45
Bulgan	Dashinchilen	37.05
Bulgan	Gurvanbulag	34.65
Bulgan	Saikhan	25.75
Bulgan	Khishig Undur	25.72
Bulgan	Buregkhangai	25.65
Tuv	Bayan Unjuul	24.35
Bulgan	Mogod	22.62
Bulgan	Orkhon	19.49
Bulgan	Bayan Agt	16.12
Darkhan	Khongor	12.60
Bayankhongor	Bumbugur	11.69
Uvurkhangai	Baruunbayan Ulaan	11.13
Bayankhongor	Bayantsagaan	10.55
Bayankhongor	Bogd	10.41
Bayankhongor	Bayangovi	9.87
Bayankhongor	Baatsagaan	9.65
Khovd	Zereg	9.38
Bulgan	Khangal	9.35
Tuv	Bayandelger	8.94
Bayankhongor	Jinst	8.94
Uvurkhangai	Bogd	8.89
Uvurkhangai	Bayangol	8.84
Bulgan	Khutag Undur	8.79
Bayankhongor	Bayan Ovoo	8.56
Uvurkhangai	Guchin Us	8.50
Uvurkhangai	Nariin Teel	8.41
Khovd	Mankhan	8.20
Zavkhan	Urgamal	8.00
Dundgovi	Saintsagaa	7.88
Khovd	Erdeneburen	7.55
Umnugovi	Nomgon	7.53
Uvurkhangai	Sant	7.50
Khovd	Chandmana	7.36
Bayankhongor	Buutsagaan	7.25
Zavkhan	Songino	7.01
Bayankhongor	Ulziit	6.99
Khovd	Most	6.78
Bulgan	Bugat	6.60

Zavkhan	Santmargats	6.37
Dornod	Bulgan	6.21
Zavkhan	Shiluustei	6.16
Khovd	Darvi	6.14
Uvurkhangai	Tugrug	6.09
Dundgovi	Khuld	6.07
Uvurkhangai	Ulziit	6.01
Uvurkhangai	Khairkhandulaan	5.96
Khovd	Buyant	5.85
Khovd	Duut	5.76
Zavkhan	Tes	5.75
Khovd	Dorgon	5.73
Dundgovi	Erdenedalai	5.71
Zavkhan	Zavkhanmandal	5.57
Zavkhan	Asgat	5.55
Bayankhongor	Khureemaral	5.45
Bayan Ulgii	Bayannuur	5.40
Zavkhan	Dorvoljin	5.40
Khovd	Myangad	5.38
Khovd	Tsetseg	5.36
Zavkhan	Tudevtei	5.29
Bayankhongor	Bayanlig	5.22
Uvurkhangai	Uyanga	5.15
Dundgovi	Delgertsogt	5.14
Dundgovi	Luus	5.09

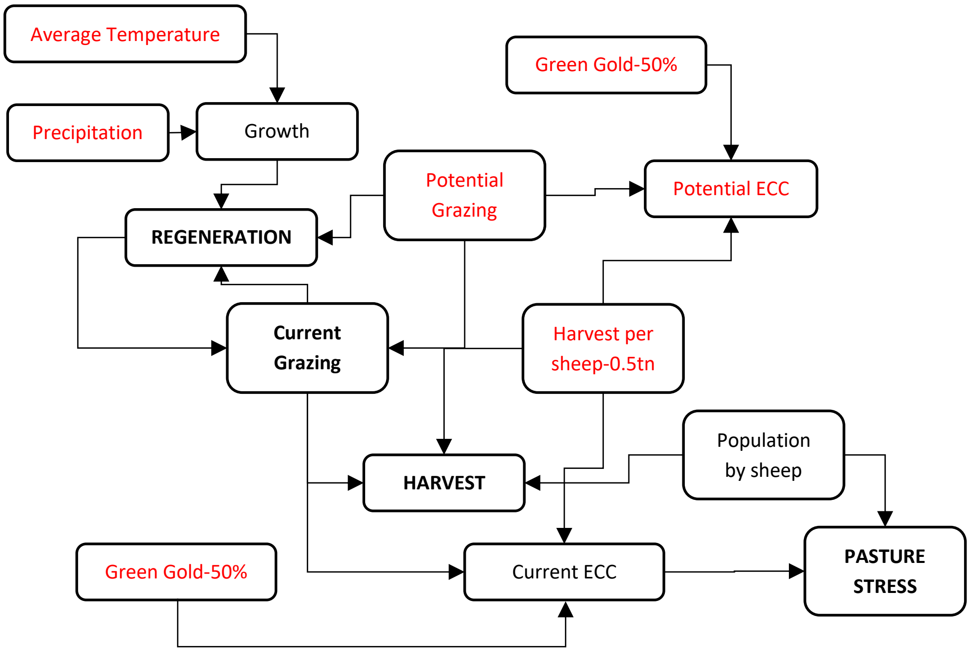
Figure A.3 2017-2018 winter, spring grazing capacity, %



