Correlation analysis between the biomass of oasis ecosystem and the vegetation index at Fukang

Weiguo Liu[*a,b,c], Wei Gao[b,c,d], Zhiqiang Gao [e], and Xinli Wang[d]
[a]College of Resources and Environment, Xinjiang University, Urumqi, China;
[b]Xinjiang Laboratory of Oasis Ecology, Xinjiang University, Urumqi, China;
[c]International Center for Desert Affairs-Research for Sustainable Development in Arid and Semi-arid Land, Urumqi, China;
[d]USDA UV-B Monitoring and Research Program, Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO, USA;
[e]Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China

ABSTRACT

The information of biomass and productivity of an ecosystem is an essential to evaluate the ecosystem and its environment. This sort of data is usually retrieved from satellite data. However, the accuracy of the retrieval and the algorithms for the retrieval vary with the environment and the type of the ecosystem. In this study, the relationship between the biomass of oasis ecosystems at Fukang, Xinjiang, China and the normalized vegetation index (NDVI) was established in order to derive biomass data of the ecosystem from satellite data. The NDVI data were from the MODIS data with a resolution of 250 meters. Biomass measurements were taken in August, 2003 at 53 sampling sites. Linear and nonlinear regression analyses were performed on this data set. In general, the nonlinear models perform better than the linear models although all of them can successfully generate biomass data with the input of NDVI. Among those nonlinear models, the model $Y = -593.3NDVI^3 + 7509.7NDVI^2 - 1268.9NDVI + 191$ performs the best in terms of the retrieval accuracy, where Y represents the biomass.

Keywords: oasis ecosystem, biomass, remote sensing, vegetation index, Fukang

1. INTRODUCTION

The ecosystem biomass and its fertility have been an important research direction in ecology in the last few decades. A prime database has been established through the endeavors of many researchers who were involved in various research projects[1]. The normalized vegetation index (NDVI) data have been derived from the NOAA/AVHRR satellite data since 1980s to monitor the dynamics of vegetation and the fertility of ecosystems. Good relationships have been established between the biomass of ecosystems and the NDVI as well as between the ratio vegetation index and the green plant biomass[2].

The researches on ecosystem biomass in China began in 1980s. In early works, the Land MSS data were used to derive leaf area index (LAI) of vegetation and biomass[3, 4]. Later, the Landsat TM and NOAA/AVHRR data were more frequently used to monitor vegetation growth and biomass[5-7]. NOAA/AHRR data have been used to study the different type NDVI and the RVI characteristics of northern Xinjiang and to determine the time of turning green for each type of grassland. Different types of natural pasture forage grasslands were defined using the outputs of remote sensing dynamically monitoring pattern of the slope center-section in northern Tiansan Mountain. A unitary linear return model and a nonlinear model were proposed based on a spectrum vegetation index. Li Jianlong and Jiang Ping used "3S" to carry out remote sensing estimation and forecasting of the different grassland types in northern Xinjiang[8, 9]. In the previous researches, the TM or NOAA/AHRR data were commonly used to establish return models based on the relationship between NDVI/RVI and grassland biomass for monitoring vegetation biomass and its spatial and temporal variations. However, the relationship, especially the parameters and coefficients in the models, vary with vegetation type, ecosystem, environment, and geographical location. Accurate retrieval of biomass data at a specific region needs detailed study on the ecological features of this region. This study focuses on the oasis ecosystems at Fukang, Xinjiang, China.

[*] Corresponding author, Email: wgliuxj@126.com, phone: 86-991-8582520

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NDVI and RVI data were derived from MODIS satellite data. Biomass measurements were taken at 53 sites in August, 2003. Relationships between NDVI/RVI and the biomass were well established through linear and nonlinear regression analyses. Linear and nonlinear models were constructed to reproduce the biomass measurements using NDVI/RVI data. Coefficients of the models were determined by a best fitting technique specifically for this region. Satisfactory results were obtained from these models.

2. MATERIALS AND METHODS

2.1 Study area

Fukang is located at the northeastern foothill of Tianshan Mountain, the center of Eurasia (E87°46' -88°44', N43°45' - 45°29'). The land area is 862,800 km^2, which is a combination of agriculture and pasture farm. The oasis area is 30,700 km^2, surrounding the oasis in the region of general wilderness. The vegetation of the oasis ecosystem consists of farmland and wilderness. From south to north the region is covered by Pipa firewood wilderness, juiciness salt firewood class wilderness, fan reason Chinese tamarisk clump, sand dune's Sacsaoul, and white sacsaoul wilderness. Generally speaking, the vegetation productivity has the direct ratio to the number of animals sustainable, and is related to the plant type, desert variety, desert degree of coverage size, desert adult plant's height, and so forth. These factors are also related to the growth season, temperature, and rainfall[10].

