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Progress and Prospects of the Natural Restoration of Damaged Vegetation after the Earthquake

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Abstract

Vegetation plays an important role in soil and water conservation, water conservation and carbon sequestration of an ecosystem. The restoration of damaged vegetation is of great significance to the maintenance of species diversity and the restoration of the regional ecological environment. It is also one of the most effective measures to improve the fragile ecosystem. This paper summarizes the research results from decades of damaged vegetation recovery in the process of vegetation recovery, the main driving factor and the restoration mode.

Keywords

Geological Disaster, Damaged Vegetation, Vegetation Restoration, Ecological Restoration, Secondary Disaster

1. Introduction

With the increasing frequency of earthquakes and secondary disasters around the world (Ye & Kuang, 2022), the ecological problems caused by vegetation damage in earthquake-stricken areas are becoming more severe (Dai et al., 2011). This not only aggravates the degradation of regional ecological function but also leads to the further fragmentation of wildlife habitat (Xu et al., 2016). Additionally, the restoration of the natural environment and ecosystem in earthquake disaster areas is a long-term and complex process, and the growth of surface vegetation is a critical indicator for evaluating this process (Wu et al., 2008). On May 12, 2008, an 8.0 MS earthquake hit Wenchuan County, Sichuan Province, China, causing 1701 landslides, 1844 rock collapses and 1093 cases of slope in-stability (Earthquake Emergency and Rescue Department of China Earthquake Administration, 2015), resulting in 69,227 deaths, 17,923 missing and direct economic loss of 852.309 billion Yuan. The earthquake caused not only huge casualties and property losses but also serious damage to the regional ecological environment (Xie et al., 2008). With a total area of about 50,104 km^2, of which the damaged forest area is as high as 946 km^2, caused by the earthquake, landslides, debris flows, collapses, and other secondary disasters, a considerable amount of forest vegetation was directly buried or killed. As a result, the forest coverage rate reduced by 1.87%, changing the regional topography, soil characteristics, and vegetation succession process (Zhang et al., 2011). Therefore, the study on the natural restoration of damaged vegetation after the earthquake can not only help deepen the cognition and theory of vegetation restoration and evolution in earthquake-stricken areas but also provide a theoretical basis for vegetation restoration and ecological reconstruction in the worst-hit areas in southwest China after the earthquake.

Vegetation restoration refers to the restoration of biodiversity and ecosystem functions by protecting existing vegetation, closing forests or building artificial forests, planting and grass vegetation, restoring or rebuilding destroyed or destroyed forests and other natural ecosystems (Song, 2001). The natural and artificial restoration of vegetation is the most effective measure to improve the ecological environment of fragile and degraded ecosystems (Zeng et al., 2014). This paper summarizes the main research results of plant community structure characteristics, vegetation coverage changes, main driving factors and restoration methods of post-earthquake vegetation restoration at China and other countries from 2000 to 2022. This paper discusses the future development trend of post-earthquake damaged vegetation research, aiming to provide a scientific and effective reference for the restoration of the ecological environment, construction of ecological civilization and prevention and control of natural disasters in earthquake-stricken areas.

2. Research Status of Damaged Vegetation Restoration after an Earthquake

With the continuous progress of information technology, research on the restoration of damaged vegetation after the earthquake involves not only the large-scale analysis of remote sensing interpretation (Yang et al., 2018) but also the microscale analysis of vegetation and soil microorganisms, showing an overall research trend of multiple scales and multiple angles (Zhang et al., 2015). At the same time, the study of damaged vegetation restoration after the earthquake is gradually linked to the development of society, economy and ecological civilization and is closely related to environmental science, geology, biochemistry, geography and other interdisciplinary research (Wang et al., 2014). In the Chinese CNKI database, the terms “earthquake + after earthquake” yielded 396 research papers between the years 2000 and 2022, In the Web of Science database, the terms "vegetation restoration + vegetation" yielded 6622 research papers between the years 2000 and 2022.