Source: National Agency for Meteorology and Environment Monitoring

Diamond 1. The comprehensive information about the model

The ecological carrying capacity (ECC)



Exogenous variables:

Average temperature, Precipitation, Potential grazing, Potential ECC, Green gold-50%, and Harvest per sheep-0.5tn.

Endogenous variables:

Growth, REGENERATION, Current Grazing, HARVEST, Current ECC, Population by sheep, and PASTURE STRESS.

EQUATIONS:

$$Growth = \beta_0 + \beta_1 * precipitation - \beta_2 * ave\_temperature$$

$$REGENERATION = Growth * \left(1 - \frac{Current\ Grazing}{Potential\ Grazing}\right) * Current\ Grazing$$

$$HARVEST = (Harvest\ per\ sheep - 0.5tn) * (Population\ by\ sheep)$$

$$Current\ Grazing = REGENERATION - HARVEST$$

$$Current\ ECC = \frac{(Current\ Grazing) * (Green\ Gold - 50\%)}{Harvest\ per\ sheep - 0.5tn}$$

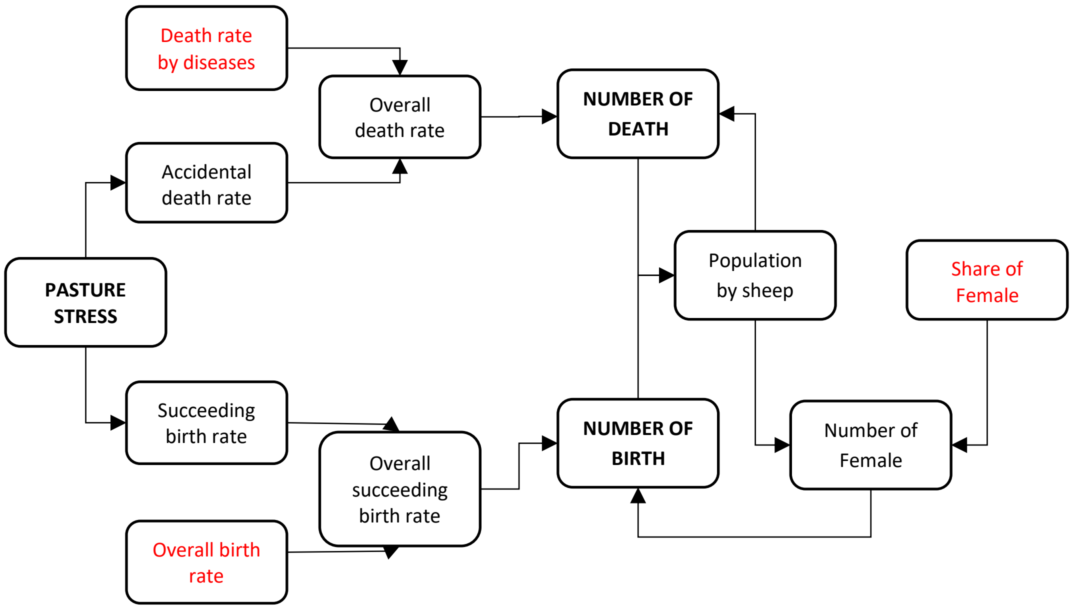
$$PASTURE\ STRESS = \frac{Current\ ECC}{Population\ by\ sheep}$$

If pasture stress has value more than 1, it means that there is an overgrazing.

