Framework of a Regional Impacts Assessment Model and Its Application on Arid/Semi-Arid Region

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Abstract: Regional impacts assessment model is an indispensable tool for the study on environmental and economical change and the impacts on ecosystems. In this paper a regional impact assessment model AVIMia, which is an extended version of AVIM is designed. AVIMia is consists of two components: original AVIM (Atmosphere- Vegetation Interaction Model) and an impact assessment model. Over past 50 year the arid/semi-arid grassland of North China degraded severely due to the change in Climate and social economy. AVIMia is applied to assess the impacts of climatic changes and human activities on grassland in North China, based on historical data, and the different climatic and social scenarios for this region. For the assessment of grassland, specially, the following impact facts are taken into consideration: grazing, cultivation on grassland communities and soil attributes from plot to regional scale. The model is validated by observed data of Inner Mongolia semi-arid grassland. Both the data analysis and model assessment show that: Total aboveground NPP of Inner Mongolia grassland is $771.7*10^8$ kg /yr. Edible aboveground biomass is $498.1*10^8$ kg /yr. Typical steppe and meadow steppe dominate the production of this region. Total estimated livestock holding capacity is 45.51million sheep unit. The grassland is overgrazed more than 100% in Inner Mongolia. Overgrazing is one of the most important reasons inducing the widespread degradation and desertification.

Keywords: Assessment； Modeling； Grassland； Climatic and economical change

1. INTRODUCTION

Natural grassland in arid and semi-arid regions is the most important renewable resource of North China. The area of Inner Mongolia grassland covers the area of 78.8 Mhm^2, That is the base of animal husbandry and regional environment, also plays a key role on gestating Mongolian nomadic civilization. The livestock holding capacity of grassland influences significantly the income and life level of local people [McArthur et al., 2000].

On the other hand temperate grassland is a major sink of global carbon [Joyce, 2000; Lecain et al., 2000; Frank and Dugas, 2001], the strength and sign of the sink is controlled greatly by the grassland utilization and management and climate, particularly, precipitation. Because Inner Mongolia is located in climatic transition zone, the north margin of East Asian Monsoon region. The grassland of this region is a relatively vulnerable ecosystem. Productivity of the grassland fluctuated with the climate variability [Mithell and Csillag, 2001]. Furthermore, degradation and desertification of the grassland are very common phenomena due to intense human activities. Primary productivity of grassland reduced continuously during past decades. In the future, with an increase in temperature of 2-4ºC combined with reduced precipitation as projected for the future in the semi-arid and arid regions of Asia, grassland productivity is expected to decrease by as much as 40-90%[IPCC, 2001].

Human activities and climate variability influence the physical processes at land surface, and through leaf area index and base cover fraction of vegetation influence albedo, roughness length of land surface, therefore energy and water balance and carbon budget of the grassland will be altered. The changing processes of grassland are the integrated consequence of the impacts of climate change and human activities. Therefore, the processes of plant eco-physiology, land surface physics and human disturbance should be coupled in the modeling of grassland,

Several models have been developed to

assessment the impacts of climate change and human activities on the grassland in recent years [Hutchings and Gardon, 2001; Campell, et al., 1999; Nouvellon et al., 2000]. These models study grassland in different ways. In this paper, the temporal and spatial pattern of the primary productivity and the livestock holding capacity of arid semi-arid grassland in North China were estimated by using an integrated assessment model.

2. MODEL DESCRIPTION AND DATA

AVIMia, an extended version of AVIM, is designed and applied to assess the impacts of climatic and social economic changes on grassland in North China (See figure 1). For different purposes AVIMia include several components of assessment. a land surface model AVIM, ecosystem or hydrological processes model. AVIM is the linkage if physical climatic processes and ecosystems or hydrological process. The outputs of hydrological model, grassland model and crop model put into an economic model. The climate data from observation or prediction of GCM was the driving force of AVIMia.

Atmosphere-vegetation interaction model (AVIM) linking physical processes at land surface and vegetation eco-physiological processes mechanically [Ji 1995] (See figure 1) was validated with different vegetation, e.g. forest, crop, grassland, and used for different regions, e.g. NECT and Tibet, and global terrestrial ecosystems [Li and Ji, 2001; Lu and Ji, 2002].