2.2 Data

Biomass measurements used in this study were taken in August, 2003 from 53 sampling sites, which evenly distributed in the Fukang oasis ecosystems. The reason to take the measurements in August is that the plants are usually the most exuberant during this time of a year. The measurements were made as follows. Firstly, the growth area of 250m×250m was selected to be approximately evenly distributed, which had the vegetation community representation and the measurable region. This area was divided into 10m×10m grids in view of the bush or the micro-phanerophyte either bush or half bush 5m×m5 spots. Secondly, a square of 1m×1m was randomly selected from each spot. Plants in the square were harvested. The plants were cut neatly along ground to weigh. Finally, the harvested plants from each square are placed into the drying oven at 105 °C to dry for 8-10 hours. Then they were weighed to obtain the biomass measurements. The quadrant geographical position was determined by using GPS. Figure 1 shows the spatial distribution of the 53 quadrants.

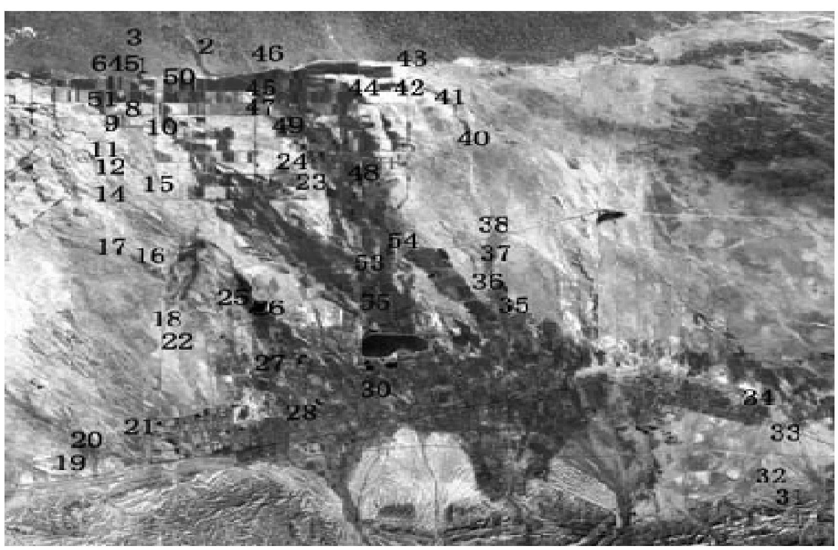

Figure 1 The locations of the sampling sites.

MODIS satellite data were obtained from the Xinjing Meteorological Bureau on the clear days in August, 2003. The data, which were taken when the Sun was at the position with the highest solar elevation angle, were used in this study.

2.3 Methods

Biomass measurements at the squares were averaged using a geometric averaging approach to obtain the biomass for each grid. Regression techniques were employed to construct linear and nonlinear statistical models reflecting the relationship between the NDVI/RVI and the biomass.

3. CORELATION ANALYSIS

3.1 Vegetation index

The vegetation index is derived from satellite data of several wavelength bands by using linear and nonlinear algorithms. The index reflects the abundance and vigorousness of green plants on the earth. It contains the synthetic information of green vegetation's leaf area index (LAI), degree of cover, chlorophyll content, green biomass as well as the absorbed photosynthesis effective radiation (APAR)[11]. Usually, the vegetation index may represent more than 90% of vegetation information and it eliminates the influence of the external factor, such as remote sensing calibration as well as atmospheric, observational, and illumination geometric conditions. Thus it represents well the growth condition and the spatial distribution of the green plants and it can macroscopically reflect the biophysical characteristics of the green plants biomass and degree of cover. Thus it has been widely applied in land utilization cover survey, vegetation cover density assessment, and crop recognition[13].

More than 20 vegetation indices have been proposed and used at present[11]. Among which, NDVI, RVI, DVI, MSAVI are the commonly used. They were proposed according to different research area characteristics and the different research objects of the researcher. The research has indicated that there is good agreement between green plants' degree of cover and the biomass[12]. Generally speaking, NDVI and MSAVI are sensitive to the growth condition and the spatial distribution of green plant density and they are influenced strongly by the soil properties. They are suitable for the early growth stages of crops and in the region with low degree of vegetation coverage. They are good vegetation indices for the vegetation research of arid semi-arid oasis ecosystems.

