Science Press

Online system, http://www.scar.ac.cn
Sciences in Cold and Arid Regions
2010, 2(6): 0514–0521
DOI: 10.3724/SP.J.1226.2010.00514

Modeling dynamic assessment of ecosystem services based on remote sensing technology: A sampling of the Gansu grassland ecosystem

Jian Wang [1*], ZhengHua Chen [2]

1. Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou, Gansu 730000, China
2. School of the Environment, Guangxi University, Nanning, Guangxi530004, China

*Correspondence to: Dr. Jian Wang, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences. No. 320, West Donggang Road, Lanzhou, Gansu 730000, China. Email: wjian@lzb.ac.cn

Received: 21 May 2010 Accepted: 28 July 2010

ABSTRACT

The ecosystem is important because it is the life sustaining system for human survival. Three ecosystem characteristics are: regional particularities, ecosystem complexity and conventional cultural particularities. This paper develops a remote sensing based dynamic model to assess grassland ecosystem service values involving multidisciplinary knowledge. The ecological value of grassland ecosystems is focused on using a remote sensing technique in the model, and setting up the framework for a dynamic assessing model. The grassland ecological services condition and value in 1985 is used as the benchmark. The dynamic model has two adjusting indicators: biomass and price index. The biomass is simulated using the CASA (Carnegie-Ames-Stanford Approach) model. The price index was obtained from statistics data published by the statistical bureau. Results show that the grassland ecosystem value in Gansu Province was 28.36 billion Chinese Yuan in 1985, 140.37 billion in 1999 and 130.86 billion in 2002.
Keywords: ecosystem services value; dynamic assessing model; remote sensing; CASA; biomass; price index

1. Introduction

Ecosystem services provide the elementary foundation and supportive element for human survival and development. It has a high status in the "green GDP (Gross Domestic Product)" and constitutes part of the global economic value, which is also a key assessment indicator when estimating the national and regional sustainable development and potential power.

The ecosystem services concept first appeared in the 1940s when Vogt (1948) first promoted the concept of natural capital when discussing national debt. During the 1970s, the ecological value assessment, whose core is natural capital, received general attention all over the world. Along with global problems of natural resources shortage, environmental deterioration, and rapid increase in human population, many specialists, scholars, governments and international organizations were engaged in this ecosystem services assessment, and tried to bring it into the GDP assessment system. Some natural ecosystems for human "environmental services" functions were listed (Gordon, 1992). One purpose of this work was to remind people that ecological services has great value rather than being worthless, and if services are damaged, people have to spend a great deal of effort to avoid sickness and produce equivalent services. Holdren and Ehrlich (1974) and Ehrlich (1981) discussed the ecosystem functions of soil fertility and gene pool persistence, and how ecological diversity loss would affect ecological services and functions. Westman (1977) estimated that overall globally, the value of natural ecosystem services and functions exceeded 33×10^{12} \$US, close to 2 times of global GDP. Near the end of the 20th century, ecological services assessment became an important topic due to the works of Daily (1997) and Costanza *et al.* (1997). Costanza *et al*. (1997) estimated that 17 ecological services and functions for 16 ecosystems had a total value of 33 268×10^9 \$US/year, about 1.8 times of global GDP, and the assessment was still considered conservative. Pimentel *et al*. (1997) collected and analyzed international natural capital and ecosystem services value research. They compared the international and American biological diversity economic value, and estimated their waste disposal and soil formation. Their conclusion was that the global biological diversity value was 2 928×10^9 \$US, which was less than Costanza *et al.* (1997). The large differences between these results indicate the uncertainty of ecosystem services assessment and processing calculation.

Therefore, assessment research is still in the exploration stage and there are no integrated and general assessment models which consider all of the ecological services and functions. The existing assessment models can not respond quickly to dynamic changes. The dynamic assessment model is expected to calculate the present ecosystem economic value and its variation with time. It is useful in recognizing the value of ecosystem services in order to pay more attention to protection and management. The assessment results can help decision makers when considering the costs of ecosystem services and functions, and to promote the establishment of an ecological compensatory mechanism and management. It is interdisciplinary, involving ecology, resource economics, environmental economics and ecology economics (Zhang, 2002).