Grassland model describes the impacts of animal grazing on grassland: including the reduction of leaf area index, photosynthesis, and biomass caused by livestock intake; selective intake in different species; effects of trampling on plant and soil density and dejecta fertilizing. The input of AVIMia include vegetation types, soil texture and climatic data, and data selected to human activities. The output of AVIM includes the eco-physiological and land surface physical variables: biomass, NPP, LAI, soil moisture, sensible and latent heat, etc.

The grassland communities are classified into 23 types based on the dominant species of communities provided by the grassland vegetation atlas of China with a resolution of 25*25km2. For simplicity, the grassland types were integrated and classified into six main types as usually do: meadow (type 1), meadow steppe (type 2- 7), typical steppe (type 8-15), desert steppe (type 16-21), steppe desert (type 22), and desert (type 23).

The species compositions of community vary with water and energy gradient on regional scale and with soil texture and grazing density on smaller

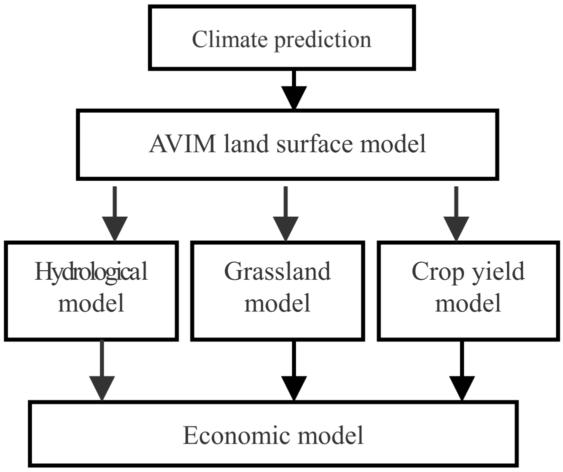

Figure 1 Framework of aregional impacts assessment model AVIMia.

scales. Meanwhile the species composition is dominated by the species with grazing tolerant attributes such as trampling tolerance, poor soil fertility tolerance and less edibility, e.g. *Artemisia frigida*. The major dominant species of Inner Mongolia grassland communities are *Stipa spp.*. There are 6 types of soil texture for use in simulation. Input climatic data involve the 30 years averaged monthly maximum, minimum temperature, relative humidity, wind speed, radiation, and precipitation grid cell data (Cramer climate data), and the daily climate data collected for 20 stations in studying domain. A weather generator was used to generate daily climate from monthly climate data. The integration time step of the model is 30 minutes

Parameters of grassland community composition and structure are collected from Editorial Board of Inner Mongolia Grassland Resources [1990]. Parts of the photosynthesis parameters are derived from Du and Yang [1988]. Soil parameters refer to the work of Jia et al. [1997]. Other physical and physiological parameters refer to Li and Ji [2001]. Model is validated by the observation data from EMDI and Chen and Wang [2000].

3. RESULTS

3.1 Simulation of Net Primary Productivity of Grassland

Interannual variation and gradient of NPP

Interannual variation of grassland NPP (See figure 2) was simulated with observed daily climate data for 27 years at 20 sites in center of Inner Mongolia. The average annual NPP of this region is 261.2g/m2/yr. The highest NPP reaches 315 g /m2/yr in 1994 and the lowest down to 213.58 g /m2/yr in 1980, a typical ElNino year. Generally NPP varies with the precipitation and ElNino event. In ElNino year usually accompanied with lower precipitation in this area. However, high precipitation may not induce high productivity. Pre-year precipitation, biomass and base cover also influence the productivity of grassland in next year [O'Connor et al., 2001]. The inter-annual variability of productivity in desert region is higher than that of other grassland types. These results agree to the observation data [Li, 1993; Editorial Board of Inner Mongolia Grassland Resources, 1990].

