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Original Research

Ecological Degradation Assessment of World Natural Heritage: A Case Study of Bogda Site in Tianshan

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Abstract

World Natural Heritage Site (WNHS) is a typical demonstration of global diversity protection. To realize the sustainable development of WNHSs under the contradiction of protection and utilization, an index system based on the framework of exposure- sensitivity- resilience was constructed to diagnose the ecological degradation of WNHSs, and the degree and structure of ecological degradation were evaluated and visualized in Bogda, Tianshan Mountains, Xinjiang. The results show that: (1) The criterion layers of threat factors, resilience and changes of heritage value showed different spatial distribution characteristics. (2) The level of ecological degradation in Bogda site was mainly mild degradation, while the degradation was serious around the scenic spots with intensive tourist activities and along the road. The seriously degraded area was the least, accounting for 1.89% of the study area, followed by ecological health area (6.22%), moderately degraded area (13.87%), and mildly degraded area (78.03%). (3) The overall conservation management status in Bogda site remained good. Low -low -low is the main type of ecological degradation, followed by high -high -high, high -high -low, low -high -high and low -high -high. The diagnosis and analysis of ecological degradation would provide scientific basis for the conservation, management and ecological restoration of Bogda site.

Keywords: World Natural Heritage, ecological degradation, degraded types, Bogda

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Introduction

The World Natural Heritage represents the essence of natural areas in geoscience, bioecology and aesthetics, and is the highest level of nature protected area internationally recognized [1-2]. It is of great significance for the study of ecosystem protection and management in the evolution process of earth science and the sustainable development model of harmonious coexistence between human and nature [3-4]. The selection and establishment of natural heritage sites rely on the "Global Geological Framework of World Heritage", "the Global 200 ecological zones", biodiversity hotspots, bird reserves, plant diversity areas and other biogeographic zones, which play a typical demonstration role in the protection of global biodiversity, biological diversity and landscape diversity [5-7]. In recent years, world natural heritage sites have been under unprecedented pressure due to climate change, natural disasters and human activities [8-10]. The World Heritage Committee has summarized 14 major factors and 83 secondary factors that affect the value of World Natural Heritage sites, including infrastructure construction, transportation facilities, pollution, water conservancy facilities, use of biological resources, resource exploitation and climate change. These factors lead to changes in the ecosystem structure and process of natural heritage sites, which threaten the value and integrity of the heritage sites and pose a great threat to the sustainable development of the WNHS [11-12]. Due to the high value of World Natural Heritage, many sites had been developed and constructed on a large scale after their successful application for World Heritage, resulting in increasingly prominent resource and environmental problems such as ecological degradation, vegetation destruction, biodiversity reduction, environmental pollution and human-land conflict. Therefore, the authenticity, integrity and ecological fragility of the heritage site were under great pressure and challenge [13-15]. Under the contradiction between conservation and utilization, it has become an urgent task to protect and restore the ecosystem services of Natural Heritage Sites, maintain the healthy state of the ecosystem, restore the degraded ecosystem, and realize the sustainable development of natural heritage sites.

The diagnosis of ecological degradation by scholars was mainly realized through quantitative diagnosis of biology, habitat, landscape, land use, ecological process and ecological function by combining remote sensing data, survey data, measured data and other multivariate data [16-19]. For the world natural heritage, the protection of heritage value elements was the key point in the conservation and management of heritage sites, therefore, it was a hotspot that the research of the degradation caused by the change of the carrier of heritage value elements. The vulnerability of geographical value of natural heritage sites was caused by the instability of typical geological processes and geomorphologic features and their sensitivity to external stress [20]. Vegetation change, green biomass, vegetation structure and vegetation types were used to reflect the conservation effectiveness of habitat and biodiversity [21-22]. The aesthetic value of landscape changed not only in biophysical characteristic (e.g., mountains, trees), but also in concepts (e.g., wilderness) and emotions (e.g., excitement) [23].