In this paper, a dynamic grassland ecological services value assessment model is established based on ecology, economics and remote sensing. The model takes the value of 1985 as a standard, and has two adjustment indicators: biomass and price index. The biomass was calculated using the CASA (Carnegie-Ames-Stanford Approach) model. The price index was obtained from statistics data published by the statistical bureau of China (National Bureau of Statistics of China, 2003). In the ecological value assessment system, the service of food supply is selected as the benchmark of grassland's other ecological service, because it could be exchanged in the market. The non-market ecological services were valued by a questionnaire. Three characteristics of ecosystem services are discussed in this paper: regional particularities, ecosystem complexity, and conventional culture particularities.

2. Study site

The study site is in the Gansu Province, in northwestern China, which is a typical arid and semiarid region (Figure 1). Most of the region in Gansu Province has low precipitation 40–800 mm a year and high evaporation. The precipitation decreases from southeast to northwest, whereas the evaporation increases from southeast to northwest.

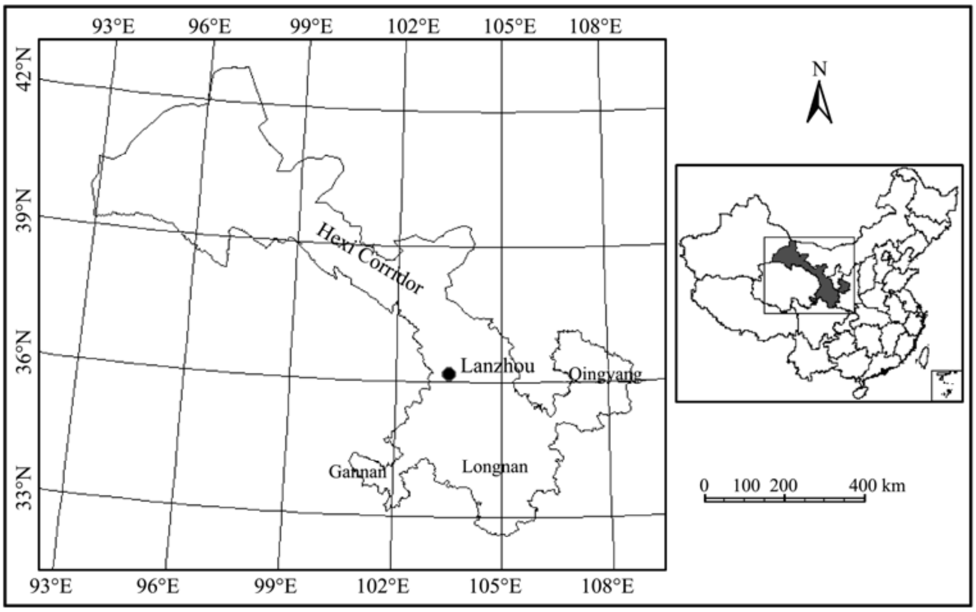

Figure 1 Location of Gansu Province

3. Method

3.1. Three characteristics of ecosystem services

Costanza *et al*. (1997) divided the global ecosystem into 16 categories and 17 ecological services. Every ecosystem has a different effect on the environment. Omar (2002) summarized the elementary goods and services provided by five main ecosystems, and the results emphasize in particular the ecological services. The most likely reason was that each ecosystem had its own ecological services weight; and researchers only emphasize the important services and ignore the unimportant ones. Here, three characteristics for ecosystem services are studied.

3.1.1 Regional particularities

The grassland ecosystems provide services throughout the world. If they lie in different zones, their main ecological services realized by people may not be the same. For example, the grassland adjacent to a desert is often valuable for its soil fixing and avoidance of desertification. This kind of ecological service of grasslands distant from deserts may be ignored.

