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Ecological effects of the road and railway in the Golmud-Lhasa section of the Qinghai-Tibet traffic corridor

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Abstract: The Qinghai-Tibet corridor includes road and railway in the highland area, characterized as the highest altitude, longest route and various sensitive ecosystems. Quantitative analysis of ecological effects along the Qinghai-Tibet corridor is critical to understand the impact of different traffic infrastructure on global hotpot of biodiversity maintenance. In this study, the Golmud-Lhasa national highway, railway and expressway were selected to analyse the impact of buffer zone and the pattern of landscape, thereby clarify the land use change, vegetation dynamics and landscape change. The results showed that the dominant type of grassland decreased and unused land increased in 2020 within the national highway buffer zone. As for railway station buffer zone, dominant grassland and unused land decreased while construction land increased in 2020. In buffer zones of national highway, there were contrary trends in cropland across periods, which decreased in 2000 and 2020 while increased in 2010; in different periods, the proportion of forest, water body and unused land increased, while the proportion of shrubland and construction land decreased, and waterbody and grassland were increased obviously within 0-3000m. In buffer zones of railway station, there were threshold effects in each land use types alongside distance gradients, in details, the threshold of grassland, shrubland and unused land was about 8000m. The vegetation status in the national highway and railway station buffer zone were improved over time, especially in the buffer zone of railway stations in 2010 and 2020. The results of landscape pattern index showed that although the highway construction caused the increased landscape fragmentation, it also improved the diversity and evenness of landscape. Therefore, the future expressway construction should be aimed at improving connectivity and maintaining stability.

Keywords: Qinghai-Tibet traffic corridor; national highway; railway; expressway; ecological effect; landscape pattern

1. Introduction

Transportation construction engineering is characterized by long distance and wide coverage, and the complex and diverse types of ecosystems alongside have complex impacts on the ecological environment, making them a research hotspot in the field of ecological environmental protection [1]. Transportation corridors have greatly contributed to rapid socio-economic development, but also generated a series of ecological and environmental problems [2,3] In the last two decades, with the development of transportation infrastructure and the increasing focus on ecological environmental protection, the study of road ecology has gradually emerged, which provides valuable scientific suggestions for transportation infrastructure by analyzing the interrelationship between roads and the surrounding environment [4].

With the economic and social development, the ecological impact of transportation is not only on main roads, but also involving ecological effects of railway and expressway. Theoretical summaries and quantitative analyses of linear transportation ecological effects on landscape, biology, habitat, and pollution have been conducted in many researches [5,6,7]. Relevant results expand the practical application of road ecology from multiple perspectives. However, most of the studies focus on the analysis of ecological effects generated by single pattern while neglected the ecological impacts generated by different forms of transportation infrastructure, especially in regions where both highway and railway are the dominant transportation patterns.

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Qinghai-Tibet Plateau as the Asia water tower is the important ecological security barrier in China. The high-altitude and low temperature geoclimatic characteristics make the regional vegetation and soil extremely sensitive to climate change, which is known as a "sensitive area" for global change research [8]. The interactions between environmental and surface processes on the Qinghai-Tibet Plateau create a series of ecological effects in the context of climate warming, and thus further increased ecosystem instability [9]. The contradiction between the instability of ecosystems and the pressure of human activities such as transportation construction may further increase the ecological vulnerability, which leads to a series of ecological degradation problems such as vegetation degradation, soil erosion and desertification, especially the destruction of large alpine grassland ecosystems [10]. As part of the Qinghai-Tibet corridor, railways and highways on the Qinghai-Tibet Plateau are geographically close to each other with large altitude span, and the related ecological effects need to be further clarified. Quantitative analyses targeting ecological effects along railroads and highways can help clarify the impacts of transportation infrastructure on Asian ecological security barriers and global biological hotspot reserves. Therefore, this study took the railway and national highway in the Golmud-Lhasa section (referred to as the Golmud-Lhasa section) as the research object, and analyzed the changes of land type, vegetation cover and landscape pattern in different construction forms to clarify the ecological effects generated by the construction and operation of the transportation corridor.