According to **Figure 1**, domestic articles on vegetation recovery were less than 10 articles/year from 2000 to 2007. After the Wenchuan earthquake of 2008, the number of related papers increased significantly, the research level diversified and developed, and the related papers gradually entered prestigious domestic journals, such as Geographic Journal, Ecological Journal and Environmental Science. In the Chinese CNKI database, reaching a peak of 38 articles/year in 2013. According to **Figure 2**, It can be seen from **Figure 2** that the academic papers on post-earthquake vegetation restoration published in the foreign Web of Science database show an overall upward trend; Between 2000 and 2004, the number of papers was less than 100 per year; Since 2005, the number has been increasing, reaching the highest peak of 558 pieces/year by 2021, among which the reports on vegetation after the Wenchuan earthquake have increased significantly.

2.1. Study of the Community Structure Characteristics of the Damaged Vegetation

The structural characteristics of a vegetation community can reflect the process of vegetation restoration to some extent, and different plant communities can represent and reflect the different stages of vegetation restoration. Luo et al. (2018) assessed the recovery situation, recovery potential, and succession pattern of the community by analyzing the characteristics of vegetative communities in various climate zones affected by the Wenchuan earthquake. The number of plant species in the earthquake disaster region expanded dramatically, according to research by Cui et al. (2018). However, most of these were pioneer species, such as chrysanthemum families and grasses, representing the natural dissemination of local species around the disaster body as a result of external pressures

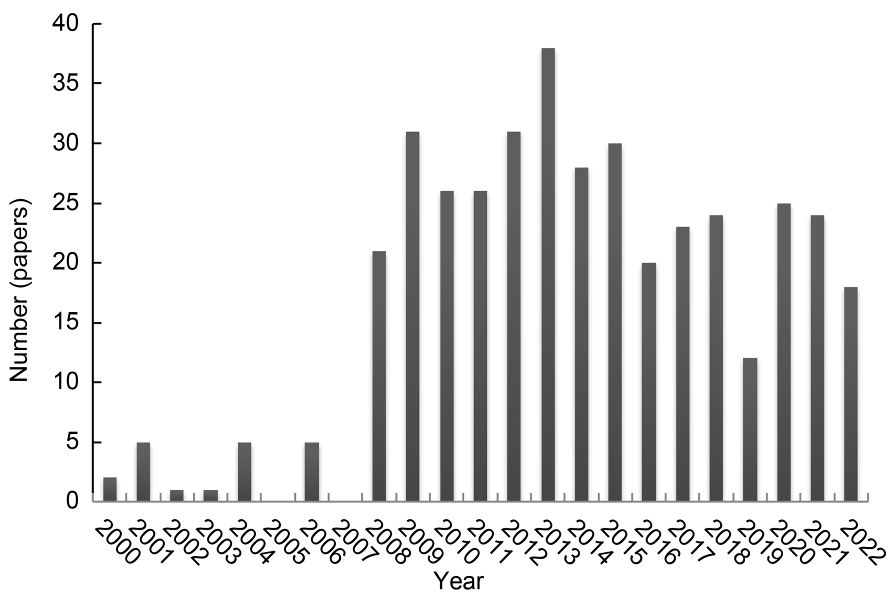

Figure 1. Changes in the number of literature in the CNKI database over the years.