3.1.2 Ecosystem complexity

Ecosystems have complicated services and functions. Although Costanza *et al.* (1997) listed 17 ecological services, there are still some services that could be added to the list. This list partly represents the focus of people in that period and the development of science and technology.

3.1.3 Conventional culture particularities

Culture, amusement and gene resources have ethnologic, historical and national affects. This would cause different assessments and attitudes of the same ecosystem services. For example, herbs as raw material have a high value in Chinese traditional medicine but their value is not acknowledged in other countries.

Therefore, the classification of the 17 categories ecosystem is appropriate only on a global scale. The regional ecosystem categories should be adjusted according to its regional environmental characteristics. It is necessary to recombine the 17 categories in accordance with Gansu Province actual conditions. As a result, 11 categories of ecological services are included: gas regulation, climate regulation, disturbance regulation, wind erosion control and sand fixture, water resource provision, soil erosion control, waste treatment, gene resistance, food production, raw materials, recreation and culture.

3.2. Model structure

The ecosystem services value has temporal and spatial variation, and also fluctuates with time. They are different if the grasslands ecological conditions are different year after year. Therefore, in this research, the dynamic monitoring model selected the ecological service value of 1985 as the benchmark, taking both biomass and monetary factors into account as adjustment factors (Figure 2).

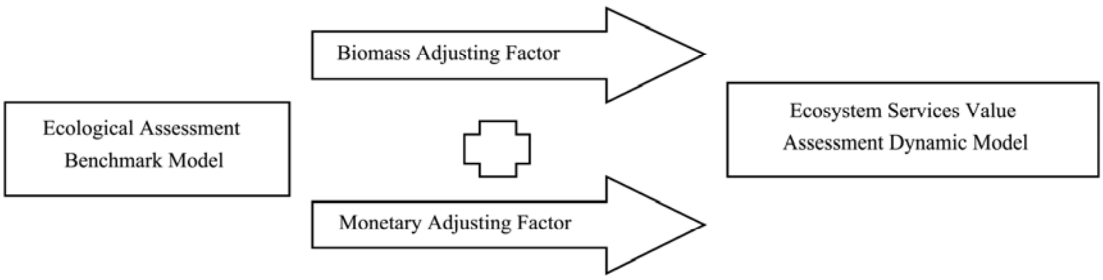

Figure 2 Flow chart of ecosystem services assessment dynamic model

3.2.1 Ecological assessment benchmark model

The ecological value is the overall sum of each ecological value and is represented by the following equation:

$$P_i = \sum_{j=1}^{11} \sum_{i=1}^{n} w_{ij} \quad (1)$$

where P_i is the i ecosystem benchmark value; i is the ecosystem category; j is ecological service; w_{ij} is unit value.

3.2.2 Biomass adjustment factor

The biomass changes with temporal variation, and the biomass is also the biophysics parameter which shows resource quantity. Therefore, the biomass variation is the reflection of plant growth and impact that ecological services provide. It is the main indicator of grassland ecological services value change. The biomass adjustment factor is defined below:

$$\beta = M_m / M_b \quad (2)$$

where M_b is the benchmark year biomass; M_m is the monitoring year biomass. They are calculated using the CASA model.

3.2.3 Monetary adjustment factor

The price of grass as stockbreeding forage changes with time. These changes affect the whole ecological services value and the representation of inflation. The price level is usually estimated by the consumer price index. Therefore, according to the ecosystem services characteristics, the consumer price index of rural areas is defined as price dynamic adjustment factor.

3.2.4 Dynamic model

The ecosystem services assessment dynamic model is presented below:

$$V_i = \beta \times \phi \times P_i \tag{3}$$

where V_i is the ecological services value for a special grassland ecosystem, such as warm woodland, alpine grass field; β is the biomass adjustment factor; ϕ is the price index adjustment factor; P_i is the ecological services benchmark value for a special grassland ecosystem.