2. Materials and methods

2.1 Study area

The Golmud-Lhasa section of Qinghai-Tibet traffic corridor (Figure1, 29°38 - 36°24′N, 90°32′-94°55′E) includes highways and railways, including the recently opened Nagqu-Lhasa section of the expressway, ranging from 2756m to 6226m. The average annual temperature ranges from -6 to 20°C and decreases from southeast to northwest. Due to the influence of climate and mountains, precipitation on the Qinghai-Tibet Plateau has obvious spatial differences, with annual average values ranging from 50 to 2000 mm [11]. The regional temperature of the Qinghai-Tibet Plateau is significantly negatively correlated with latitude and altitude, the daily difference in temperature is large and the interannual variation is small [12]. The Golmud-Lhasa section of the Qinghai-Tibet Railway is 1142 km long, of which 84% is locate at high altitude over 4000 m. The Nagqu-Lhasa Expressway is the highest expressway in the world, passing through several landscape zones such as grassland, snow mountains and wetlands along the route, and has been opened to traffic in August 2021.

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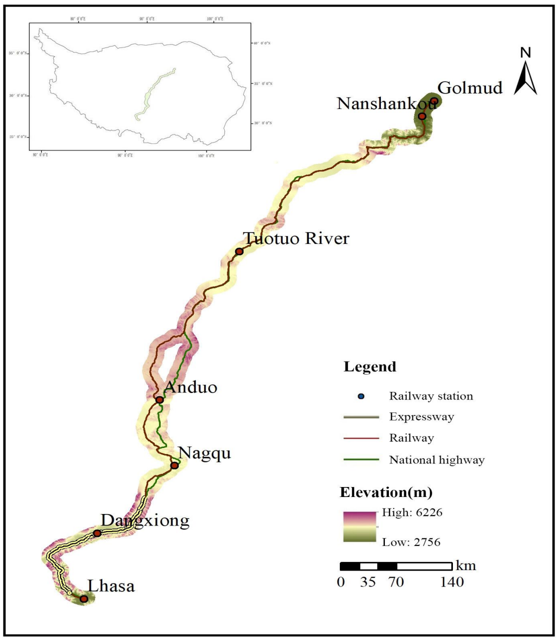

Figure 1. The study area location

2.2 Data preparation

The LUCC (land use and land cover) data used in this study were obtained from the 2000, 2010 and 2020 products of the GlobeLand30 dataset, which was divided into 10 land use types, and were finally combined into 7 categories according to the needs of the study: cropland, forest, grassland, shrub, water, construction land and unused land. NDVI was calculated from the MOD13Q1 product with a spatial resolution of 250 m and a temporal resolution of 16 days for annual maximum synthesis. The calculation of cropping raster and vegetation index for the study area was performed in GEE (Google Earth Engine). The data of highways and expressways were obtained from 20Q4 NIMIF-G Navigation Electronic Map Data (2020); the railway data were obtained from National Basic Geographic Information Data.

The Normalized Difference Vegetation Index (NDVI) is a vegetation index commonly used to reflect the vegetation growth status, which is sensitive to green vegetation [13]. The calculation equation is as follows.

$$\mathrm{NDVI} = \left(\frac{\mathrm{IR} - \mathrm{R}}{\mathrm{IR} + \mathrm{R}}\right) \tag{1}$$

where IR is the pixel value in the infrared band and R is the pixel value in the red band. The remote sensing images were subjected to raster annual maximum calculation.

2.3 Materials and Methods

2.3.1 Buffer analysis

This study used buffer analysis to calculate the influence of national highway and railway on land use and vegetation index variations. The buffer zones of national highway and railway stations were selected as 200, 500, 1000, 1500, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, 10000 m. For the categorical variable land use types, Tabulate Aera in ArcGIS10.8 was used to calculate the area of various land use types within the buffer zones. For the continuous variable NDVI, the Zonal Statistics as Table tool in ArcGIS10.8 was used to calculate the mean values of NDVI within different buffer zones, and the line graph of NDVI changes with increasing buffer distance was plotted.

2.3.2 Landscape pattern analysis

Considering the expressway construction is still in the non-operational period, the analysis mainly focused on the impact of expressway construction on the landscape pattern. This study was

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based on the 2020 road data (the Nagqu-Lhasa Expressway is in the partial completion stage), so the impact on the regional landscape pattern was only calculated within the partially opened sections. This study calculated the multiple landscape pattern indices including Patch Density (PD), Largest Patch Index (LPI), Edge Density (ED), Fractal Dimension Index_Mean (FRAC_MN), Landscape Division Index (DIVISION), Aggregation Index (AI), Shannon's Diversity Index (SHDI), Shannon's Evenness Index (SHDI), Contagion (CONTAG) at the landscape and patch class levels by using Fragstats 4.2.