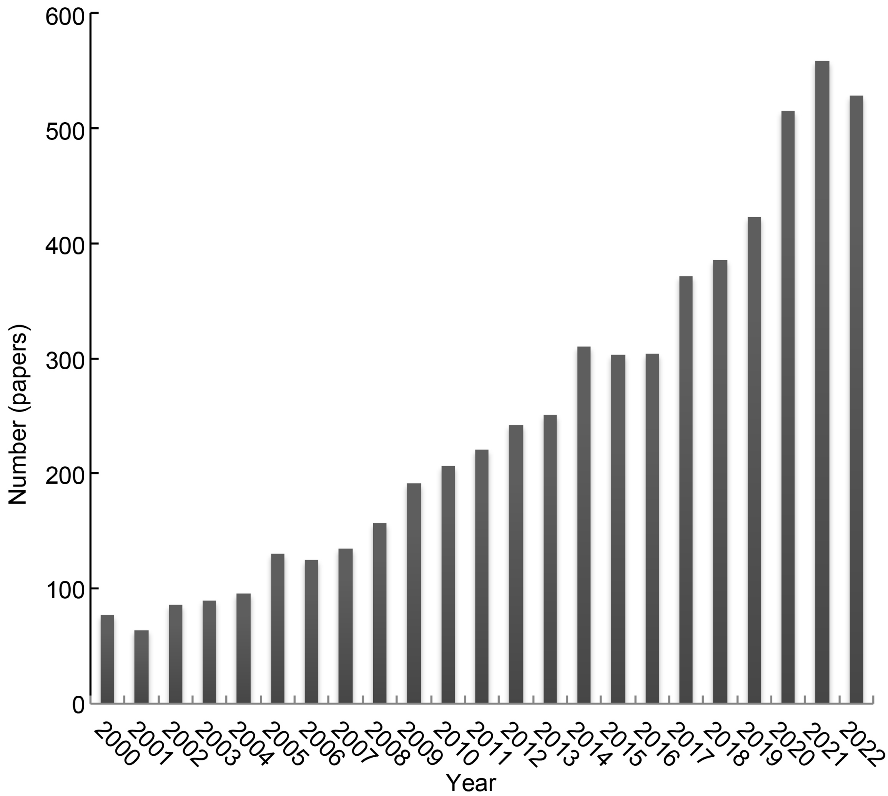

Figure 2. Changes in the number of documents on post-earthquake damaged vegetation restoration in the Web of Science database over the years.

including wind media. Zhang et al. (2011) found that the floristic structure of pioneer plants was basically the same as that of the original plants. In the recovery process, the vegetation community species grew from rapid growth in the early stage to gradual stability in the later stage, and the herbaceous-shrub community structure gradually developed into the tree-shrub community structure, stabilizing the change process. Through the analysis of the ecosystem types affected by the earthquake disaster and a sample survey of the ground vegetation, Yang et al. (2020) discovered that while most of the damage caused by the earthquake has recovered to some extent, the forest community has not yet fully recovered. However, the ecosystem quality is steadily improving due to a relatively stable positive succession process.

2.2. Study of the Dynamic Change in the Damaged Vegetation Coverage

Vegetation cover change is an important indicator of the evolution of the natural ecological environment, and the dynamic monitoring of vegetation change is an essential basis for assessing the quality and suitability of the ecological environment (Shao, 2020). Peng et al. (2016) monitored the dynamic change in vegetation cover in the Wenchuan-Dujiangyan section of the Minjiang River and analyzed the spatial dynamic pattern change in vegetation damage and restoration before and after the Wenchuan earthquake. Xiong et al. (2018) estimated vegetation coverage by constructing a binary image model in Wenchuan earthquake-stricken areas, examined the relationship between vegetation coverage and terrain factors and highlighted the close relationship between vegetation coverage and terrain factors. Based on the mixed image decomposition method (Xu et al., 2012), they monitored the vegetation cover change in the riparian zone in the arid river valley of the Minjiang River by using Landsat TM satellite remote sensing data. After the Wenchuan earthquake, Li et al. (2016) assessed the vegetation recovery in the Longxi River Basin in Dujiangyan using quantitatively the medium-resolution imaging spectrometer-Vegetation Index (MODIS-NDVI) time series. They found that there was a lag in the response of vegetation coverage to earthquake damage.

2.3. Study of the Drivers Affecting the Restoration of Damaged Vegetation

In the process of damaged ecological restoration in earthquake-stricken areas, there are two main driving factors: natural factors, including climatic conditions, soil physical and chemical properties, topography and landform; and human factors, including human economic activities and ecological restoration projects. Zhou et al. (2021) monitored the vegetation changes in the giant panda habitat after the earthquake and found that the spatial distribution of planting changes was mainly affected by four factors: annual precipitation, annual average temperature, elevation and soil type, with mutual enhancement and nonlinear enhancement serving as the driving factors. According to Jiao et al. (2014) topographic factors affect natural conditions, such as surface photoheat and temperature, and indirectly affect the restoration of vegetation coverage through the transmission and redistribution of water, heat and nutrients in the region. Sun et al. (2016) discovered that on a regional scale, hydrothermal conditions control the distribution of plant species, plant life types and vegetation types in the region, while landscape and smaller scale patterns are affected by environmental and biological factors. Chang et al. (2007) suggested that slope is a key determinant in the landslide and the subsequent vegetation restoration process. Lu et al. (2012) concluded that vegetation recovery was positively correlated with slope and negatively correlated with an elevation in general, probably because with the increase in elevation, the farther away from the valley area, the corresponding deep cutting weakened.

