Effects of Biological Soil Crust on Photographic Measurements of Vegetation Coverage Postprint

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Abstract

The accuracy of vegetation coverage measurement significantly influences the scientific validity of research conclusions. In arid and semi-arid degraded grassland regions, particularly in mining areas subjected to severe disturbance, the development of Biological Soil Crust (BSC) exerts certain impacts on vegetation coverage measurement due to its spectral and color similarity to green vegetation. Taking the Yimin Open-pit Mining Area as the study region, we collected four groups of quadrat photographs each for moss crust, lichen crust, and algae crust from both the west dump and inner dump (with each group containing one photograph before watering and one after watering), along with one group of quadrat photographs without crust as a control. Employing the digital photography method to extract vegetation coverage, we applied different data processing approaches (maximum likelihood classification and RGB threshold method), established comparative experiments, analyzed whether BSC influences vegetation coverage measurement, the magnitude of such influence, whether the influence degree is affected by BSC water content, compared the merits and demerits of various conventional processing methods, and investigated whether the effect of BSC on extracted vegetation coverage values can be eliminated by integrating texture features with color information. Research conclusions: 1) When extracting vegetation coverage using conventional data processing methods based on photography, the presence of BSC leads to overestimated vegetation coverage values, with moss crust and lichen crust showing more significant impacts after water absorption than before, while algae crust exhibits the opposite pattern; 2) Among BSC at three successional stages, overestimation is most pronounced in quadrats containing moss crust, followed by lichen crust, whereas the pattern in quadrats with algae crust is not evident; 3) Higher BSC coverage within quadrats corresponds to lower vegetation coverage and less accurate vegetation coverage measurement; therefore, attention must be paid to BSC influence when studying grassland mining regions with low herbaceous vegetation coverage and developed crusts; 4) Attempts to propose improved extraction methods through texture information application revealed that pure texture classification yields extremely low accuracy, while classification combining texture information with RGB color information achieves relatively high accuracy; 5) Comparison of the two conventional classification methods indicates that the RGB threshold method is less accurate than maximum likelihood classification, with vegetation coverage overestimation nearly double that of the maximum likelihood method. Comparison of the two improved extraction methods shows that both can effectively enhance measurement accuracy, with the texture classification method based on band synthesis performing best. The accuracy ranking of the four methods from highest to lowest is: texture combined with RGB method > maximum likelihood classification considering biological soil crust > ordinary maximum likelihood classification > RGB threshold method.

Full Text

Preamble

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Effect of Biological Soil Crust on Photographically Measured Value of Vegetation Coverage

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Abstract

Vegetation coverage plays a crucial role in regional and global research on hydrology, meteorology, and ecology, among other fields. The accuracy of its estimation profoundly affects the scientific validity of research conclusions. With the popularization of high-precision digital cameras, photographic methods have become widely used for vegetation coverage estimation in micro-regions due to their objectivity and high precision. However, in arid and semi-arid degraded steppe regions, especially in severely disturbed mining areas, the development of biological soil crust (BSC) can affect photographically measured vegetation coverage values because its spectral signature is similar to that of vegetation.

This study selected the Yimin open-pit mining area as the research site. Four groups of photographs (before and after sprinkling water) containing moss crust, lichen crust, algae crust, and a control group without BSC were collected as samples from the west dump and inner dump. Vegetation coverage was extracted using the digital photographic method, and data were processed using different methods—maximum likelihood classification and RGB threshold method—

to establish a comparative test. The extracted values were compared with truth values obtained by manually outlining vegetation coverage to analyze the effect of BSC on vegetation coverage measurement, evaluate the extent of this effect, and determine whether the effect was related to BSC water content.

Based on the comparison of conventional methods, a more accurate method was proposed to eliminate the effect of BSC on estimated vegetation coverage by combining texture and color information. The main conclusions were as follows: (1) The existence of BSC led to overestimation of vegetation coverage when using conventional methods, with moss crust and lichen crust showing more significant effects after watering, whereas the results for algae crust were opposite. (2) Among the three successional stages of BSC, samples containing moss crust led to substantial overestimation of vegetation coverage (up to ten times the truth value using the RGB threshold method and up to six times using maximum likelihood classification), followed by lichen crust (up to four times the truth value using the RGB threshold method and up to two times using maximum likelihood classification). Algae crust was not significant because the variance was too large. (3) When BSC coverage increased or vegetation coverage decreased, the accuracy of estimated vegetation coverage decreased, suggesting that the effect of BSC cannot be ignored in low vegetation coverage mining areas on the steppe. (4) In an attempt to improve the estimation method using texture information, the accuracy of texture classification alone was very low, while combining texture information with RGB color information resulted in high accuracy. (5) For the two conventional classification methods, the RGB threshold method led to vegetation coverage overestimation as large as twice that of maximum likelihood classification. For the two proposed methods, both effectively increased accuracy, although the method based on band stacking was better. Comparing the four estimation methods, the accuracy ranked as follows: texture combined with RGB method > maximum likelihood classification considering BSC > maximum likelihood classification > RGB threshold method.