3. Results and Discussion

3.1 Interannual area variation of different land use types within the buffer zone

The interannual variation of different land use areas within the 10km buffer zone alongside the national highway can be derived from Figure 2a. The area of cropland varied greatly between years, and the area of forest was close to the area of grassland, which was the dominant land use type in the buffer zone and decreases in 2020. Unused land was the dominant type behind grassland, with a larger increase between 2010 and 2020. The interannual variation of the area of different land use types within the 10km buffer zone near the railroad station can be derived from Figure 2b. The area of cropland showed a decreasing trend followed by an increasing trend; the interannual variation of forests was not obvious; the area of grasslands showed a little change from 2000 to 2020; the area of shrubland showed a slight decrease between years; the area of water body showed a significant increase from 2010 to 2020; the area of construction land showed an increasing trend between years and nearly doubled from 2010 to 2020; the area of unused land showed a decreasing trend between 2010 and 2020.

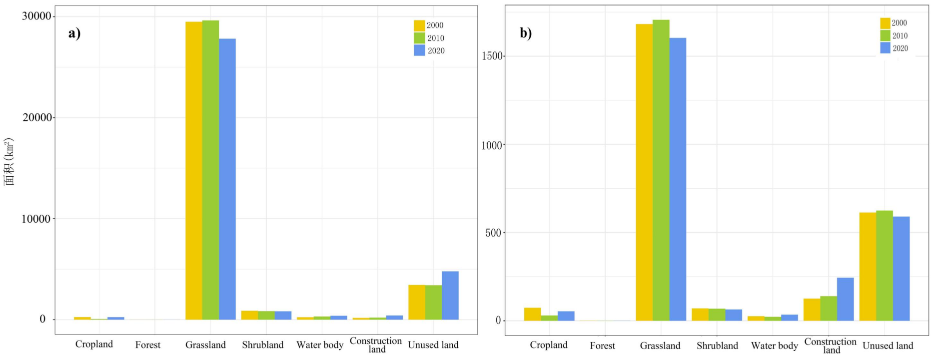

Figure 2. Land type area within 10km buffer zone of national highway and railway station （a. National highway；b. Railway station）

3.2 Effect of buffer distance on land use distribution

3.2.1 Influence of buffer distance on land use distributions of national highway

There were obvious inter-annual variations in the distance gradient of cropland distribution of national highway, which showed an overall decreasing trend in 2000 and 2020, while an increasing trend in 2010 (Figure.3a). The distribution of forest, grassland, shrubland, water body, construction land and unused land were consistent with the increase of buffer distance. The distribution of forest generally tended to increase, and only decreased at 3000-4000m and 7000-9000m (Figure.3b). The distribution of grassland increased in the range of 0-3000m, then remained constant, and showed a slight increase at first and then a slight decrease in 2020 (Figure.3c). The distribution of shrubland in general showed an increasing trend and then decreased, and the decrease in 2020 was more drastic than the other years outside the distance of 4000m (Figure.3d). The distribution of water body fluctuated more obviously but showed an increasing trend in general (Figure.3e); the distribution of construction land in general showed a decreasing trend, and the decrease in 2020 was less than the rest of the years (Figure.3f). The distribution of unused land generally showed an increasing trend, in 2020 it showed a sharp rising trend after 3000m, and the magnitude was greater

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than the other years (Figure.3g). Generally, the productive land use types increased with the increasing buffer distance, and forests and shrubland were positively correlated with distance within 3km, indicating that the main range of the impact of national highway on natural ecosystems was within 3km.