2.4. Study of the Restoration Mode of Damaged Vegetation

To speed up the restoration and reconstruction of the post-earthquake ecological environment, ecological restoration technology is mainly divided into two categories biotechnology and engineering technology. Different restoration methods are selected based on the nature and severity of the earthquake-damaged ecosystem' will be a more suitable alternative (Gao & Yang, 2007). Usually, in earthquake-damaged ecosystems, vegetation restoration is the key to ecological restoration. After the damage caused to the ecosystem by the earthquake, the self-organization and mediation ability of the ecosystem, combined with moderate manual intervention, is used to allow the damaged ecosystem to gradually recover or develop into a benign cycle (Ma et al., 2012). Human-led vegetation restoration succession, supplemented by artificial measures, can accelerate the restoration of damaged or degraded ecosystems to a certain extent. In manual intervention, engineering and technical measures are generally used to stabilize the slope or to provide optimal circumstances for vegetation restoration, mainly slope stability engineering, drainage and soil and water conservation engineering, and afforestation engineering (Du & Yang, 2017). The slope type, soil slope and rock slope engineering measures are divided according to the degree of seismic loss, distribution, type, and site characteristics, using ecological engineering treatment technology based on vegetation restoration (Liu et al., 2010). The ecological restoration after an earthquake disaster should be adapted to local conditions, the climate environment should be fully considered and natural restoration should be as far as possible. In areas with difficult natural recovery, monitoring should be strengthened to appropriately control and reduce the chance of invasive plants (Duan et al., 2020). The configuration of plants is mainly based on altitude, temperature, soil, water and other site conditions, as well as strip, functional and other comprehensive design (Wang et al., 2006).

3. Summary of Research Methods for Damaged Vegetation Restoration after the Earthquake

3.1. Field Measurement Method

Research on restoring damaged vegetation after an earthquake is mainly divided into two categories. One is based on the field measurement data, using statistical analysis, sampling, instrument and model methods to study the degree of vegetation damage and restoration (Xie & Li, 2022). Data measured in the field usually include data about vegetation and the surrounding environmental factors. The field measurement method can only be used to determine the vegetation coverage of the selected sample site. Studies have proved that quadrat size is a significant factor affecting measurement accuracy (Wang et al., 2013). The results of some ground measurements are very different. Due to the influence of its own limitations, field measurement is only applicable to the measurement of grassland cover in sample-level areas, and it is unsuitable as an independent measurement method for the study of grassland coverage on a large spatial scale. It must be combined with remote sensing data to effectively solve regional and even global ecological process problems.

3.2. Remote Sensing Estimation Method

The remote sensing estimation method mainly establishes the corresponding analysis index for local areas, such as the vegetation recovery rate and landscape pattern index, to reflect the vegetation coverage information at different spatial scales and its trend of change (Wu et al., 2019). The advantage of this method is that it can quickly and efficiently extract the damaged area and assess the degree of damage and recovery status of the disaster area, making it suitable for large-scale disaster investigation and long-time series recovery assessment. The estimation techniques for vegetation coverage are still relatively weak, especially in the scope of application and accuracy of estimation (Yin et al., 2011). From the perspective of data sources, hyperspectral remote sensing for vegetation coverage estimation has high estimation accuracy and is an ideal data source for vegetation coverage estimation (Cui et al., 2019). However, the challenges of difficult data acquisition, a narrow scan width and a long revisit cycle restrict the further application of hyperspectral data. Scholars have confirmed the potential of multispectral remote sensing to estimate vegetation coverage. In the future, an increasing number of multispectral sensors will provide sufficient data sources for estimating vegetation coverage (Bao, 2008). From the perspective of the estimation method, the spectral index method is applicable to certain areas and specific vegetation types and has high estimation accuracy, but it is not generally universal due to regional limitations. On the other hand, the spectral hybrid analysis method has a certain physical significance, a simple model that is easy to popularize, and considerable potential for estimating vegetation coverage (Ni et al., 2009). The linear spectral hybrid model has uncertainty when estimating vegetation coverage, simplifying the complex interaction process between electromagnetic waves and ground objects, ignoring the spectral heterogeneity of hybrid image elements, and easily leading to lower estimation accuracy.