Keywords: vegetation cover; photographic method; biological soil crust; open-pit mine; texture analysis

1. Study Area Overview

The Yimin No. 1 open-pit mine is located in Ewenki Banner, Hulunbuir City, Inner Mongolia Autonomous Region. The mining area has an annual average temperature of -1.9°C, annual precipitation of 375.4 mm, and annual evaporation of 1166.0 mm. The temperature annual range is 13–16°C. The designed scale is 10.0 Mt/a, with a mining area of 23.60 km^2, west dump of 7.40 km, inner dump of 4.10 km, and along-bank dump of 4.10 km. Soils in the mining area are mainly artificial stacked soil. The main vegetation types are artificially restored *Iris ensata*, *Leymus chinensis* (Trin.) Tzvel, and *Hippophae rhamnoides* Linn; *Taraxacum mongolicum* Compositae.

Due to intense mining activities, the topography and landforms have changed, and the ecological environment has been severely damaged. Soil salinization around the mining area is serious due to grazing and mining activities. Reclamation work is mainly carried out in the west dump, inner dump, and along-bank dump. Because the soil layers in the dumps are disrupted, vegetation planting is difficult. Under such conditions, some drought-tolerant cryptogams act as pioneer plants in environmental succession. BSC is mainly moss crust and lichen crust, with algae crust being less common. The west dump has been reclaimed for years, with almost complete slope settlement. The dominant moss species is *Anomodon minor*. Only a small part has vegetation restoration, mainly moss crust and lichen crust. The inner dump has been reclaimed for years without settlement, with good vegetation growth and underdeveloped crust. The along-bank dump has been reclaimed for years.

2. Data Collection

Since water content affects BSC activity, which can influence vegetation coverage measurement, we selected clear days with no rainfall for several days before shooting. In the west dump and inner dump of Yimin mining area, we photographed ground-dry conditions. Sample plot inner edge size was 30 cm × 30 cm. Photographs were taken with a Canon EOS 550D camera. Each sample plot contained herbaceous vegetation, BSC (moss crust, lichen crust, and algae crust, four groups each), and other soil backgrounds. Each group included one photograph before and one after sprinkling water. A control group without BSC was also collected.

After photographing each sample plot, we uniformly sprayed 1.0 mm of water on each plot using a spray kettle, then photographed again to obtain wet sample plot photographs. The camera was held with both arms stable, positioned at the center point of the sample plot, maintaining a vertical downward angle at about 1.0 m height. A large sun umbrella was used to shade the sample plot area to avoid local shadows. To highlight the magnitude of BSC' s effect on vegetation coverage, we specifically selected areas with sparse vegetation and extremely low coverage.

3. Data Preprocessing and True Value Acquisition

[Figure 1: see original paper] shows the schematic diagram of Yimin open-pit mining area.

To reduce edge geometric distortion, we used ArcGIS software for geometric correction of photographs. Five points were selected as control points: four right-angle vertices and the center point of the photograph, assigned coordinates (0,0), (1000,0), (1000,1000), (0,1000), and (500,500). Photographs were then cropped along the inner edge of the sample plot so that all cropped photographs had an actual size of 30 cm × 30 cm.

Vegetation coverage true value was obtained by manually outlining vegetation range in the ArcGIS software environment combined with visual interpretation to calculate vegetation coverage. Since this method yields very high precision and approaches the accurate value of vegetation coverage, this value is referred to as the "true value." The data preprocessing procedure is shown schematically in [Figure 2: see original paper].

4. Mainstream Methods for Vegetation Coverage Acquisition

To determine whether vegetation coverage measurement is affected by BSC and the sign and magnitude of this effect, vegetation coverage true values must be compared with values extracted by mainstream processing methods. We selected the most widely used RGB threshold method from color space discrimination methods and the most widely used Maximum Likelihood classification from image classification methods.