3.3. P_i calculation

The unit value P_i is an important element for establishing the benchmark model. Most researchers use the unit value from Costanza *et al.* (1997). These results do not show the ecological services regional characteristics, because the regional unit value is the basis of evaluating a special zone. Summarizing Costanza *et al.* (1997) and UNDP (2002) ecological services categories, the ecological services can be divided into three types: life supporting services like the oxygen provision, and life promoting services like water purification and amusement. From another point of view, ecological services can be divided into two types: direct services and indirect services, and in accordance with direct value and indirect value. The former can be exchanged on the market while the latter can not. The issue then is how to calculate the direct value and indirect value.

3.3.1 Calculation of direct value

Different ecosystems have their own direct services. For the grassland in Gansu Province, its main direct service is food production for livestock, because livestock breeding is the main income for the farmers. Therefore, the grassland direct value can be represented by its livestock capacity, represented by the following equation:

$$P_i = S \times L_i \tag{4}$$

where P_i is the unit food producing value for each grassland, S is the unit sheep price, L_i is the livestock capacity for the ith type of grassland.

3.3.2 Calculation of indirect value

Indirect ecological services value assessment is more complicated. The popular method is from ecological economics, such as the cost analysis method. In this paper, the indirect value is calculated using an expert questionnaire (23 related experts in China) giving the relative weight between the grassland ecosystem direct and the indirect value. The expert questionnaires were normalized and processed. The unit grassland ecological value in Gansu Province was obtained. Table 1 includes the relative value, livestock capacity, and unit ecological value of different type grassland.

Table 1 Relative value, livestock capacity, unit price of different type grassland in Gansu Province

Grassland type	Warm woodland	Warm shrub	Temperate grassland	Temperate deserts	Cold deserts	Cold grassland field	Alpine grass field	Swampy plain
Relative ecological value	17.93	20.67	16.89	12.44	8.65	7.11	11.02	16.18
Theoretical livestock capacity (sheep number/ha)	1.89	0.98	0.66	0.25	0.08	0.42	1.49	2.17
Unit price (Yuan/ha)	5,858.99	2,482.80	1,231.42	324.35	85.27	694.56	3,615.98	6,167.39

3.4. NPP retrieval using remote sensing data

Net Primary Productivity (NPP) is the main plant parameter to estimate terrestrial ecosystem substance circulation and energy flow. It is also the main parameter in analyzing atmospheric CO_2 concentration. The NPP is recognized as the main biomass indicator for an ecosystem. There are numerous NPP models which have their own merits, emphasis, parameter demand and actual applications (Cramer *et al*., 1999). In this research, the CASA (Carnegie-Ames-Stanford Approach) developed by Potter *et al.* (1993) and Field *et al.* (1995) was selected to estimate the NPP.

3.4.1 Results of CASA

CASA is a mechanism model based on the plant physiology process, which is widely used in large scale and global scale carbon circulation estimation research (Potter *et al*., 1993; Field *et al*., 1995). It is a popular and general plant NPP model (Piao *et al*., 2001). The model has two dominating driving variables: APAR (absorbed photosynthetically active radiation) and LUE (light use efficiency), which can be calculated from soil moisture, precipitation, and temperature. CASA is a processing model, complicated and requires many parameters. Satellite data provide increased multi-temporal and multi-spectral data for land surface parameters and other necessary plant and environmental retrieval variables. This information offers powerful tools for the research of NPP distribution, seasonal and annual variation. In this research, 1999 and 2002 were selected as ecological value assessment monitoring years and 1985 as the benchmark year. Thus, the NPP in those three years are calculated. Figure 3 is the NPP map in Gansu Province in 2002.

In table 2 the NPP statistics results are listed. It indicates that the NPP in Gansu province increased during those years. The grassland mean increase rate is 0.06 gC/(m^2 yr).