3.2 Vegetation index retrieval

According to vegetation's physiological and ecological characteristics in the study area, we used remote sensing image processing software ENVI and geographic information system software Arc view and Arc info to retrieve the NDVI, RVI, DVI, and MSAVI vegetation indices in August, 2003, at Fukang, Xinjiang, China from the MODIS image data. The equations used in the retrieval are as follows[15]:

$$NDVI = \frac{b_2 - b_1}{b_2 + b_1},$$

$$DVI = b_1 - b_2,$$

$$RVI = \frac{b_1}{b_2},$$

$$MSAVI = \frac{2b_1 + 1 - \sqrt{(2b_1 + 1)^2 - 8(b_1 - b_2)}}{2},$$

where b_2 and b_1 represent the near-infrared wave band and the red wave band of the MODIS image, respectively.

3.3 The correlations between vegetation index and biomass

The four vegetation indices (NDVI, RVI, DVI, and MSAVI) and the ecosystem biomass measurements were used to carry out correlation analysis. The purpose was to examine the closeness between the vegetation index and the biomass, to derived correlation equations between vegetation index and biomass, and to determine if the overall biomass in the study region can be retrieved based on these equations from the vegetation index data.

A close correlation exists between vegetation index and biomass. Therefore, it is feasible to establish remote sensing monitoring model of oasis ecosystem plant biomass based on vegetation index data. In order to obtain a good performance model, linear and nonlinear regression analyses were conducted and the results are presented in Table 1.

Nonlinear regressions include polynomial, S-shaped, exponential, and logarithmic models. In the table, Y is the biomass; R is the comprehensive correlation coefficient; and R^2 is the R-square.

1. In the linear models, the best fit was obtained by using NDVI with a square correlation index value of 0.743 and an R value of 0.862. The next closer fit was obtained by using MSAVI. The R-square was 0.726 and the R value was 0.852. The lowest accurate fittings occurred when DVI and the RVI's were used. Their R values are 0.807 and 0.810, respectively. One thing that should be noted is that a linear model can be used to derive vegetation biomass from vegetation index data.
2. In the second order polynomial models, the best fit was obtained by using MSAVI. The R and R-square values were 0.864 and 0.746, respectively. The next was obtained by using NDVI with an R-square of 0.743 and an R value of 0.862. The lowest accurate fitting occurred when DVI's was used. The R was 0.807. One thing should be pointed out that the second order polynomial models had certain improvements over linear models (except the DVI index) in fitting accuracy.
3. In the third order polynomial models, the best fit was obtained when NDVI, MSAVI, the RVI were used. The models using these three indices had almost the same coefficients and the R values and R-square values were the same (0.867 and 0.752, respectively). The worst fitting occurred when DVI was used with an R value of 0.777 and an R-square value of 0.604. The regression equations have statistical significance. Compared with the aforementioned models, the third order polynomial models in general had certain improvements over the linear and second order polynomial models (except the DVI index) in fitting accuracy.
4. The best S-shaped curve fitting was obtained by using MSAVI with an R value of 0.861 and a R-square value of 0.741. A good fitting was also obtained when NDVI was used. The R value and R-square value were 0.860 and 0.740, respectively. The values of DVI and RVI's were greater than 1 and, therefore, they could not be used in the S-shaped curve fitting.
5. In the exponential models, the best fit was obtained by using MSAVI. The R value and R-square value were 0.852 and 0.726, respectively. The R value was 0.826 when NDVI was used. Lower fitting accuracy occurred when RVI and DVI were used. In general, the fitting precision of the exponential models was lower than other models.
6. In logarithm models, the best fitting precision between vegetation index and vegetation biomass was obtained by RVI. The R value and R-square value were 0.857 and 0.734, respectively. The regression equation has statistical significance. The worst fitting occurred when DVI was used with an R value of 0.748 and an R-square value of 0.559. The models using NDVI, MSAVI had almost the same coefficients and fitting precision.

From the above analysis and the results presented in Table 1 we can conclude that the third order polynomial model, $Y = -5593.3NDVI^3 + 7509.7NDVI^2 - 1268.9NDVI + 191$, has the highest fitting precision. This conclusion agrees with the results of Qi[14]. It can be also seen that different vegetation indices perform different when they used in different models. For example, the RVI performed the best in exponential models and MSAVI performed the best in logarithm models. The lowest fitting accuracy occurred in both exponential and logarithmic models when DVI was used. In addition the NDVI performed the best while the DVI the worst in different models generally.