The degradation of heritage sites emphasized the change and influence on heritage value carriers, and also focuses on exploring the deep-rooted causes of degradation from the aspects of degradation mechanism, impact results and community management. The impact of community livelihoods was usually the main cause of ecological degradation of heritage sites. Mucova et al. analyzed the land use and land cover changes in Quirimbas National Park, Northern Mozambique, Africa. From 1979 to 2017, the National Park was threatened by multiple challenges, such as poaching, deforestation, illegal exploitation of mining resources, hunting, uncontrolled burning, community invasion to exploit the basic resources for their survival [24]. Delgado-Aguilar et al. analyzed the relationship between ecosystem service demand and forest degradation by combining remote sensing images and spatial data of local community livelihood. The research showed that the undisturbed forests were hot spots for providing ecological services, however, they may be in danger if uncontrolled forest use continues [25]. Riddell et al. explored the impact of upstream invasive pollution on the health of aquatic ecosystems and protected species in Kruger National Park, South Africa. The diversity of anthropogenic activities upstream created distinct challenges for each river [26].

Furthermore, the ecological integrity of natural site also depended on its connection to the wider landscape, environmental degradation around a natural site could reduce its size and increase edge effects, so natural sites became increasingly isolated [27]. Laurance et al. found that degradation occurring around protected areas could easily lead to similar degradation within protected areas, including trends in forest loss and anthropogenic pressure [28]. In order to avoid further damage to natural heritage sites, the protection of landscape around natural heritage sites and low-impact land use in buffer zone communities were also important for natural heritage conservation.

The diagnosis of ecological degradation by scholars were mainly carried out through multi-scale and multivariate data. The analysis and judgment of the key value elements and the social functions in geography, aesthetics, biology and ecology of each heritage site was a hot spot in the research of ecological degradation of heritage sites. The extent and spatial distribution of ecological degradation of the WNHSs were evaluated by using diversified data and methods, taking into account the outstanding universal value, the pressure and the spatial distribution of the resilience capacity of the world natural heritage sites. This provided a scientific and reasonable judgment basis for ecological protection and management of heritage sites.

This paper took Bogda as the research area, and carried out a comprehensive diagnosis of ecological degradation of the WNHS from the perspectives of heritage threat factors, resilience and changes of heritage value elements. According to the degradation diagnosis results and field survey, suggestions for the conservation and management of typical degraded areas of Bogda are put forward, which provide a scientific basis for the realization of the protection and management requirements of "strict protection and sustainable utilization" of Bogda site, and also has guiding significance for the restoration activities of other WNHS.

Survey of the Study Area

Bogda Heritage Site is located in the east of the Tianshan Mountains in Xinjiang, China. The central coordinates are N43°50'00", E88°17'12", with a total area of 38,739 hectares and a buffer area of 41,547 hectares. Bogda belongs to the continental temperate climate zone. It is a wet island in the desert center of the arid region. The annual average temperature is 2.5ºC and the annual average precipitation is 444 mm. Bogda Heritage Site is a typical representative of the north slope of Tianshan Mountain in Xinjiang and the mountainous vertical natural zone in the global temperate arid zone. Within a horizontal distance of less than 30 km and with an elevation of 3,055 meters, Bogda Heritage site has six vertical zones of natural vegetation: alpine cushion vegetation, alpine meadow, sub-alpine meadow, mountain evergreen coniferous forest, meadow steppe and temperate steppe, which is of global significance to study the succession of biological communities in mountain ecosysIn accordance with the Operational Guidelines of the United Nations Heritage Convention, Xinjiang Tianshan Mountain was listed as a World Natural Heritage based on criteria VII and IX [29]. Bogda region has a huge drop of more than 5,000 meters from the desert belt to the alpine snow and ice belt, which is a concentrated display of the integrated natural landscape in the temperate arid region, such as snow peaks, glaciers, river marshes, alpine lakes, forests and steppe, desert and gobi. In a very small horizontal scale, a complete vertical band spectrum has been developed, which is of outstanding global significance for the study of the succession of mountain ecosystem communities under global change, and reflects the high quality of geological value, bioecological value and aesthetic value.

