Spatiotemporal Variations of NDVI in Xinjiang Tianchi Bogda Peak natural reserve from 1990 to 2015

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Abstract: The spatial characteristics of NDVI of Xinjiang Tianchi Bogda Peak natural reserve are analyzed by using the AVHRR and MODIS NDVI date from 1990 to 2015. The temporal change of NDVI of this natural reserve is analyzed by using one variable linear regression and the correlation analysis. The results indicate that, the NDVI values are higher in north than those in south in 2015. As the altitude increases, the NDVI first increases, and then decreases. According to the grading results, the proportion of the moderate vegetation grade is larger than others. From 1990 to 2015, the change rate of NDVI is 0.0171/5a (p > 0.05). The NDVI of this natural reserve shows an increasing tendency, except for 2005-2010. The results of this study provide a theoretical basis for the management department to fully understand the vegetation status in the natural reserve, and to make policies and measures accordingly.

1. Introduction
With the economic development of China, the economic development activities within natural reserves are increasing day by day. Some natural reserves are overloaded and utilized, causing severe degradation of ecosystems, resulting in serious damage to ecosystem functions in natural reserves. The decline of ecosystem health directly threatens the sustainable development of natural reserve. Vegetation is an important part of protected area ecosystem, vegetation condition reflects the health status from the an important aspect. NDVI (Normalized Difference Evaluation Index) is an aspect of characterizing vegetation status. Many researchers have investigated the NDVI of the study area from different aspects and also analyzed the vegetation status, changing characteristics, causes and dynamics of the changes in specific research areas1[8]. There is yet little research on the vegetation status of Xinjiang Tianchi Bogda Peak natural reserve.

According to the characteristics of the study area, this study analyzes the spatial variation of the NDVI and its characteristics with altitude and different landscape zones; a linear regression and a correlation coefficient model are used to study the NDVI of time series change and correlation with time change from the whole protected area and single pixel scales, and the significance of correlation is also
tested. The distribution and variation characteristics of NDVI in different functional areas are also studied. Based on the above analysis, the vegetation distribution and time series change characteristics of the protected area are obtained, which provide theoretical support for the relevant departments to conduct effective management for the area.

2. Overview of the study area
Tianchi Natural Reserve, a provincial reserve established in 1980 with the approval of the people's Government of Xinjiang Uygur Autonomous region, was renamed the Xinjiang Tianchi Bogda Peak natural reserve, in 2007, located at the northern foot of Bogda, East Tianshan Mountain, is a forest ecosystem type natural reserve, the primitive complete temperate mountain forest ecosystems, the typical complete vegetation vertical belts, the rare and endangered wild animals and their habitats as well as the rich glaciers, the rivers, and lakes are the main protected objects. The protected area has a complete and obvious vertical belt structure of natural landscape, and the ecosystem is a prominent regional representation in the arid area of the hinterland of Asia. It was approved by UNESCO to be integrated into the World Network of Biosphere Reserves in 1990. The ecological status is extremely important.

3. Data sources
The data of 1990 - 2015 were collected, e.g., every five years of NDVI, boundary of the protected area and so on. The NDVI data for 1990 and 1995 are annual averages of AVHRR NDVI with a spatial resolution of 1000 m. The NDVI data for 2000 - 2015 are annual averages of MODIS NDVI with spatial resolution of 250 m. Boundary of the protected area download from WDPA website. Land use classification data from satellite GF1 with a spatial resolution of 8 m.

4. Research method
4.1. One variable linear regression model
This study uses the one variable linear regression method to analyze the variation trend of NDVI over time, and establishes the one variable linear regression equation between y and x.

\[ y = a + bx \]  \hspace{1cm} (1)

Where a is a constant, the intercept of the formula; b is the rate of change, and its formula is as follows:

\[ b = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sum (x_i - \bar{x})^2} \]  \hspace{1cm} (2)

Where x represents time, y represents the NDVI value, b is the NDVI change trend over time. When b > 0, indicates that the NDVI value increases with time t, otherwise it shows a declining trend. A larger \( |b| \), indicates a more obvious trend.

4.2. Correlation analysis
Correlation analysis is used to study the relationship between NDVI change and time, the correlation coefficient r is expressed as:

\[ r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}} \]  \hspace{1cm} (3)
Where $\bar{x}$ and $\bar{y}$ are the mean values of variables $x$ and $y$, respectively, $-1 \leq r \leq 1$, when $r = 0$, the two variables are not correlated, when $r > 0$, the two are positively correlated, and vice versa.