The economic carrying capacity (EcCC)

Brief introduction: It consists of two section; mechanical change in the number of the livestock and profit maximization.

Section 1. Mechanical change in the number of the livestock



Succeeding birth rate illustrates the percentage of surviving animal infants per 100 animals; Share of female shows the percent of livestock able to give birth.

Exogenous variables:

Death rate by diseases, overall birth rate, and share of female.

Endogenous variables:

Accidental death rate, succeeding birth rate, overall death rate, overall succeeding birth rate, population by sheep, number of female, NUMBER OF BIRTH, and NUMBER OF DEATH.

EQUATIONS:

$$Accidental\ death\ rate = \alpha_0 + \alpha_1 * PASTURE\ STRESS$$

$$Succeeding\ birth\ rate = \gamma_0 - \gamma_1 * PASTURE\ STRESS$$

$$Overall\ succeeding\ birth\ rate = (Overall\ birth\ rate) * (Succeeding\ birth\ rate)$$

$$Number\ of\ Female = (Population\ by\ sheep) * (Share\ of\ Female)$$

$$Overall\ death\ rate = Accidental\ death\ rate + Death\ rate\ by\ diseases$$

$$NUMBER\ OF\ DEATH = (Overall\ death\ rate) * (Population\ by\ sheep)$$

$$NUMBER\ OF\ BIRTH = (Overall\ succeeding\ birth\ rate) * (Number\ of\ Female)$$

$$\Delta Population\ by\ sheep\ = NUMBER\ OF\ BIRTH - NUMBER\ OF\ DEATH$$

The equations above show how the mechanical change in the number of livestock is calculated. Slaughtering plays a significant role in the change of livestock numbers but is defined by the herder's decision based on livestock income and expenses. As such, the following optimization equation will be added into the model and as part of the economic carrying capacity in order reflect this decision.

Diamond 2. Household optimization problem

$$Max \left\{ \int_t^{\infty} P_t * Livestock_t - C(Livestock_t, Grazing_t, Tax_t) \right\} e^{-it} dt$$

$$^{1}subject\ to \frac{dGrazing_t}{dt} = 0.5 * G(Grazing_t) - H(Livestock_t)$$

$$\geq livestock \geq 0$$

where:

$P_t - the\ expectation\ incomes\ of\ milk, cashmere, and\ so\ on, when\ feeding\ the\ animals$

$Livestock_t - the\ number\ of\ animal$

$C(Livestock_t, Grazing_t, Tax_t) - expenditure\ function\ of\ the\ animals$[2]

$$C(Livestock_t, Grazing_t, Tax_t) = Livestock_t * \left(c_t + Tax_t - \beta * \frac{(Grazing_t - H(livestock_t))}{0.5} \right)$$

$Tax_t - the\ tax\ on\ livestock, and\ it\ will\ increase\ the\ expenditure\ of\ livestock$

$G(Grazing_t) - the\ growth\ function\ of\ grazing, and;$

$$G(Grazing_t) = Grazing_t + SubsGrowth \left(1 - \frac{Grazing_t}{Grazing_{\max}} \right) * Grazing_t$$

$$SubsGrowth_t = \beta_0 - \alpha_1 * AveTemprature_t + \alpha_2 * Precipitation_t$$

$$H(Livestock_t) = Livestock * .5\ ton$$

Hamilton's function:

$$L = livestock_t * \left(P_t - \left(c_t + Tax_t - \beta * \frac{(Grazing_t - 0.5 * livestock_t)}{0.5} \right) \right) + \lambda \left(0.5 * Grazing_t \left(1 + SubsGrowth \left(1 - \frac{Grazing_t}{Grazing_{\max}} \right) \right) - 0.5 * livestock_t \right)$$

[1] (Ministry of Food and Agriculture; Swiss agency for Development and Cooperation SDC, 2015)