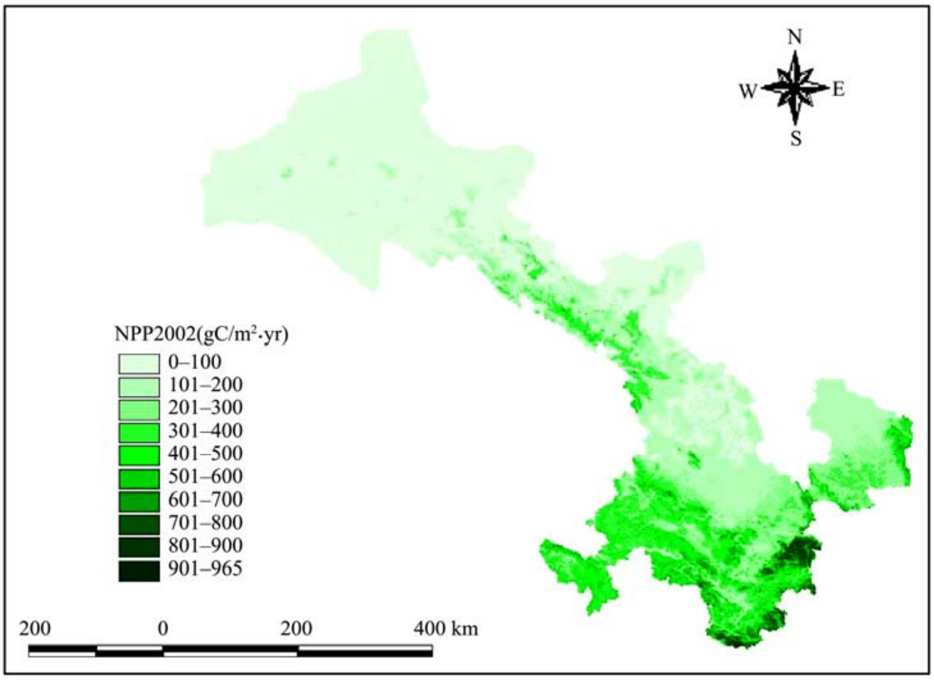

Figure 3 NPP distribution in Gansu Province, 2002(Unit: gC/(m^2 year))

Table 2 Total amount of calculated NPP in Gansu Province (1TgC=10^{12}gC)

Year	NPP in Gansu (TgC/yr)	Grassland NPP in Gansu (TgC/yr)
1985	59.29	22.89
1999	73.67	31.46
2002	94.99	36.33

3.4.2 NPP results validation

Validation is a necessary part of remote sensing retrieval, and it is the foundation and guarantee for the application of the results. Generally speaking, field validation is the most trustworthy way of assessing the retrieval data. Unfortunately, because there are not enough field data, in some cases cross-validation is used instead.

3.4.2.1 Field validation

The 1982–1985 grassland field biomass (including woodland) data were selected for validation. The 185 sample sites included all of the typical types of grasslands and each had an area of 1×1m^2. The dried grass weights are recorded, then multiplied by 0.45 because of the dry matter conversion ratio in order to adapt to NPP calculated results, the unit is gDW/(m^2 yr). The scatter diagram of the field validation data and model calculation data show a good relationship (see Figure 4). The trend curves have a similar shape.

3.4.2.2 Cross-validation with other NPP models

Related model results are selected to validate the CASA retrieval results. The NPP literature in the Heihe Basin is scarce, so the C-FIX NPP calculated by Lu (2003) is chosen for this purpose. The comparison of the results is shown in Table 3.