During the correlation analysis, the significance level of correlation coefficient between NDVI and time change is determined by checking the significance test table of correlation number. According to the confidence level $\alpha$ and the critical value of correlation coefficient from the critical value table, as shown in Table 1. The correlation coefficient is tested against the level of 0.05 and 0.01. When $r > 0$, $0 < r < 0.8114$ ($p > 0.05$), the trend of NDVI increasing with time is not obvious; $0.8114 < r < 0.9172$ ($0.01 < p < 0.05$), the increasing is obvious; $r > 0.9172$ ($0.01 < p < 0$), the increasing is very obvious. When $r < 0$, $-0.8114 < r < 0$ ($p > 0.05$), the decreasing of NDVI with time is not significant, $-0.9172 < r < -0.8114$ ($0.01 < p < 0.05$), the decreasing is significant, and the decreasing of $r < -0.9172$ is very significant.

### Table 1. Critical value of correlation coefficient

| Degree of freedom | Probability level 0.05 | Probability level 0.01 |
|-------------------|-------------------------|-------------------------|
| 4                 | 0.8114                  | 0.9172                  |

5. Result analysis

5.1. Spatial distribution analysis of NDVI

The value range of NDVI for the whole protected area in 2015 was -0.0161-0.7684. According to the condition of the natural reserve and the common use of NDVI, NDVI is divided into 6 levels [9]. Different levels correspond to different vegetation conditions, the range of NDVI values of each level and the number of pixels of different levels and their proportions are shown in Table 2. The spatial distribution of levels is shown in Figure 1.

### Table 2. NDVI Grading results

| NDVI range | Bare land | Sparse vegetation | Less vegetation | Moderate vegetation | Dense vegetation | Very dense vegetation |
|------------|-----------|-------------------|-----------------|---------------------|-----------------|----------------------|
| $NDVI \leq 0.1$ | 889       | 452               | 1079            | 1971                | 1529            | 282                  |
| $0.1 < NDVI \leq 0.15$ | 452       | 1079              | 1971            | 1529                | 282             |                      |
| $0.15 < NDVI \leq 0.3$ | 1079      | 1971              | 1529            | 282                 |                 |                      |
| $0.3 < NDVI \leq 0.45$ | 1971      | 1529              | 282             |                     |                 |                      |
| $0.45 < NDVI \leq 0.6$ | 1529      | 282               |                 |                     |                 |                      |
| $NDVI > 0.6$ | 282       |                   |                 |                     |                 |                      |

As can be seen from Table 2 that the number of pixels with moderate vegetation level accounts for the largest proportion, which is 31.78%, indicating that moderate vegetation widely distributes in the natural reserve, followed by dense vegetation, and the smallest distribution is very dense vegetation, with its proportion of pixels is only 4.55. It can be seen from Figure 1 that the NDVI value is low in the south yet high in the north. The vegetation status in the northern region is above the moderate vegetation level, while the southern part of the natural reserve is mainly bare land and sparse vegetation. Based on the analysis of the spatial distribution of various types of land cover shown in Figure 2, the surface cover of the southern region is dominated by non-vegetation permanent glaciers and bare rock texture, and the NDVI value is basically less than 0.15. The northern area is dominated by vegetation types such as forested land, sparse forest land, and high-coverage grass. Therefore, the NDVI is mainly greater than 0.45, and the vegetation status is good.
Figure 1. NDVI values and levels of spatial distribution

Figure 2. Distribution of land cover types in natural reserve
5.2. NDVI changes with altitude
The altitude of the study area is between 1291 - 4582 m, and the altitude of the natural reserve is divided into four zones, namely, glacier and snow zone, mountain coniferous forest zone, alpine subalpine zone, and low mountain zone\[^{10}\]. Due to different natural conditions like climates and soils, different landscape belts have different types and numbers of vegetations, and their NDVI values are also different.

With an interval of 200 m, the average NDVI value in this interval is the representative value, and the curve of DEM and changes of NDVI values are obtained, as shown in Figure 3.

As can be seen from Figure 3 that the NDVI value of vegetation first increases and then decreases with the altitude of DEM, which is roughly consistent with the distribution of landscape belts. When the DEM altitude is less than 2291 m, the NDVI value increases with the increase of the altitude, from about 0.38 to 0.54. Between 2491 and 4582 m, the NDVI value decreases with the increase of altitude, from about 0.54 to about -0.001.