[2] It relies on the number of livestock (+), grazing (-), and tax (+)

$$\frac{\partial L}{\partial Livestock} = P_t - c_t - Tax_t + 2\beta * Grazing_t - 2\beta * livestock_t - 0.5\lambda = 0$$

$$\frac{\partial L}{\partial \lambda} = 0.5 * Grazing_t * \left(1 + SubsGrowth\left(1 - \frac{Grazing_t}{Grazing_{max}}\right)\right) - 0.5 * Livestock_t = 0$$

$$\dot{\lambda} = -Hamilton_{Grazing} =$$

$$-\left(2\beta * livestock_t + 0.5\lambda\left(\left(1 + SubsGrowth - \frac{Grazing_t * SubsGrowth}{Grazing_{\max}}\right) - \frac{Grazing_t * SubsGrowth}{Grazing_{\max}}\right)\right)$$

$$\frac{\partial L}{\partial Livestock} = P_t - c_t - Tax_t + 2\beta * Grazing_t - 2\beta * livestock_t - 0.5\lambda = 0$$

$$\boldsymbol{\lambda^* = 2 * (P_t - c_t - Tax_t + 2\beta * Grazing_t - 2\beta livestock_t)}$$

$$\dot{\lambda} = -Hamilton_{Grazing} = 0$$

$$-\left(2\beta * livestock_t + 0.5\lambda\left(1 + SubsGrowth - \frac{2Grazing_t * SubsGrowth}{Grazing_{\max}}\right)\right) = 0$$

$$-\left(2\beta * livestock_t + (\boldsymbol{P_t - c_t - Tax_t + 2\beta * Grazing_t} - \boldsymbol{2\beta livestock_t})\left(1 + SubsGrowth - \frac{2Grazing_t * SubsGrowth}{Grazing_{\max}}\right)\right) = 0$$

$$-2\beta * livestock_t + 2\beta * livestock_t\left(1 + SubsGrowth - \frac{2Grazing_t * SubsGrowth}{Grazing_{\max}}\right) - (P_t - c_t - Tax_t + 2\beta * Grazing_t)\left(1 + SubsGrowth - \frac{2Grazing_t * SubsGrowth}{Grazing_{\max}}\right) = 0$$

$$2\beta * lievestock_t\left(SubsGrowth - \frac{2Grazing_t * SubsGrowth}{Grazing_{\max}}\right) = (P_t - c_t - Tax_t + 2\beta * Grazing_t)\left(1 + SubsGrowth - \frac{2Grazing_t * SubsGrowth}{Grazing_{\max}}\right)$$

$$\boldsymbol{livestock_t^* = \frac{\left(1 + SubsGrowth - \frac{2Grazing_t * SubsGrowth}{Grazing_{\max}}\right)(P_t - c_t - Tax_t + 2\beta * Grazing_t)}{\left(SubsGrowth - \frac{2Grazing_t * SubsGrowth}{Grazing_{\max}}\right)}}$$

$$0.5 * Grazing_t * \left(1 + SubsGrowth\left(1 - \frac{Grazing_t}{Grazing_{max}}\right)\right) - 0.5 * Livestock_t = 0$$

$$Grazing_t * \left(1 + SubsGrowth\left(1 - \frac{Grazing_t}{Grazing_{max}}\right)\right) = \frac{\left(\mathbf{1 + SubsGrowth - \frac{2Grazing_t * SubsGrowth}{Grazing_{max}}}\right)(\mathbf{P_t - c_t - Tax_t + 2\beta * Grazing_t})}{\left(\mathbf{SubsGrowth - \frac{2Grazing_t * SubsGrowth}{Grazing_{max}}}\right)}$$

$$Grazing_t * \left(1 + SubsGrowth\left(1 - \frac{Grazing_t}{Grazing_{max}}\right)\right) = \frac{(\mathbf{P_t - c_t - Tax_t + 2\beta * Grazing_t})}{\left(\mathbf{SubsGrowth - \frac{2Grazing_t * SubsGrowth}{Grazing_{max}}}\right)} + (\mathbf{P_t - c_t - Tax_t + 2\beta * Grazing_t})$$