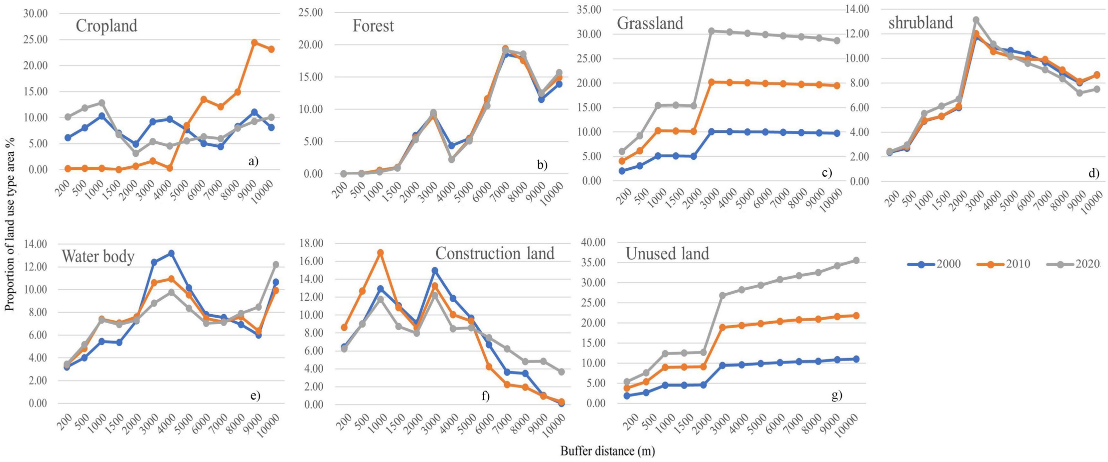

Figure 3. The influence of national highway buffer distance land use area distributions

3.2.2 Influence of buffer distance on land use distributions of railway station

According to the buffer analysis of railway station, the distance trends of cropland and water distribution in the buffer zone of railway station had relatively obvious interannual variation. The distance trends of cropland distribution generally increased in 2000 and 2020, while fluctuated in 2010, especially in 8000-10000m (Figure.4a). The inflection point of the distance trend of water body distribution in each year was at 4000m, and the decrease degree was higher in 2000 (Figure.4e). The interannual variation of forest, grassland, shrubland, unused land and construction land remained relatively consistent. The distance trend of forest distribution showed an overall increase but a sharp decline at 9000-10000m (Figure.4b). The distance trend of grassland distribution increased within 0-8000m and increased sharply after 3000m (Figure.4c). The distance trend of shrubland distribution increased within 0-8000m as well as decreased sharply after 8000m (Figure.4d). The distribution of construction land showed obvious fluctuation in general, and increased within 0-4000m, moreover the fluctuation of the change in 2020 was less (Figure.4f). The distribution of unused land increased in the range of 0-8000m and a sharp decrease after 8000m (Figure.4g). The construction of railway stations led to passenger flow increase, and the continuous optimization of the layout of the stations drives the development of the surrounding infrastructure. In this study, the positive correlation between forest, shrub and grassland area and distance were more obvious in the range of 3-8km, indicated that the ecological recovery is faster in the region outside 3km.

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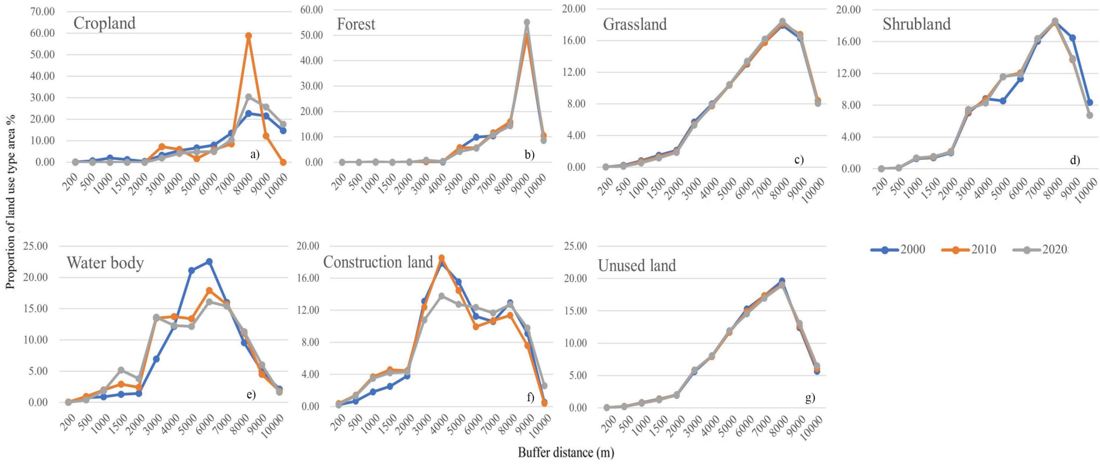

Figure 4. The influence of railway station buffer distance on area proportions of land use types (a. Cropland; b. Forest; c. Grassland; d. Shrubland; e. Water body; f. Unused land; g. Construction land.)