The RGB threshold method is based on the color combination 规律 of vegetation and non-vegetation features reflected in digital photographs. Digital numbers (DN) are composed of three primary colors: Red (R), Green (G), and Blue (B). Zhang Xuexia et al. [29] concluded that the information composition 规律 of the three primary colors can be comprehensively described as: if DN_G > DN_R AND DN_G > DN_B, then f_cover = 1 (vegetation); else f_cover = 0 (non-vegetation).

The Maximum Likelihood (ML) classification method involves manually selecting training samples. The computer evaluates the similarity between other pixels and training categories based on the mean and variance of training samples, then classifies the entire photograph. Statistical analysis yields vegetation coverage.

5. Proposed Improved Method for Vegetation Coverage Acquisition

To improve the accuracy of photographic method for vegetation coverage extraction and explore methods that can accurately identify BSC and distinguish it from vegetation, we proposed an improved Maximum Likelihood classification method that considers BSC as a separate training category. Theoretically, this should greatly improve classification accuracy.

For texture feature-based vegetation coverage acquisition, texture features can effectively identify BSC. Different texture feature statistics reflect different information. We used the GLCM (Gray-Level Co-occurrence Matrix) texture module to extract photograph texture features. By comparing how various feature statistics reflect the closeness between extracted vegetation coverage and true values under pure texture classification versus band-stacked classification that fuses texture and color information, we found that pure texture classification has extremely low accuracy, while band-stacked classification has high accuracy. Among these, covariance best reflects sample plot photograph information.

6. Results and Analysis

6.1. Vegetation Coverage Extraction Using Mainstream Methods

Analysis of the 12 groups of data (averages) reveals that when extracting vegetation coverage from sample plots in the study area, all plots containing moss crust, lichen crust, or algae crust yielded results far higher than true values using conventional RGB threshold and Maximum Likelihood methods. In contrast, plots without BSC showed minimal difference from true values, within normal error range. The overestimation was most pronounced in moss crust plots, where the RGB threshold method overestimated up to 10 times the true value, followed by lichen crust (up to 4 times). This is because moss and lichen crusts appear green, causing color confusion with green vegetation, although their spectral characteristics differ significantly from vegetation. Algae crust data showed large variance with unclear patterns.

Comparing vegetation coverage extraction values before and after watering reveals that moss and lichen crust plots had higher values after watering. This occurs because moss and lichen crusts lose activity due to water deficiency in dry states; after watering, they regain activity, increasing green portions and showing spectral changes similar to green vegetation [12]. In contrast, algae crust plots showed post-watering values close to or lower than pre-watering values because algae reflectance decreases after water absorption [30], consistent with other scholars' findings.

Comparing the accuracy of the two classification methods shows that the RGB threshold method is less accurate, with vegetation coverage overestimation nearly twice that of Maximum Likelihood classification.

6.2. Vegetation Coverage Extraction Using Improved Methods

Using the two proposed improved extraction methods (Maximum Likelihood considering BSC and texture combined with RGB) with covariance as the texture feature statistic, analysis of 12 groups of data (averages) yields the following conclusions: (1) Identifying BSC as a separate class improves accuracy. The classification accuracy of Maximum Likelihood method considering BSC is greatly improved compared to not considering BSC, demonstrating BSC's impact on vegetation coverage measurement. (2) The band-stacked texture classification method performs best. From comparison of extracted values with true values, this method most accurately reflects vegetation coverage, theoretically enabling better identification and distinction of BSC. (3) The two improved methods work best for lichen crust plots, especially for high-precision identification of watered lichen crust. Moss crust plots still show higher post-watering values than pre-watering values, indicating that texture features alone are not suitable for distinguishing moss crust from steppe vegetation. For accurate vegetation coverage extraction in the study area, combining texture features with color information can achieve high accuracy.

6.3. Comparative Analysis of Four Methods' Accuracy

Comparing vegetation coverage extraction error percentages across four methods confirms that for BSC-containing plots, improved methods yield higher accuracy than conventional methods. The accuracy ranking from high to low is: texture combined with RGB method > Maximum Likelihood classification considering BSC > Maximum Likelihood classification > RGB threshold method.

6.4. Accuracy Analysis of Four Methods for Feature Recognition

To investigate error sources and determine how much BSC was misidentified as vegetation, we used Matlab software' s pixel-by-pixel comparison function to compare actual classification results (manual outlining), conventional method results, and improved method results. Using actual classification as the benchmark, we calculated the number and proportion of pixels misidentified as vegetation pixels (i.e., BSC misidentified as vegetation) under RGB threshold, Maximum Likelihood, Maximum Likelihood considering BSC, and texture combined with RGB methods.