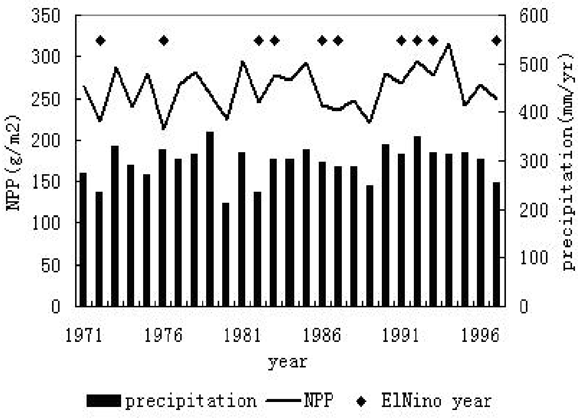

Figure 2 Inter-annual variations of grassland NPP of Inner Mongolia and their relationship with precipitation.

These 20 sites distribute ranging from semi-humid to arid region. The gradient of precipitation is accompanied by the gradient of the grassland productivity (See figure 3). With the incline of precipitation, from 457 mm/yr to 108 mm/yr, the productivity decreased from 421.28 g/m^2/yr to 84.62g/m^2/y. Correlation coefficient between production and precipitation reaches 0.95. In the contrast, the gradient of temperature does not show clear relationship with productivity. Correlation coefficient is –0.34. This result shows that the precipitation is the dominant limitation factor of productivity.

Regional aboveground NPP and biomass

The different types of grassland in Inner Mongolia distribute along the climate gradient in precipitation and temperature from northeast to southwest, namely meadow and meadow steppe in northeast; typical steppe in central region; and desert steppe and desert in southwest. The above ground primary productivity of grassland shows the same gradient with precipitation, decreases with the incline of precipitation from northeast to southwest (See figure 4).

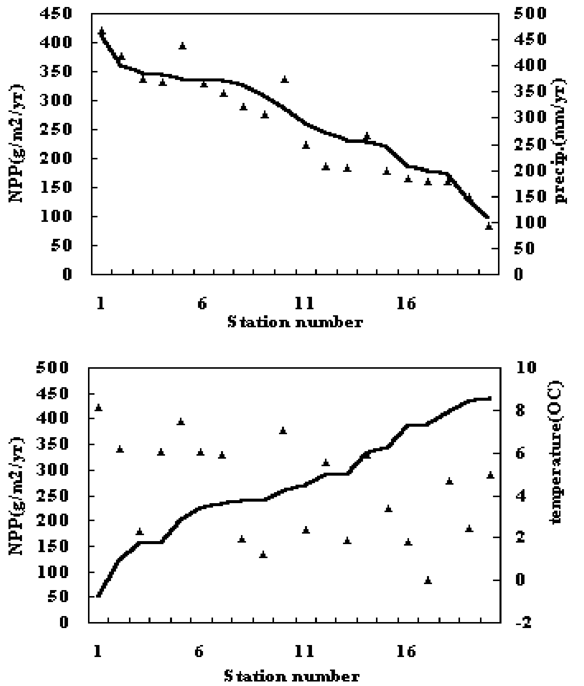

Figure 3 The gradient of precipitation and temperature of 20 grassland sites and simulated NPP. Line represents precipitation or temperature, and triangles represent NPP in the figure.

The specific primary productivity of meadow reaches 247 g/m^2/yr, which is the most productive type among the six types. The productivity of desert is very poor. It only gets 22.2 g/m^2/yr (See table 1). Mean productivity of the 6 communities types of meadow steppe, 8 communities types of typical steppe, 6 communities types of desert steppe, and 1 community type of steppe desert are 198.9 $g/m^2/yr$; 80.76 $g/m^2/yr$, 51.59 $g/m^2/yr$, and 32.4 $g/m^2/yr$, respectively.

Total estimated aboveground net primary productivity of this region is 771.7×10^8 kg/yr (See figure 6). This result agrees to the work of Gao [1995]. The total production of typical steppe is $223.5*10^8$kg/yr. Aboveground biomass is converted to edible aboveground biomass according to the method of Editorial board of Grassland Resources of Inner Mongolia [1990]. Total edible aboveground biomass amounts to $498.1 *10^8$ kg /yr (See figure 6). Typical steppe take up the largest area in the total grassland area, amount to 27.67 Mhm^2. The simulated edible aboveground biomass for typical steppe is $200*10^8$kg/yr. Meadow steppe takes the second place in edible biomass, $141.6*10^8$kg/yr.