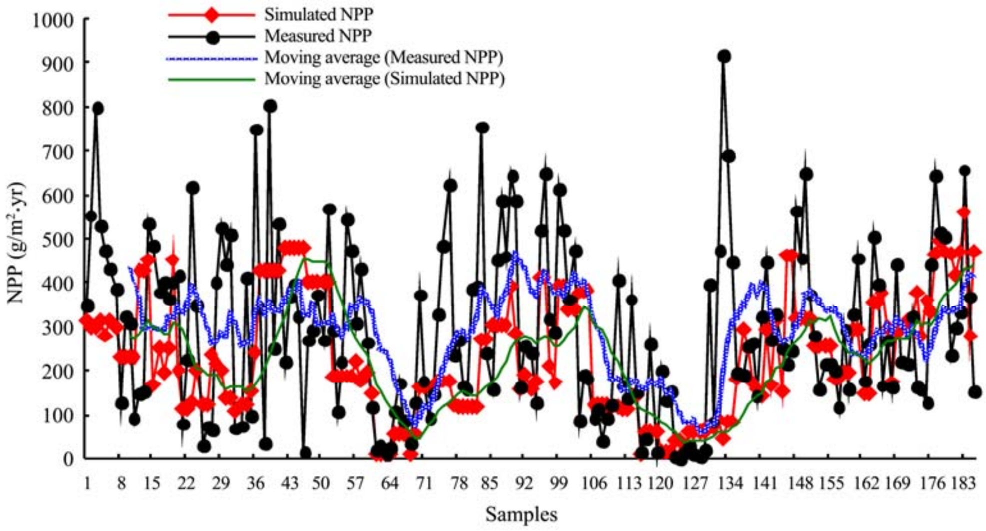

Figure 4 Simulated and field measured NPP data distribution and trend curves

Table 3 Compare Simulated results in Gansu Province

Author	Model	Time	NPP(PgC/yr)	Difference	Note
Wang (2004)	CASA	2002	0.095	11.2%	NPP calculated by C-FIX is overestimated (Lu, 2003)
Lu (2003)	C-FIX	2002	0.119		

4. Results and analysis

4.1. Results

Based on the benchmark year and the dynamic assessment model, the 1999 and 2002 ecological services values were evaluated and their spatial distribution is shown in Figure 5.

The grassland ecological services value in Gansu Province was 28.36 billion in 1985, 140.37 billion in 1999, and 130.86 billion in 2002, showing an increase since 1985. In its ecological services categories, wind protection and sand fixation had the highest value, followed by water and soil maintenance. These two services provide a large contribution to the environment of this province. Statistically, the counties of Subei and Maqu had the highest values with 22.6 billion and 19.1 billion in 1999 respectively. Also, Xiahe and Sunan exceeded 10 billion. The lowest ones were Qinan, Zhangjiachun, Qingshui and Gangu counties. There were 11 counties whose value is less than 100 million in 2002.

4.2. Analysis

4.2.1 Variation of moisture and heat

The grassland ecological value in Gansu Province has increased from 1985. After analyzing the dynamic model structure, the NPP is the key factor for the ecological value in a naturally controlled ecosystem services. The moisture and heat conditions include solar irradiation, temperature, precipitation, atmospheric moisture and atmospheric CO_2 concentration. These factors influence the NPP not only directly but also indirectly through the soil. Normally, the forest NPP has a positive relationship with temperature and evaporation. However, this does not necessarily mean that temperature increases lead to increases in Net Ecosystem Production (NEP). In some cases, it will lead to a decrease in NEP. A temperature increase will speed up the soil organic matter decomposition and CO_2 release into the atmosphere. This process will reduce the ecosystem net carbon storage. It is well known that the annual distribution of temperature and solar total irradiation will affect the plant growing period. It has been proven that precipitation influences the plant regional distribution and NPP according to photosynthesis moisture demand, moisture balance and carbon fixation. Usually, the proper amount of water will prolong the growth period, which increases the NPP. In arid and semiarid areas, precipitation is the main limiting factor. According to the research of Shi *et al.* (2002), Li and Liu (2000) and Shen (2003), in northwestern China (including Gansu Province) the climate has changed from warm and dry to warm and wet over the past 30 years.