Traditional ground statistical measurement will no longer be the mainstream method to obtain vegetation coverage but will only serve as the auxiliary and calibration method for modern measurements, such as remote sensing (Jia et al., 2013). The vegetation index has become the primary method for monitoring vegetation cover and improving the accuracy of model and inversion results by making better use of remote sensing data with high spectral and spatial resolution.

4. Research Outlook on the Restoration of Damaged Vegetation after the Earthquake

The process of vegetation restoration has an important influence on the aboveground vegetation ecosystem and the restoration of species diversity (Zhang et al., 2014). Therefore, the study on the restoration of damaged vegetation after the earthquake has remarkable guiding significance for the development of human society and the restoration of degraded ecosystems. However, the current study on the restoration of damaged vegetation after an earthquake is not perfect, which is mainly reflected in the following aspects:

1) Researchers both at home and abroad have focused on the specific and detailed analysis of the damaged vegetation in a certain earthquake event, and there have been few studies that compare and analyze the impact of multiple

seismic events on land surface vegetation. Therefore, researchers can compare and analyze the post-earthquake vegetation recovery process in different areas to explore the more universal research results.

2) To date, natural recovery and artificial recovery, and the relationship between climate conditions, topography and landform and plant community structure and characteristics, are unknown, making it difficult to summarize the vegetation recovery measures applicable to different environmental backgrounds. In addition, the guidance for promoting local vegetation restoration and ecosystem succession is still insufficient. Therefore, in the future, the differences between natural recovery and artificial recovery in earthquake areas can be compared and analyzed, and the relationship between different habitat conditions and plant community characteristics can be studied more comprehensively, allowing for the development of vegetation restoration in different environments.

3) For the remote sensing analysis of vegetation coverage, previous studies, including the setting of threshold values or the calculation of confidence intervals, are not generally applicable, the accuracy is not high and the fitting effect of time series fluctuations is not ideal. The change monitoring method of time series faces many challenges, such as the analysis results are usually not intuitive, phenological changes and mutations cannot be clearly distinguished and change monitoring on a wide range of data typically requires considerable time and cost. In subsequent studies, we can attempt to use vegetation index data with a greater regional range and a higher spatial resolution to implement the significant data-intensive calculation of the vegetation dynamic change monitoring method.

5. Discussion

At present, research on the restoration of damaged vegetation after the earthquake has attracted wide attention in academia and society. Vegetation restoration is an important link in post-disaster reconstruction, and many scholars have also conducted systematic and in-depth studies on the restoration of damaged vegetation after an earthquake. However, the restoration of earthquake-damaged vegetation is a long-term change process, and the succession process is slow. The heat of such studies decreases as the time of the earthquake incident passes. Moreover, most of the studies lacked pre-earthquake vegetation habitat data, making it difficult to carry out comparative analysis before and after the micro level. At the same time, monitoring the restoration and change of the damaged vegetation mainly depends on field measurement and remote sensing estimation, but both have certain limitations. Therefore, in the future, there is a need to conduct a more thorough analysis of the driving factors, combining field measurement and remote sensing estimation for the ideal of damaged vegetation recovery evolution data after the earthquake. To design suitable restoration schemes for different earthquake event types in different areas, it will be necessary to explore the succession and ecological natural recovery mechanism and law and provide a theoretical basis and practical guidance for earthquake ecological reconstruction and natural protection.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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