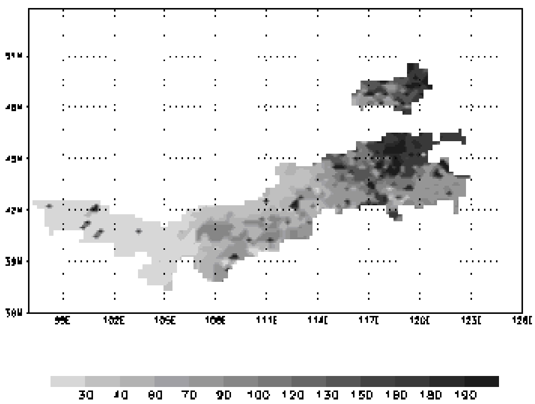

Figure 4 Simulated aboveground NPP of the Inner Mongolia grassland ($g/m^2/yr$).

3.2 Assessment of Livestock Holding Capacity

According to the method of Editorial board of Inner Mongolia Grassland Resources [1990], Grassland livestock holding capacity is estimated as follow equations:

$$L_h=A/N_{ay}$$
$$N_{ay}=D_n*365/P_m$$

Where, L_h is livestock holding capacity, A is available grassland area, N_{ay} is the grassland area needed per sheep in a year. D_n is the daily appetite; P_m is edible biomass of grassland.

The total livestock holding capacity of Inner Mongolia grassland estimated by the model is 45.51 million sheep units (See figure 6). Overall livestock holding capacity for typical steppe reaches 18.3 million sheep units, covering 40% of the total. Meadow steppe takes the second place in livestock holding capacity. Typical and meadow steppe dominate the livestock holding in Inner Mongolia. Meadow has the highest productivity among the six types, however due to smaller in area, the total productivity is not dominant. As to the livestock holding rate meadow is the largest, which amount to 1.3 sheep unit/ hm^2. It is almost 10 times higher than that of 0.14 in desert area.

Table 1. Main communities and estimated aboveground NPP ($g/m^2/yr$) of Inner Mongolian grassland

Index	Community types	ANPP
1	Meadow	247.1
2	*Leymus chinesis* meadow steppe	164.7
3	*Stipa baicalensis*	186.1
4	*Cleistogenes polyphylla*	113.1
5	*Filifolium sibirium*	177.0
6	Carex meadow steppe	148.7
7	Artemisia and semi-shrub	205.1
8	*Leymus chinesis*+ *Stipa grandis*	137.4
9	*Stipa grandis*	117.3
10	*Stipa krylovii*	57.2
11	*Stipa bungenna*	51.8
12	*Cleistogenes squarrosa*	73.2
13	Other species typical steppe	80.6
14	*Artemisia frigida*+ *Poa spp.*	54.4
15	Artemisia spp,+seim-shrub	74.3
16	*Stipa klemenzii*	37.7
17	*Stipa breviflora*	69.9
18	Shrub +*Stipa breviflora*	55.3
19	Other species desert steppe	48.3
20	*Artemisia frigida*+ small grass	49.3
21	Artemisia and semi shrub	49.0
22	Steppe desert	32.4
23	Desert	22.2

4. DISCUSSION

Inner Mongolia semi-arid/arid grassland region is belongs to temperate monsoon climate region. The temperature increases from northeast to southwest, and the precipitation has opposite pattern, decreasing from northeast to southwest. This opposite pattern causes the imbalance of water and energy. It means that the warmer area with less precipitation, and cooler area with more precipitation. 60-75% of the total annual precipitation happens in summer. It varies from 50 to 450mm/yr in Inner Mongolia with high variability [Wang, 1997]. The amount and the time of precipitation are the most important determinants of short and long-term grassland productivity [O'Connor, et al., 2001]. Grassland productivity is greatly constrained by drought.