Data Sources and Methods

Data Sources and Processing

The data sources of this study included field survey data,c, Resources and Environmental Science and Data Center of Chinese Academy of Sciences, Geospatial Data Cloud, NASA Data Center, Google Earth, etc. All layers had the same geographic range, using the WGS_1984_UTM_44N geographic coordinate system and 30 m spatial resolution (Table 1).

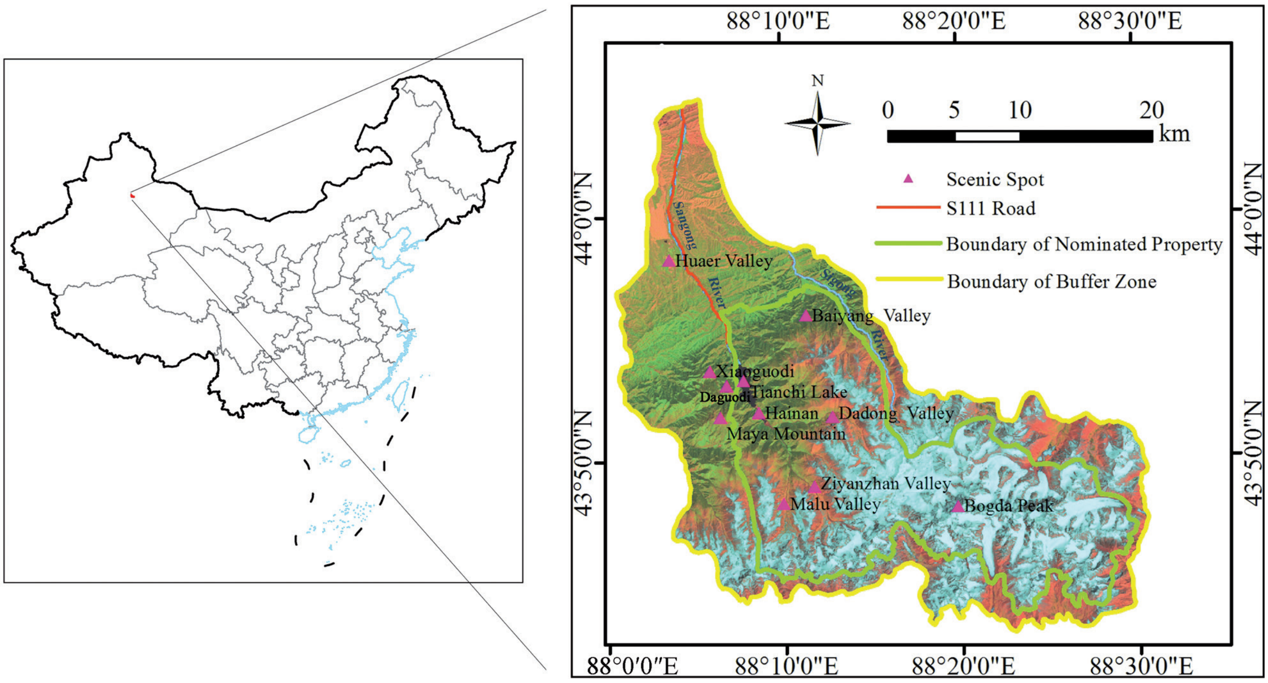

Fig. 1. The sketch map of study area.

Table 1. Data sources and information of ecological degradation in Bogda.

Data Type	Data Sources	Data Processing Method
Land classification data	Geospatial Data Cloud	Unsupervised classification, reclassification
Normalized Difference Vegetation Index (NDVI)	Geospatial Data Cloud	Band calculation, standardization
Net Primary Productivity (NPP)	NASA Databasa	Resample, standardization
Database Information	Data Center of Resources and Environment Science of Chinese Academy of Sciences	Buffer analysis, distance analysis, visibility analysis, grid calculation, reclassification, standardization

Establishment of Index System

The basic idea of index system was that the degraded degree of a vulnerable system depends on the exposure, sensitivity and adaptation. The framework was the coupling of the external pressure and the system's own attributes, which highlighted the internal cause mechanism of the degradation and provides an evaluation framework for system degradation assessment. On the basis of scientific, comprehensiveness and operability, indicators were constructed with threat factors, resilience of heritage site, and changes in heritage value elements as the criteria layers to comprehensively diagnose the ecological degradation of NWHS (Table 2), and the diagnostic analysis results would be used as the basis for protection and management of NWHS.