4.2.2 Landuse/landcover change

The grassland area has decreased by 34,736 ha in Gansu Province from 1986 to 2000, which is 25.1% of the grassland (Yan, 2003). Why have the grassland ecological services value increased when the area has decreased? Besides moisture and heat factors, the change in landuse/landcover also influences the value. The grassland categories affect the total value significantly. For example, the maximum ecological value of grassland is 70 times higher than the minimum one. 90.649% of the decrease in grassland has changed to farmland. High, middle and low covered grassland account for 22.298%, 34.888% and 42.814% respectively. The new grassland came mainly from woodland, and makes up 63.969%. The new grasslands were mainly high and middle covered grassland, 44.243% and 49.601% respectively, the low covered grassland only 6.156%. In summary:

(1). The new formed grassland came mainly from woodland. These grasslands are usually high and middle covered grassland, with high ecological services values.

(2). Most of the grassland that changed from grassland to farmland were middle and low covered grassland.

(3). Grassland degradation is a crucial factor for the Gansu environment, the process chiefly happens in warm desert regions and the cold arid regions where the ecological values are low.

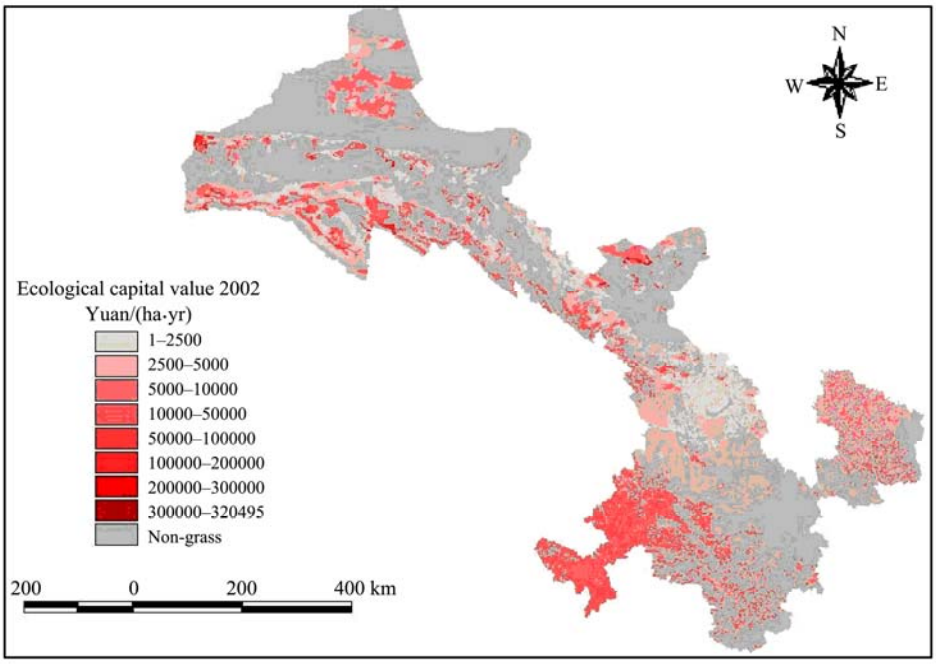

Figure 5 Ecological capital value distribution of grass ecosystem in Gansu Province, 2002 (Unit: Yuan/(ha yr))

5. Discussion

5.1. Problems

The establishment of the model and technology flow has made some progress in using remote sensing data for grassland ecological services value assessment. After an elementary dynamic framework and system is set up, the model runs automatically. The model can achieve the demands of dynamic ecological services assessment on a regional scale and has a high precision. There are however some shortcomings which need improvement through more research.

5.1.1 Quantitative level improvement

The traditional ecological economics was widely used in the establishment of benchmark year models. The expert survey determined the relationship between direct ecological value and indirect value. This method had limitations because of the reliance on the expert's knowledge and experience. To a large extent, the relationship was subjective rather than objective. Although the data were normalized during processing, the personal bias could not be removed. The principal problem is how to improve the ecological value assessment quantitatively. This means improving the indirect value assessment in the dynamic model such as gas regulation, water resources maintenance, and soil fixation.