$$\left(Grazing_t + Grazing_t * SubsGrowth - \frac{Grazing_t^2}{Grazing_{max}}\right) * \left(SubsGrowth - \frac{2Grazing_t * SubsGrowth}{Grazing_{max}}\right) = \left(1 + SubsGrowth - \frac{2Grazing_t * SubsGrowth}{Grazing_{max}}\right) * (P_t - c_t - Tax_t + 2\beta * Grazing_t)$$

$$Grazing_t * SubsGrowth + Grazing_t * SubsGrowth^2 - \frac{3Grazing_t^2 * SubsGrowth}{Grazing_{max}} - \frac{2 * Grazing_t^2 * SubsGrowth^2}{Grazing_{max}} + \frac{2 * Grazing_t^3 * SubsGrowth}{Grazing_{max}^2} = P_t - c_t - Tax_t + 2\beta * Grazing_t + SubsGrowth * P_t - SubsGrowth * c_t - SubsGrowth * Tax_t + 2\beta * Grazing_t * Subsgrowth - \frac{2Grazing_t * SubsGrowth}{Grazing_{max}} * P_t + \frac{2Grazing_t * SubsGrowth}{Grazing_{max}} * c_t + \frac{2Grazing_t * SubsGrowth}{Grazing_{max}} * Tax_t + \frac{4\beta Grazing_t^2 * SubsGrowth}{Grazing_{max}}$$

$$Grazing_t * SubsGrowth + Grazing_t * SubsGrowth^2 - (3 + 4\beta) * \left(\frac{Grazing_t^2 * SubsGrowth}{Grazing_{max}}\right) - \frac{2 * Grazing_t^2 * SubsGrowth^2}{Grazing_{max}} + \frac{2 * Grazing_t^3 * SubsGrowth}{Grazing_{max}^2} = P_t - c_t - Tax_t + +SubsGrowth * P_t + SubsGrowth * c_t - SubsGrowth * Tax_t + 2Grazing_t\left(\beta + \beta * Subsgrowth - \frac{SubsGrowth}{Grazing_{max}} * P_t + \frac{SubsGrowth}{Grazing_{max}} * c_t + \frac{SubsGrowth}{Grazing_{max}} * Tax_t\right)$$

$$\frac{2 * SubsGrowth^2}{Grazing_{max}^2} * Grazing_t^3 - \left(\frac{3 + 2SubsGrowth}{Grazing_{max}}\right) * Grazing_t^2 + \left((SubsGrowth - 2\beta) * (1 + SubsGrowth) - \frac{2 * SubsGrowth}{Grazing_{max}} * (P_t - c_t - Tax_t)\right) * Grazing_t - (1 + SubsGrowth)(P_t - c_t - Tax_t) = 0$$

VI. REFERENCES

Allington, G. R., Li, W., & Brown, D. G. (2015). Modeling System Dynamics in Rangelands of the Mongolian Plateau. *Building Resilience of Mongolian Rangelands* (pp. 216-21). Ulaanbaatar: Nutag Action and Research Institute.

Briske, D. D., Derner, J. D., Milchunas, D. G., & Tate, K. W. (2011). Chapter1: An Evidence-Based Assessment of Prescribed Grazing Practices. In U. S. Agriculture, *Conservation Benefits of Rangeland Practices: Assessment, Recommendations, and Knowledge Gaps* (pp. 21-74). Washington D.C.

Cossins, N. J., & Upton, M. (1987). The Borana pastoral system of Southern Ethiopia . *Agricultural Systems* , 199-218.

Densambuu, B., Ulambayar, B., Battur, A., Sainnemekh, S., Nyam-Ochir, G., & Bestelmeier, B. (2015). Defining the Ecological Site Descriptions and its Use as a Rangeland Management Tool in Mongolia. *Building Resilience of Mongolian Rangelands* (pp. 19-23). Ulaanbaatar: Nutag Action and Research Institute.

Enkh-Amgalan, A. (2013). *A solution to provide a suitable livestock taxation for herders.* Ulaanbaatar, Mongolia : The Centre for Policy Research.

Gao, T., Yang, X., Jin, Y., Ma, H., Li, J., Yu, H., . . . Xu, B. (2013). Spatio-Temporal Variation in Vegetation Biomass and Its Relationships with Climate Factors in the Xilingol Grasslands, Northern China. *PLOS| One*, 1-10.