Exposure was the degree of interference and stress of the system, which was measured by threat factors. The process of ecosystem degradation under natural or

Table 2. Ecological degradation evaluation index system and weight in Bogda.

Criterion Layer	Index Layer	Index Source	Index Weight
Threat factors (0.2493)	Frequency of natural disasters(B11)	[13, 25, 33-35]	0.1156
	Infrastructure construction(B12)		0.0794
	Road Building(B13)		0.2842
	Pollution sources(B14)		0.0243
	Tourist activity(B15)		0.1767
	Community activity(B16)		0.2464
	Intensity of conservation and management (B17)		0.0409
	Illegal activities(B18)		0.0324
Resilience (0.5936)	NPP(B21)	[36-40]	0.3650
	Vegetation coverage(B22)		0.0403
	Vegetation community type(B23)		0.2363
	Landscape adaptation(B24)		0.0634
	Landscape sensitivity(B25)		0.1938
	Landscape vulnerability(B26)		0.0480
	Geographical vulnerability(B27)		0.1004
Change of heritage value (0.1571)	Damage rate of geological heritages(B31)	[24, 37, 41-44]	0.1693
	Significant geomorphic loss(B32)		0.2813
	Changes in vegetation coverage(B33)		0.2626
	vegetation productivity change(B34)		0.0557
	Habitat integrity change(B35)		0.0408
	Changes in ecosystem types(B36)		0.0921
	Changes in aesthetic value(B37)		0.0983

human disturbances was determined by the intensity, duration and scale of the disturbances [30]. Sensitivity was the ease with which the exposed unit was affected by pressure and disturbance. From the analysis of threat sources, the threats faced by heritage sites were summarized into natural factors, tourism, community development, management, pollution, illegal activities, etc. The resilience of a heritage site was the ability of an ecosystem to maintain its original state of function and structure in response to stress and disturbance [31]. The potential production vitality, ecosystem structure, ecological environment vulnerability and other indicators reflected the resistance and adaptability of heritage sites in the face of interference and stress [32]. Adaptive capacity is the ability of the exposed unit to deal with and recover from adverse effects. Taking the change of heritage value as the point of penetration, the heritage value carrier was selected from the perspectives of geological value, bio-ecological value and aesthetic value, so as to realize the evaluation of the change degree of the elements of NWHS.

Index Weight Calculation

The first round of questionnaire was conducted on a 10-point scale. Twelve experts in the fields of geography, biology, ecology and 6 residents of surrounding communities were invited to score each indicator. According to the results, the importance score of each evaluation indicator was obtained. When the score was greater than 6, the indicator was included in the indicator system. Finally, a three-dimensional framework for ecological degradation assessment index system was constructed while considering the threat factors, the resilience of ecosystem, and the change of heritage value. According to the comparison and judgment of experts and communities' residents on each criterion layer and index in the first round, the judgment matrix of relative importance of each evaluation index was obtained, and the results of each matrix passed the consistency test (CR<0.1).

It could be seen from Table 3 that the experts attached importance to resilience on the criterion layer, and the weight of the criterion layer is sorted according to resilience (0.5936) > threat factors (0.2493) > change of heritage value (0.1571). In the study area, the weights of indicators related to geological and geomorphic distribution and vegetation distribution were generally large, which also verified the important value of Bogda as a typical mountain ecosystem in the succession of biological communities.

Calculation Method of Criterion Layers and Ecological Degradation Index

According to the collected data of each index, the corresponding comprehensive weight obtained, the score of each criterion layers was obtained by a weighted sum of the index. The specific calculation formula was as follows:

$$I_{(0)} = \sum_{m=1}^{j} w_j x_{ij}$$

Where: $I_{(0)}$ is the score of each criterion level; W_j is the comprehensive weight of each index; X_{ij} is the standardized data of each indicator.