The analysis shows that moss and lichen crusts have relatively large impacts on vegetation coverage, while algae' s impact is relatively small, consistent with previous conclusions. For BSC-containing plots, improved methods yield higher extraction accuracy than conventional methods, with accuracy ranking from high to low as: texture combined with RGB method > Maximum Likelihood considering BSC > Maximum Likelihood classification > RGB threshold method. This further validates the conclusions and demonstrates that improved vegetation coverage extraction methods for BSC are effective. The texture combined with RGB method is the optimal data processing method among the four.

shows the accuracy analysis of different methods for object recognition, presenting the pixel count and percentage of BSC misidentified as vegetation for each method across different BSC types.

[Figure 7: see original paper] compares the percentage error of each classification method before and after watering, while [Figure 8: see original paper] illustrates computer misidentification schematically.

7. Discussion

When extracting vegetation coverage using photographic methods, the presence of moss and lichen crusts causes significant overestimation of measured vegetation coverage, while algae crust' s effect shows unclear patterns. After water absorption, moss and lichen crusts turn green and exhibit spectral characteristics similar to green vegetation, leading to more significant overestimation.

Algae crust' s reflectance decreases after water absorption, reducing the degree of overestimation.

Among the three successional stages of BSC, moss crust has the most obvious impact on vegetation coverage, followed by lichen crust, while algae crust has the weakest effect. The proposed improved methods can effectively improve vegetation coverage measurement accuracy. The study area is a degraded steppe mining region in an arid/semi-arid zone, characterized by large variations in environmental factors, especially in initially reclaimed mining areas where various environmental factors interact in complex ways [10]. Ecosystems gradually recover from extremely harsh conditions, and BSC develops abundantly. Based on these conclusions, when studying vegetation coverage in similar regions such as degraded steppe areas and ecologically restored mining zones, improved extraction methods should be considered to provide more accurate values for other vegetation coverage-based studies.

This study found that wet moss and lichen crusts have greater impact on vegetation coverage than dry crusts because water absorption makes their spectral characteristics similar to green vegetation. This conclusion indirectly reflects one reason why remote sensing model methods may severely overestimate and produce unstable measurements in such regions. If remote sensing images are acquired shortly after rainfall, vegetation coverage will be overestimated due to water-absorbed crust effects. If the study area experiences intermittent rainfall, vegetation coverage values extracted from remote sensing images of the same area at different times will vary significantly, potentially leading to incorrect research conclusions. Therefore, it is necessary to consider BSC and precipitation effects when using remote sensing model methods to extract vegetation coverage. For BSC-developed regions, images acquired during periods without precipitation should be selected, and texture features should be considered to eliminate BSC effects.

Different BSC types have varying water absorption capacities, ranging from less than 2000% to more than plant dry weight [31]. For example, *Sphagnum nemoreum* Scop can absorb water up to 94.3% of its own weight. Different water absorption capacities lead to different color changes, spectral variation degrees, and misidentification rates, making the relationship between independent and dependent variables a noteworthy research topic. Without using improved methods, some BSCs are misidentified as vegetation during computer-automated processing, while others are identified as non-vegetation. This may be due to certain characteristic differences between misidentified and correctly identified BSCs. For instance, in photographs of moss crust plots alone, misidentified BSCs have colors similar to green vegetation, while correctly identified BSCs may be insufficiently water-absorbed or permanently inactive due to prolonged desiccation in poor ecological conditions. Specific physicochemical property analysis requires designed laboratory experiments.