4. CHARACTERISTICS OF BIOMASS DISTRIBUTION

The MODIS multi- spatial and temporal phantom NDVI vegetation indices in the study area were obtained through computation analysis. The model $Y = -5593.3NDVI^3 + 7509.7NDVI^2 - 1268.9NDVI + 191$, which has the highest fitting precision as concluded in the previous section, was used to derive biomass from the NDVI data. The results of derived biomass in the study area are shown in Figure 3. The spatial distribution of biomass at Fukang exhibited, in general, the pattern of higher in the inner part and lower in the outer areas, especially in the oasis ecosystems. The increases of biomass occurred mainly from the end of May to August. The biomass reached its maximum valued in July and August when the plants were in their most vigorous growth stage. The biomass started to decrease in August. This is the main feature in oasis ecosystems. The characteristics of crop growth and farming practices in the oasis ecosystems produced more biomass in the ecosystems. In addition, the water resource in the ecosystem helped the biomass accumulation. On the other hand, much less biomass was produced in the desert areas around the oasis ecosystems because of the shortage of water, plant, and agricultural management.

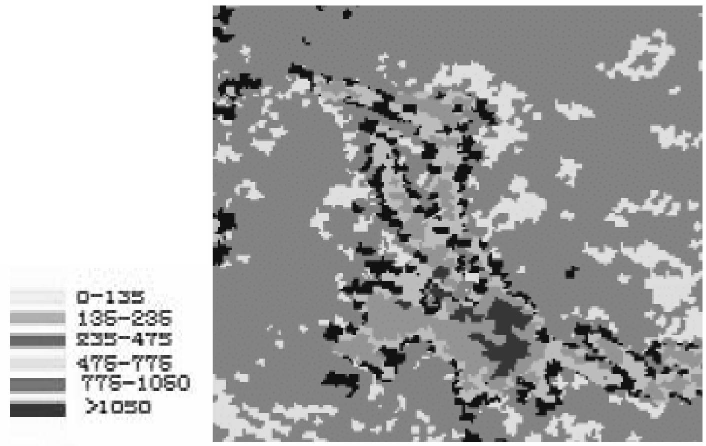

Fig.3-1 Spatial distribution of biomass in June

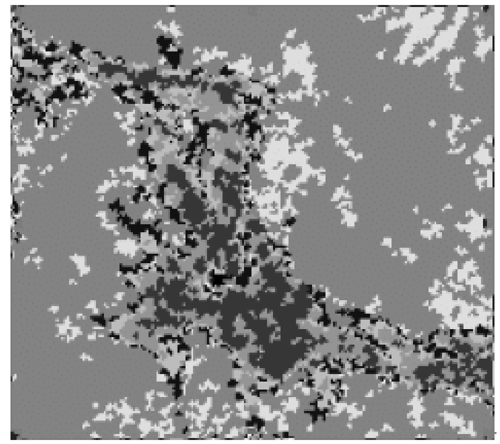

Fig.3-2 Spatial distribution of biomass in July

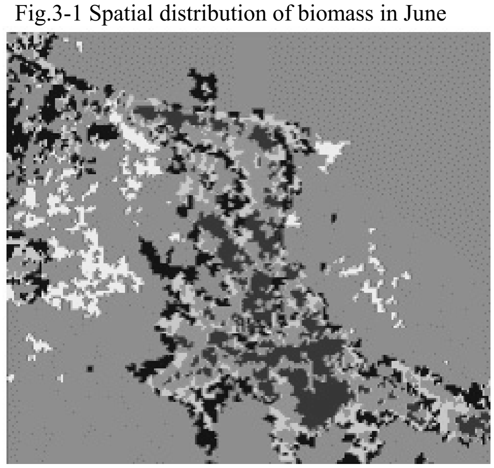

Fig.3-3 Spatial distribution of biomass in August

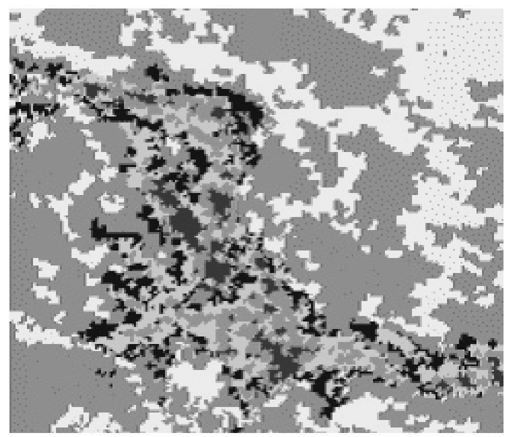

Fig. 3-4 Spatial distribution of biomass in September

Table 1 Models and their regression results

Curve type	Regression equation	R	R^2	Signif F
Straight line model y=ax+b	RVI $Y=172.023RVI+0.0005$	0.810	0.656	0.0001
	NDVI $Y=1640.6NDVI-111.5$	0.862	0.743	0.0000
	MSAVI $Y=1577.9MSAVI-298.9$	0.852	0.726	0.0000
	DVI $Y=7.1232DVI-245.5$	0.807	0.651	0.0000
Conic section model $y=ax^2+bx+c$	RVI $Y=-25.6RVI^2+392.57RVI-310.05$	0.849	0.721	0.0000
	NDVI $Y=210.4NDVI^2+1460.9NDVI-84.2$	0.862	0.743	0.0000
	MSAVI $Y=1535.4MSAVI^2-59.6MSAVI+58.3$	0.864	0.746	0.0000
	DVI $Y=0.0014DVI^2+6.795DVI-229.49$	0.807	0.651	0.0000
Cubic model $y=ax^3+bx^2+cx+d$	RVI $Y=7.594RVI^3-138.02RVI^2+855.57RVI-789.50$	0.867	0.752	0.0000
	NDVI $Y=-5593.3NDVI^3+7509.7NDVI^2-1268.9NDVI+191$	0.867	0.752	0.0000
	MSAVI $Y=-4177.5MSAVI^3+8131.4MSAVI^2-3196.7MSAVI+500$	0.867	0.752	0.0000
	DVI $Y=-0.0002DVI^3+0.0925DVI^2-3.0656DVI+81.39$	0.777	0.604	0.0000
S curve model $Y=ae^x+b$	RVI --	-------		