The resilience of the system was the effective maintenance of the value of the heritage. The higher resilience was, the more negative effects would be offset. Referring to relevant studies on ecological degradation diagnosis [45], spatial superposition analysis was carried out on the score results of each criterion layer. The calculation formula of ecological degradation was:

$$\mathrm{I} = \mathrm{T}w_T + (1 - \mathrm{R})w_R + \mathrm{H}w_H$$

Where, I is the ecological degradation index, W is the weight, T is the threat factor of heritage site; R is the resilience of the heritage site; H is the change of heritage value elements.

Classification of Degradation

According to the threshold range of each indicator and the results of field investigation, the scores of degradation diagnosis index were ranked according to the natural break method, and the ecological degradation degree of the World Natural Heritage was divided into four levels: Grade I (ecological health), Grade II (mild degraded), Grade III (moderate degraded), and Grade IV (seriously degraded).

Result and Analysis

Criterion Layer Analysis of Ecological Degradation

According to the evaluation index layers and their weights, the distribution pattern of Bogda's threat factors, resilience, changes of heritage value factors and ecological degradation was obtained (Fig. 2).

Table 3. Consistency test of evaluation matrix.

Item	Criterion Layer	Threat factors	Resilience	Change of heritage value
CR	0.0516	0.0958	0.0372	0.0775

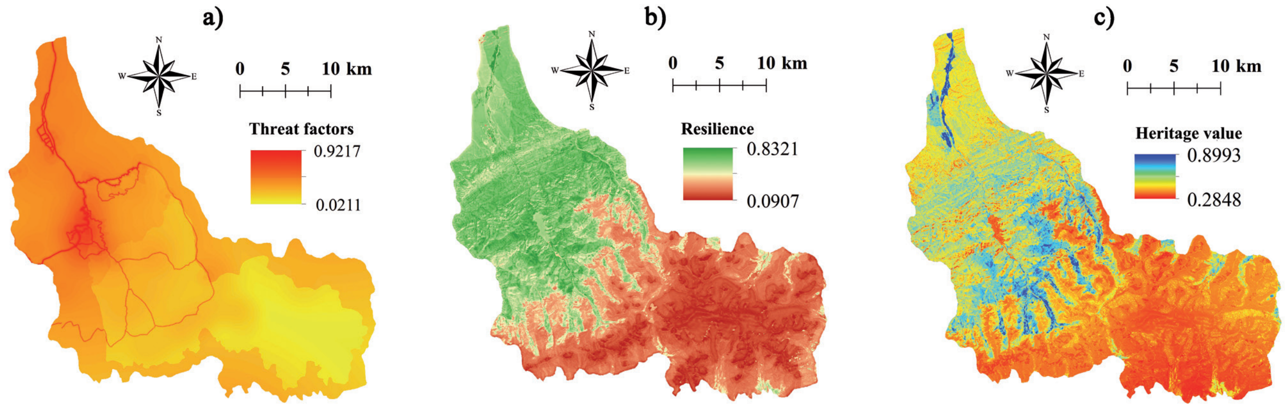

Fig. 2. Spatial distribution of each criterion layer in study area.

The mean value of threat factors was 0.2138, and the standard deviation was 0.1066. The areas with high threat degree were mainly distributed around Tianchi Lake and the tourist routes in the study area. The central part of the study area was the main gathering area of tourism activities, and the threat was closely related to the interaction between roads and tourism activities. The northern desert steppe was mostly in the buffer zone, the threat factor was greater than that of the southern mountainous area for the different management requirements.

The resilience was spatially related to land type and vegetation cover. Due to the hydrothermal combination suitable for vegetation growth, the vegetation coverage was high in the desert steppe belt, mountain grassland belt and mountain coniferous forest belt in the northern part of the heritage site and buffer zone. Their ecosystem structure was stable, and the resilience was significantly stronger than that of the cushion vegetation zone and snow and ice zone in the south.