References

[1] Research progress on vegetation coverage and its measurement methods. *Journal of Northwest A&F University (Natural Science Edition)*, 2006, 34(9): 163-170. [2] Research on rapid extraction of vegetation coverage from digital photographs. *Remote Sensing Technology and Application*, 2010, 25(5): 719-724. [3] Distribution patterns of vegetation-biological crust on abandoned farmland in different rainfall zones of the Loess Plateau. *Bulletin of Soil and Water Conservation*, 2016, 36(2): 377-386. [4] Soil moisture and wind erosion effects of artificially disturbed moss crust in Mu Us Sandy Land. *Bulletin of Soil and Water Conservation*, 2015, 35(1): 20-24. [5] Effects of biological soil crust on soil seed bank diversity and distribution characteristics in Gurbantunggut Desert. *Chinese Journal of Ecology*, 2016, 35(3): 612-620. [6] Infiltration characteristics and simulation of aeolian sandy soil under different biological soil crusts. *Acta Ecologica Sinica*, 2016, 36(18): 5820-5826. [7] Li XR, Tian F, Jia RL, Zhang ZS, Liu LC. Do biological soil crusts determine vegetation changes in sandy deserts? Implications for managing artificial vegetation. *Hydrological Processes*, 2010, 24(25): 3621-3630. [8] Moss crust affects the stability of vegetation indices in arid and semi-arid regions. *Spectroscopy and Spectral Analysis*, 2011, 31(3): 780-783. [9] Vitt DH. Patterns of growth of the drought tolerant moss, *Racomitrium microcarpon*, over a three year period. *Lindbergia*, 1989, 15(6): 181-187. [10] Review on ecological research of bryophytes in arid and semi-arid regions. *Infrared and Millimeter Wave Journal*, 2002, 22(7): 1129-1134. [11] Research on spectral variability of moss crust. *Infrared and Millimeter Wave Journal*, 2010, 29(5): 347-350. [12] Research on biological crust extraction based on spectral analysis: A case study in Mu Us Sandy Land. *Journal of Natural Resources*, 2015, 30(6): 1024-1034. [13] Zhang XS, Liu JD. Research progress on remote sensing spectra of biological soil crusts in semi-arid regions. *Spectroscopy and Spectral Analysis*, 2008, 28(8): 1842-1845. [14] Analysis of reflection spectral characteristics of biological soil crust in Gurbantunggut Desert. *Spectroscopy and Spectral Analysis*, 2008, 28(1): 28-32. [15] Research on image processing methods for measuring winter wheat coverage using photographic method. *Arid Land Geography*, 2010, 33(6): 997-1003. [16] Research on accuracy of vegetation coverage calculation using photographic method combined with digital image technology. *Bulletin of Soil and Water Conservation*, 2007, 27(1): 78-80, 85-85. [17] Rapid extraction of vegetation coverage from digital photos using vegetation determination flowchart method. *Journal of Northwest A&F University (Natural Science Edition)*, 2012, 40(8): 200-206. [18] Research on vegetation coverage measurement and its relationship with vegetation index using photographic method. Nanjing Normal University, 2005. [19] Research on dynamic rapid measurement methods of vegetation coverage in permafrost sections of Qinghai-Tibet Engineering Corridor. *Acta Ecologica Sinica*, 2013, 33(2): 412-418. [20] Error analysis of photographic method in vegetation coverage measurement. *Journal of Minjiang University*, 2008, 29(5): 120-124, 132-132. [21] Comparative study on grassland vegetation coverage measurement methods based on digital camera. *Research of Soil and Water Conservation*, 2014, 23(6): 20-27. [22] Lukina EV, Stone

ML, Raun WR. Estimating vegetation coverage in wheat using digital images. *Journal of Plant Nutrition*, 1999, 22(2): 341-350. [23] Land cover classification based on remote sensing image spectra and texture analysis: A case study of Changbai Mountain Tianchi volcanic area. *Remote Sensing Technology and Application*, 2009, 31(4): 607-616. [24] Ge SK, Carruthers R, Gong P, Herrera A. Texture analysis for mapping *Tamarix parviflora* using aerial photographs along the Cache Creek, California. *Environmental Monitoring and Assessment*, 2006, 114(1/3): 65-83. [25] Spatial analysis of effective leaf area index of evergreen broad-leaved forests in southwestern Sichuan mountains based on image texture features. *Chinese Journal of Applied Ecology*, 2014, 25(11): 3237-3246. [26] Application of image texture features based on gray-level co-occurrence matrix in land cover classification. *Geology and Prospecting*, 2004, 8(5): 458-464. [27] Application of texture analysis method in extracting image texture features for land cover classification. *Geology and Prospecting*, 2011, 47(3): 456-461. [28] Zhou Q, Robson M. Automated rangeland vegetation cover and density estimation using ground digital images and a spectral contextual classifier. *International Journal of Remote Sensing*, 2001, 22(17): 3457-3470. [29] Estimation of vegetation coverage using digital photographic method. *Journal of Beijing Forestry University*, 2008, 30(1): 164-169. [30] Analysis of physicochemical properties and reflection spectra of soil crust in Ningxia Yanchi sandy land. Beijing Forestry University, 2015. [31] Bryophyte Biology. Science Press, 1998. [32] Ecological functions of bryophytes and their role in vegetation restoration and reconstruction. *Acta Ecologica Sinica*, 2003, 23(3): 215-220.

Note: Figure translations are in progress. See original paper for figures.