5.3. Characteristics of time change in natural reserve
For the purpose of studying the change of NDVI over time in this natural reserve during the last 25 years, statistical analysis of NDVI data for every five years (between 1990 - 2015) on natural reserve is conducted, yielding average annual NDVI in 1990, 1995, 2000, 2005, 2010 and 2015. Annual NDVI trends over time and its regression analysis can be obtained, as shown in Figure 4.

As can be seen from Figure 4 that the annual average NDVI fluctuates between 0.22 and 0.33 from 1990 to 2015. Large annual NDVI value appears in 2005 and 2015, which is both 0.33. While the lowest one is in 1990, which was 0.22. The slope $b = 0.0171 > 0$, indicates that the average annual NDVI has an increase of $0.0171/5$, indicating that the vegetation coverage has been developing in a good
direction. As for the range of change, from 1990 to 1995, it is larger than that of other inter-annual periods. The NDVI increases by 0.08, and the range of changes in the remaining inter-annual periods is below 0.02.

5.4. NDVI changes between adjacent years
In order to obtain the change of the NDVI value between adjacent years in the protected area, we use the ARCGIS grid calculator to obtain the increase and decrease of the NDVI between adjacent years in the protected area, as shown in Table 3.

Based on the existing rainfall data, the annual rainfall in the natural reserve in 1995 is 761 mm, increased from 740 mm of 1990. From Table 3, it can be seen that 99.48% of the entire area has an increasing NDVI during that year. This result is consistent with Du’s study[11]. From 2005 to 2010, the NDVI of the natural reserve mainly decline. Since the beginning of this century, China’s economy has achieved unprecedented development, people’s living standard has been greatly improved, and the demand for tourism, production and living materials has continued to expand. This expansion has brought some excessive development of the tourism industry, deforestation, and excessive grazing[12-14], which ultimately results in the deteriorating ecological environment. From the perspective of vegetation, it deteriorates from 2005 to 2010, the NDVI value mainly declines. In order to curb the development of this trend, the protected area implements a comprehensive grazing prohibition in 2012[15]. It improves the vegetation status of the area from 2010 to 2015, and the NDVI in most areas returns to an increasing state.

Table 3. Changes in NDVI between adjacent years

| Statistical indicators | Years                  | 1990-1995 years | 1995-2000 years | 2005-2000 years | 2010-2005 years | 2015-2010 years |
|------------------------|------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Increasing percentage  | 99.48%                 | 54.86%          | 75.23%          | 33.63%          | 73.64%          |
| Decrease percentage    | 0.52%                  | 45.14%          | 24.77%          | 66.37%          | 26.36%          |
| Variation range        | -0.01 - 0.18           | -0.32 - 0.35    | -0.15 - 0.20    | -0.24 - 0.17    | -0.22.75 - 0.19 |

6. Conclusions
(1) From the perspective of the NDVI spatial distribution of the natural reserve, the vegetation status in the northern part of the natural reserve is better than that of the southern area. The vegetation types land cover in the northern areas are mainly high-coverage grass and woodland, while the southern area is mainly permanent glaciers and bare rocks. According to the proportion of the pixels number in different levels of vegetation conditions, the number of moderate vegetation pixels accounted for the largest proportion of the total pixels, and the smallest is very dense vegetation. The mountain coniferous forest belt has better climate and soil conditions, so its vegetation status is good. In other landscape belts, with the increase of DEM altitude, the NDVI value first increases and then decreases. The land cover types of the experimental zone and the buffer zone are mainly vegetation, dense vegetation and very dense vegetation are also located in here. Therefore, the vegetation conditions in the experimental area and buffer zone are better than those in the core area.

(2) From the perspective of temporal changes, from 1990 to 2015, the overall NDVI of the study area increased slightly, that is, the overall vegetation status was growing better; the slope b of the NDVI change of the entire area and each functional area is greater than 0, indicating its NDVI is growing. Based on the change of NDVI between adjacent years, from 1990 to 1995, due to the increase of precipitation, the NDVI in 99.84% of the protected area increased. From 2005 to 2010, the excessive development and tourism industry as well as the deforestation and over grazing have caused a decrease
to the NDVI. According to the analysis of pixels, pixel number with $b > 0$ (change of NDVI $> 0$) is greater than that of $b \leq 0$, and the increase is basically insignificant.

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