The changes of heritage value were obvious in the lower reaches of Sangong River, along the banks of Sigong River, Dadong Valley, Ziyanzhan Valley, Malu Valley. The northern part of the study area was the main area of human activities, but also the main area of vegetation growth, so the change of heritage value elements in this area was greater than that in the southern mountainous area.

Ecological Degradation Analysis

Based on the distribution of threat factors, resilience and heritage value, the distribution of Bogda's ecological degradation was mapped (Fig. 3). According to the classification of the World Natural Heritage degradation index, the distribution map of ecological degradation level of Bogda was obtained, the values was divided into four levels by natural breaks: Grade I: ecological health area (0.080-0.2608), Grade II: mild degraded area (0.2608-0.3542), Grade III: moderate

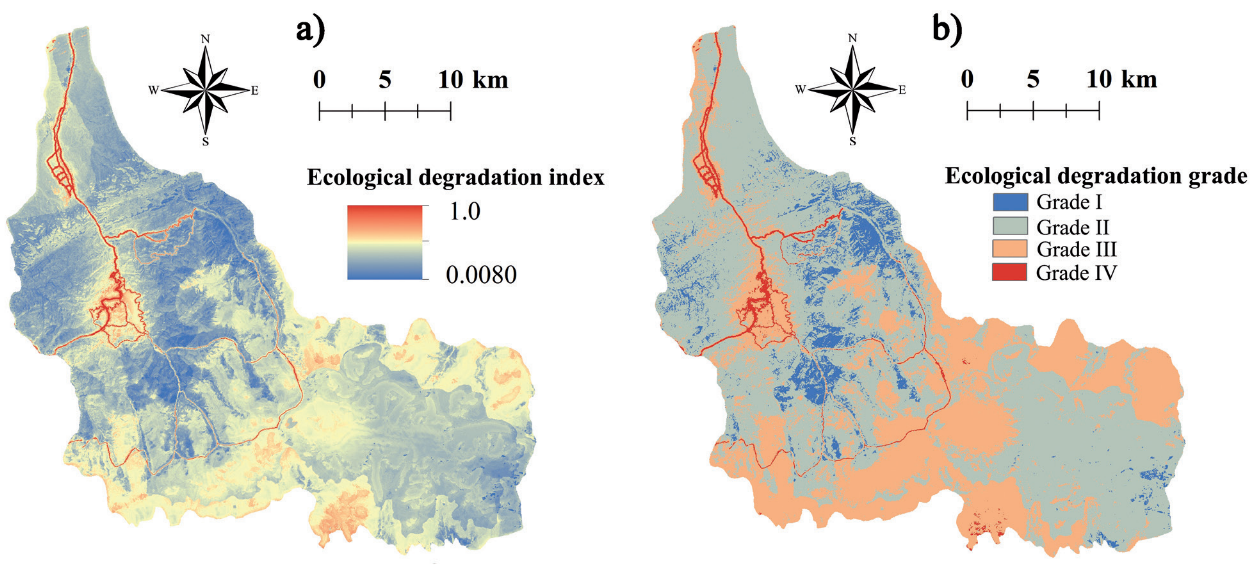

Fig. 3. Distribution of ecological degradation index and grade in study area.