During 1947-1997, in the livestock increased more than 6 times. Meanwhile the grassland productivity decreased 30-40%. The results of this paper indicate that the overall livestock holding is 102% more than expected in the area. Heavy grazing induces the degradation and the decrease of primary productivity of grassland. Furthermore overgrazing is one of the most important reasons of desertification [Manzano and Navar, 2000]. Regional imbalance in production and consumption is one problem of grassland utilization in Inner Mongolia. Meadow grassland area can holding more livestock than it holds now. Meanwhile, It is seriously overgrazed in typical and desert steppe grassland, where has heavily degraded and desertified. The Chinese government has made management policies to hold back the trend of degradation and desertification of grassland, such as the law of family rangeland; encouraging fencing, etc. Unfortunately, it is very difficult to restore the grassland due to the aridification trend of climate nd the increase of population in North China. It is a real risk of the grassland. However, local people are the most important for in grassland management. Orderly human activities are desired [Ye, et al., 2001].

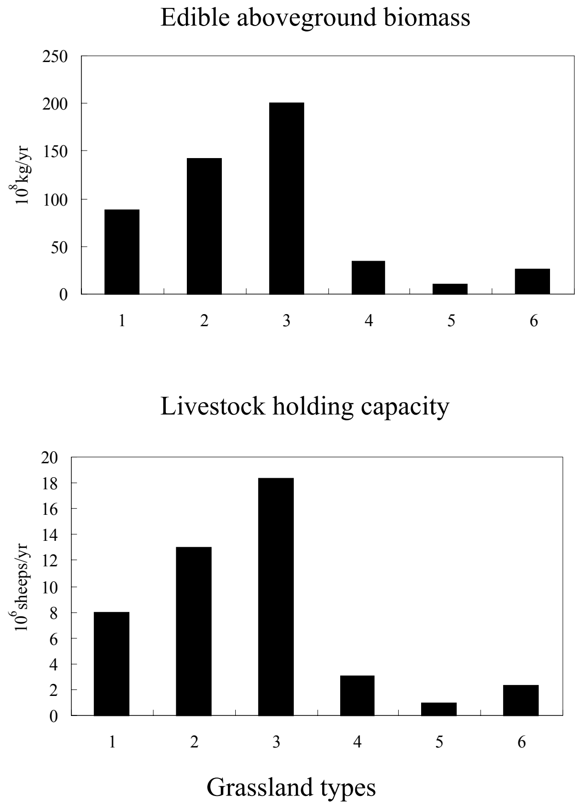

Figure 6. The total edible biomass and livestock holding capacity of Inner Mongolia grassland. Type 1 to 6 represents: meadow, meadow steppe, typical steppe, desert steppe, steppe desert, and desert, respectively.

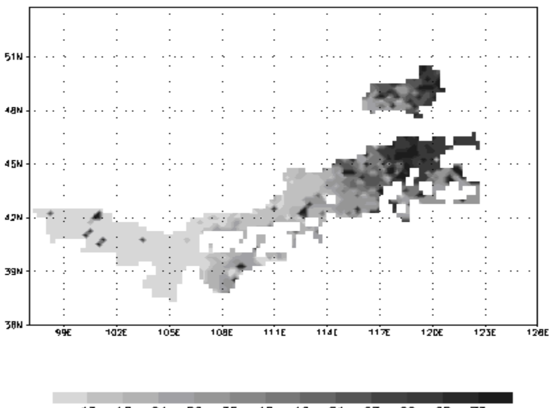

Figure 5. Simulated livestock holding capacity of Inner Mongolia grassland (sheep units/ 625 km^2/yr).

5 CONCLUSION

A framework of impact assessment model is developed based on an Atmosphere- vegetation interaction model (AVIMia). The preliminary results of its application on semi-arid and arid grassland productivity show that:

Productivity of Inner Mongolia semi-arid and arid grassland has high variability, and productivity is mainly most controlled by precipitation. Total aboveground NPP of Inner Mongolia grassland is $771.7*10^8$ kg /yr. Edible aboveground biomass is $498.1 *10^8$ kg /yr. Typical steppe and meadow steppe dominate the production of this region. Total estimated livestock holding capacity is 45.51million sheep unit. The grassland is overgrazed more than 100% in Inner Mongolia. Overgrazing is one of the most important reasons inducing the widespread degradation and desertification. Much work has been done to protect grassland, however orderly human activities are desired.

6. ACKNOWLEDGES

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