Grant, W. E., Pedersen, E. K., & Marin, S. L. (1997). *Ecology and Natural Resource Management: Systems Analysis and Simulation* . Chichester, UK: John Wiley and Sons .

Hunt, L., Mclvor, J. G., Grice, A. V., & Bray, S. (2014). Principles and guidelines for managing cattle grazing in the grazing lands of northern Australia: stocking rates, pasture resting, prescribed fire, paddock size and water points – a review. *The Rangeland journal-36*, 105-119.

Joly, F., Sabatier, R., Hubert, B., & Munkhtuya, B. (2017). Livestock productivity as indicator of vulnerability to climate hazards: a Mongolian case study. *Natural Hazards (in press)*.

Kemp, D. R., Guodong, H., Xiangyang, H., Michalk, D. L., Fujiang, H., Jianping, W., & Yingjun, Z. (2013). Innovative grassland management systems for environmental and livelihood benefits. *Procedings of the National Academy of Sciences vol. 110, no. 21*, 8369-8374.

Ministry of Environment and Green Development. (2014). *Mongolia Second Assessment Report on Climate Change.* Ulaanbaatar.

Ministry of Food and Agriculture; Swiss agency for Development and Cooperation SDC. (2015). *National Report on the Rangeland Health of Mongolia.* Ulaanbaatar.

NSO. (2015a). *Annual Report.* Ulaanbaatar.

NSO. (2015b). *The guide book to estimate statistics of Agriculture sector.* Ulaanbaatar.

Perman, R., Ma, Y., McGilvray, J., & Common, M. (2003). Chapter 17. Renewable resources. In R. Perman, Y. Ma, J. McGilvray, & M. Common, *Natural Resource and Environmental Economics* (pp. 555-597). London: Pearson Education Limited.

Piao, S., Fang, J., & Liming Zhou, K. T. (2007). Changes in biomass carbon stocks in China's grasslands between 1982 and 1999. *Global Biogeochemical Cycles*, 1-10.

Retzer, V., Nadrowski, K., & Miehe, G. (2006). Variation of precipitation and its effect on phytomass production and consumption by livestock and large wild herbivores along an altitudinal gradient during a drought, South Gobi, Mongolia. *Journal of Arid Environments* , 135-150.

Scoones, I. (1993). Economic and ecological carrying capacity: applications to pastoral systems in Zimbabwe. *Economics and Ecology*, 96-117.

Smart, A. J., Derner, J. D., Hendrickson, J. R., Gillen, R. L., Dunn, B. H., Mousel, E. M., . . . Olson, K. C. (2010). Effects of Grazing Pressure on Efficiency of Grazing on North American Great Plains Rangelands. *Rangeland Ecol Manage*, 397-406.

Snyman, H. A. (1998). Dynamics and sustainable utilization of rangeland ecosystems in arid and semi-arid climates of southern Africa. *Journal of Arid Environments vol. 39*, 645-666.

Tucker, J., Pinzon, J. E., Brown, M. E., Slayback, D. A., Pak, E. W., & Mahoney, R. (2005). An extended AVHRR 8-km NDVI dataset compatible with MODIS and SPOT vegetation NDVI data. *International Journal of Remote Sensing*, 4485-98.

Uehara, A., Yamasaki, S., Shindo, K., A, E., & G, O. (2016). *Forage intake of grazing sheep in Mongolian winter grassland is 20% higher than the UNDP index.* JIRCAS.

Wang, Z., Jiao, S., Han, G., Zhao, M., Willms, W. D., Hao, X., . . . Havstad, K. M. (2011). Impact of Stocking Rate and Rainfall on Sheep Performance in a Desert Steppe . *Rangeland Ecology and Management* , 249-256.

Wetzel, K. R., & Wetzel, J. F. (1995). Sizing the earth: Recognition of economic carrying capacity . *Ecological Economics* , 13-21.

Wijngaarden, W. v. (1985). *Elephants-Trees-Grass-Grazers: Relationship between climate, souls. vegetation and large herbivores in a semi-arid savanna ecosystem (Tsavo, Kenya).* ITC Publications .