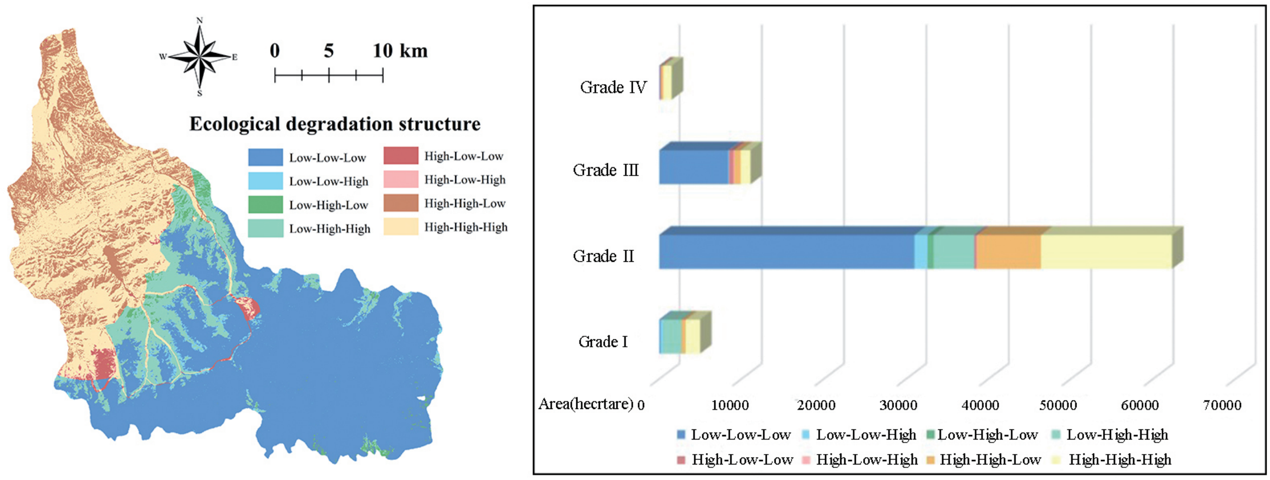

Fig. 4. Ecological degradation structure and its distribution under different degradation levels.

degraded area (0.3542-0.5215), and Grade IV: seriously degraded area (0.5215-1.0).

The level of ecological degradation in Bogda area was mainly mild degraded area, and the degradation was serious around the scenic spots with intensive tourist activities and along the road. Among them, the area of Grade IV which represented serious degradation was the least, accounting for 1.89% of the study area, followed by Grade I (6.22%), Grade III (13.87%), and Grade II (78.03%).

Ecologically Degraded Structure

According to the different combinations of exposure-sensitivity- resilience, each criterion layer was divided into high and low by natural break method. The degradation was categorized into eight types (i.e., Low-Low-Low, Low-Low-High, Low-High-Low, Low-High-High, High-Low-Low, High-Low-High, High-High-Low, High-High-High) (Fig. 4). "High-High-Low", as an illustration, is the area with high exposure-high sensitive -low response.

The overall conservation management degree in the study area was good, and the low -low -low type was the main structure type of ecological degradation in Bogda with 49.61% of the area. Followed by high - high - high type (24.86%), high - high - low type (11.55%), low - high - high type (9.01%), other structure types accounted for a small proportion.

Table 4 showed the degradation structure composition at each level. In the Grade I degradation area, the area of low - high - high and high - high - high types account for 79.46% of the research area, and the stability of high resilience and heritage value was an important guarantee to maintain the ecological health of the area. The area of low -low -low and high -high -high types in the Grade II degradation region accounted for 70.74% of the region, and the contradiction between resilience and threat factors was an important reason in the degradation level region. The area of low - low - low type in Grade III degradation region accounted for 77.01%, and low resilience was an important reason for the degradation. The risk types of Grade IV degraded areas were mainly high - high - high type. The change of heritage value caused by high threat level accelerates

Table 4. The area of degradation types under different grades (ha).

Structure \ Grade	Grade I	Grade II	Grade III	Grade IV
Low-Low-Low	142.38	30994.47	8373.51	79.47
Low-Low-High	348.93	1575.09	95.13	0.09
Low-High-Low	0	749.79	0	0
Low-High-High	2201.40	4985.46	0	0
High-Low-Low	0	238.77	572.85	134.91
High-Low-High	0	99.18	116.91	42.66
High-High-Low	521.46	7722.09	720.36	251.28
High-High-High	1733.58	15913.17	1191.60	996.48

the self-resilience of the system, which was the main reason for the serious degradation of this degradation grade.

Conclusion and Discussion

Conclusion

(1) According to the exposure, sensitivity and adaptation indexes, an index system was constructed to comprehensively diagnose the ecological degradation of world natural heritage sites with threat factors, resilence ability of heritage sites and changes of heritage value factors as the criterion layers, and the diagnostic analysis results provided a scientific basis for conservation and management of heritage sites.