5.1.2 Validation

The validation is the most important step in earth science research. The ecological services value assessment has difficulties in the validation. The model results can not be tested directly because there are no related ecological value data.

Acknowledgments: This paper was supported by the Global Change Research Program of China (2010CB951403), WP6 of FP7 topic ENV.2007.4.1.4.2 "Improving observing systems for water resource management", the National Natural Science Foundation of China (grant number: 41071227) and the Major Research Plan "Integrated Research on the Eco-Hydrological Process of Heihe Basin" of National Natural Science Foundation of China, topic (grant number: 91025001).

REFERENCES

Costanza R, Arge R, Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, Neill RV, Paruelo J, Raskin RG, Sutton P, Belt M, 1997. The value of the world's ecosystem services and natural capital. Nature, 387: 253–260.

Cramer W, Kicklighter DW, Bondeau A, Moore lili B, Churkina G, Nemry B, Ruimy A, Schloss AL, 1999. Comparing global models of terrestrial net primary productivity (NPP): overview and key results. Global Change Biology, 5(Supp.1): 1–15.

Daily G, 1997. Nature's Service: Societal Dependence on Natural Ecosystems. Island Press, Washington DC.

Ehrlich, P.R. and Mooney, H.A. (April 1993). 'Extinction, Substitution, and Ecosystem Services'.Bioscience 33(4): 248–254.

Field CB, Randerson JT and Malmstrom CM, 1995. Global net primary production: combining ecology and remote sensing. Remote Sensing of Environment, 51: 74–88.

Gordon, IM (Ed), 1992.Nature Function, Spring-Verlag, New York.

Holdren JP, Ehrlich PR, 1974. Human population and the global environment. American Scientist, 63: 282–292.

Li DL, Liu DX, 2000.Gansu Climate. Meteorologic Press, Beijing.

National Bureau of Statistics of China,2003.China Statistical Yearbook

Lu L, 2003. NPP and Carbon Cycling Research in Western China. Doctoral thesis, Graduate School of the Chinese Academy of Sciences.

Omar N, Fu HS, Silva B, Boudard E, Johansson C, Mezzetti P, Mukhopadhyay T, Ponzio R, Segal P, Stewart D, Talib A, 2002. Human Development Report, UNDP report. Oxford University Press, New York.

Piao SL, Fang JY, Guo QH. 2001. Application of CASA model to the estimation of Chinese Terrestrial Net Primary Productivity. Acta Phytoecologica Sinica, 25(5): 603–608.

Pimentel D, Wilson C, McCullum C, 1997. Economic and environment benefits of biodiversity. BioScience, 47: 747–757.

Potter CS, Randerson JT, Field CB, Matson PA, Vitousek PM, Mooney HA, Klooster SA, 1993.Terrestrial ecosystem production: a process model based on global satellite and surface data. Global Biogeochemical Cycles, 7: 811–841.

Shen YP, 2003, Glacier. Meteorologic Press, Beijing.

Shi YF, Shen YP, Hu RJ, 2002. Preliminary study on signal, impact and Foreground foreground of climatic shift from warm-dry to warm-humid in Northwest China. Journal of Glaciology and Geocryology, 24(3): 219–226.

Vogt, W(Ed), 1948. Road to Survival. William Slom, New York.

Wang J, 2004. Modeling Dynamic Assessment on Ecosystem Services Based on Remote Sensing Technology: A sampling by Gansu forest and grassland. Docroral Thesis. Graduate School of the Chinese Academy of Sciences.

Westman WE, 1977. How much are nature's services worth? Science, 197: 960–964.

Yan CZ, 2003. Soil Resource Dynamic Research in Shanxi, Gansu, Ningxia by using Remote Sensing and GIS Technology. Doctoral Thesis, Graduate School of the Chinese Academy of Sciences.

Zhang ZQ, 2002. Measuring Sustainable Development: Theory, Methodology and Application. Doctoral Thesis, Graduate School of the Chinese Academy of Sciences.