	NDVI $Y=1050.4e^{NDVI}-1064.8$	0.860	0.740	0.0000
	MSAVI $Y=919.1e^{MSAVI}-1064.6$	0.861	0.741	0.0000
	DVI ---			
Exponential curve model $Y=bm^x$	RVI $Y=111.97*1.442^{RVI}$	0.647	0.417	0.0000
	NDVI $Y=83.96*37.965^{NDVI}$	0.826	0.682	0.0000
	MSAVI $Y=54.35*34.413^{MSAVI}$	0.852	0.726	0.0000
	DVI $Y=60.89*1.02^{DVI}$	0.737	0.543	0.0000
Logarithmic curve model X=a*lny+b	RVI $Y=-25.26+613.4lnRVI$	0.857	0.734	0.0000
	NDVI $Y=1137.2+543.9lnNDVI$	0.825	0.681	0.0000
	MSAVI $Y=1048.5+700.1lnMSAVI$	0.807	0.651	0.0000
	DVI $Y=-2432.7+644.6lnDVI$	0.748	0.559	0.0002

5. CONCLUSION

We have presented the correlations between vegetation index and biomass, established regression models for deriving biomass from satellite data, and analyzed the spatial and temporal distributions of biomass at Fukang, Xinjiang, China, using the biomass data sampled in August, 2003 and the NOAA satellite data. A close relationship between actual plant biomass in the research area and the remote sensing vegetation index was found. Therefore, it is feasible to establish remote sensing monitor model of oasis ecosystem vegetation biomass based on the vegetation index. Linear and nonlinear regression analyses were conducted in order to find a model with higher fitting precision. In general, the fitting precision of nonlinear models is higher than that of linear models. The derived biomass data using nonlinear models agree more closely with the measurements. The vegetation indices performed differently in different models. For example, the RVI performed the best in exponential models while the MSAVI performed the best in logarithmic models although the DVI performed the worst in both of them. In general, The NDVI outperformed over others in polynomial models. The third order polynomial model with NDVI as its dependent variable, $Y = -5593.3NDVI^3 + 7509.7NDVI^2 - 1268.9NDVI + 191$, has the highest fitting precision with measurements.

The biomass at Fukang was distributed mainly in the oasis ecosystem and much less biomass was scattered around the ecosystems in the desert areas. In a year, the biomass increased from the end of May until August. It reached its maximum amount in July and August when the plants were in their vigorous growing stage. The amount of biomass started to decrease in August. This spatial and temporal distribution feature was established by the characteristics of crop growth, farming practices, and the water resource in the oasis ecosystems.

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