(2) According to the world natural heritage diagnostic index system, the ecological degradation distribution of Bogda was obtained. The level of ecological degradation in Bogda area was mainly mild degradation, and the degradation is serious around the scenic spots with intensive tourist activities and along the road. Among them, the area of seriously degraded seriously degraded area is the least, accounting for 1.89% of the study area, followed by ecological health area (6.22%), moderate degradation area (13.87%), and mild degradation area (78.03%).

(2) The overall conservation management degree in the study area was good. Low -low -low type was the main structure type of ecological degradation in Bogda, followed by high -high -high type, high -high -low type, and low -high -high type.

Discussion

The diagnosis of ecosystem degradation is an important reference for judging the contradiction of protection and utilization of World Natural Heritage. Tourism is widely regarded as one of the best ways to promote the protection and utilization of protected areas. It can bring positive influence and economic benefits to the local government and communities, and provide another livelihood for residents [10, 46]. But the pressure of tourism on the environment and resource of heritage site is increasing [47]. Under the requirement of integrity and authenticity, how to manage tourism has become an important challenge for heritage sites. Therefore, in the process of tourism development, the managers of heritage sites should pay more attention to the impact of the type and intensity of tourism activities on different regions [34]. The tourism activities should try to avoid the fragile areas and sensitive areas, so as to reduce the impact on the Outstanding Universal Value of heritage sites. At the same time, the protection and management of heritage sites is a dynamic process, which needs to obtain more scientific research and technical support. Heritage monitoring can systematically monitor and evaluate the WNHS, which has become the urgent need of heritage protection [30]. Monitoring sites should be established in high heritage value areas, sensitive areas, vulnerable areas, human activity gathering area and geological disaster-prone areas to acquire and accumulate data on the production process, ecological changes and tourism impacts of heritage sites. Through the analysis of monitoring data, early warning and defense measures should be taken for high risk degradation areas, and the adaptive management of construction projects should be realized by using the assessment and monitoring results, so as to maintain the health of ecosystem value, reduce the harm of heritage value and realize the sustainable development of heritage sites.

This paper made a systematic exploratory study on the diagnosis of world natural heritage degradation, and took Bogda in Xinjiang Tianshan Mountains as an example to make an empirical analysis. However, due to the limitations of authors' academic level, research field, and lack of access to relevant information caused by various reasons, the research still need to be further improved and perfected in the following aspects.

(1) The diagnostic index and threshold value of ecological degradation need to be improved. Index selection and threshold determination are very important processes in the diagnosis of world natural heritage degradation. Marine natural heritage was not considered in this paper because of the great difference between marine and terrestrial systems. Although the degradation diagnostic indicators represent the important value elements of natural heritage, they may not be fully representative. At present, there is no unified measurement method and evaluation index for degraded ecosystem. The index weight and threshold value in this paper were mostly determined based on the empirical value given by experts and previous research results, so the scientificity of evaluation results was affected by some subjective factors. In the future, the relevant theories of degraded ecosystem should be further studied, and the indicators and thresholds of degradation diagnosis should be supplemented and improved, so that the degradation status of the world natural heritage could be accurately and comprehensively reflected in the diagnosis. On this basis, the intervention degree and mode of ecological restoration can be accurately selected.

(2) Diagnosis of ecological degradation of natural heritage sites under climate change is a challenge. The extreme climate events brought by global warming bring severe tests to the allocation of water resources, environmental improvement and disaster prevention and control in the ecological process. In addition, variables or factors related to climate change may threaten the ecosystem structure and function of natural heritage sites and the distribution of endangered and endemic species, further aggravating the vulnerability of ecosystems and leading to ecosystem degradation. Climate change needs to be incorporated into the diagnosis of ecological degradation, conservation

management and planning in the future. The risk of climate change should be fully considered, especially the impact of climate change on ecosystem structure, function and suitable distribution area of living things, effective response measures should be taken in advance, and implementation measures suitable for climate change should be formulated to realize the sustainable development of natural heritage.

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Conflict of Interest

The authors declare no conflict of interest.

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