3.3 Influence of buffer distance on vegetation index between years

The buffer area of Qinghai-Tibet corridor was a low vegetation cover area. The mean values of vegetation indices of different buffer zones were calculated by using MOD17A3H NDVI product and the trend graphs were plotted with the increase of buffer area extent. The results showed that the average NDVI in the buffer zone of the national highway was 2000, 2010 and 2020 in descending order. In each year, NDVI increased slowly with distance in the 0-3000m buffer range, and the difference between 2000 and 2010 was not significant in the 0-500m range. The NDVI decreased with distance after 6000m, and greatest decrease appeared in 2000 (Figure 5a). In general, the NDVI of the buffer zone of highway didn’t vary significantly with distance. This could be attribute to the surrounding vegetation restoration measures taken during national highway construction, and the productivity increase caused by the increase in interannual variability of precipitation and temperature on the Tibetan Plateau [14].

The interannual variation of NDVI mean value changed with increasing distance in the buffer zone of railway station, which was different from that in the buffer zone of highway. The trend in 2000 was more different from that in 2010 and 2020. In the range of 0-1000m, NDVI increased with increasing buffer distance in different years, in the buffer zone of 1000-2000m NDVI showed a decreasing trend in 2000, while the remaining two years showed an increasing trend. After 2000m, the increasing trend of NDVI was obvious in all years (Figure 5b). The operation of the railway project promoted the great development of towns along the route, and the scale of town and village and industrial and mining land increased significantly, which promoted the socio-economic prosperity and development along the route [15]. In 2020, result showed the highest NDVI change rate with increasing distance, reflecting a significant improvement in vegetation recovery around the railway.

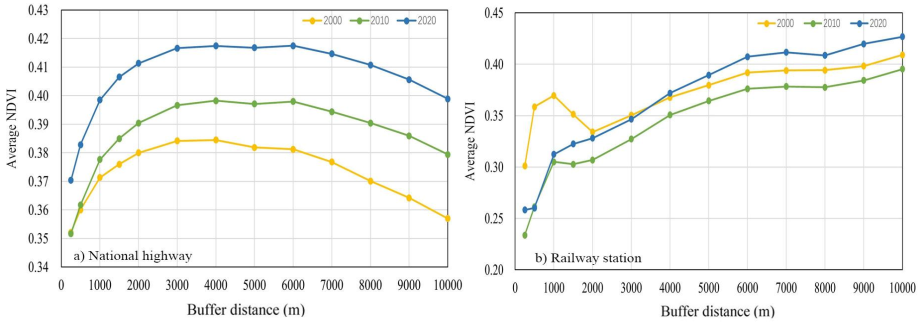

Figure 5. The NDVI trends with buffer distance of national highway and railway station (a. 10km buffer area of national highway; b. 10km buffer area of railway station)

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3.4 The impact of expressway construction on the landscape pattern

3.4.1 Impact of expressway construction at landscape level

Table 1 compared the changes in landscape level indices before and after the highway construction, showed decrease in PD, LPI, AI and CONTAG, and increase in ED, LSI, DIVISION, SHDI and SHEI after the national highway construction, while FRAC_MN remained almost unchanged. The increase in ED and LSI reflected the deterioration of overall landscape stability and increase in dispersion; the decrease in CONTAG and AI and the increase in DIVISION reflected reduced connectivity and aggregation with higher fragmentation. The increase of SHDI and SHEI reflected the increase of habitat diversity and homogeneity due to highway construction; the increase of SHEI and decrease of LPI also reflected the decrease of dominant type dominance in the landscape and the trend of homogenization. In landscape ecology, the highway had the dual function of ecological channel and barrier, serving as a bridge and link between ecosystems. The barrier function was to hinder the migration of species, while the ecological channel function promotes the material and energy exchange with other landscape elements.

Table1. Comparisons of landscape pattern indies on the landscape level

	PD	LPI	ED	LSI	FRAC_MN	DIVSION	AI	CON TAG	SHDI	SHEI
A	4.05	74.06	21.38	39.13	1.0409	0.45	97.05	76.88	0.76	0.39
B	4.17	76.58	20.88	38.27	1.0408	0.41	97.11	79.22	0.68	0.35

(A represented after expressway construction; B represented before expressway construction.)

3.4.2 Impact of expressway construction at patch class level

Based on the understanding of the landscape pattern of the whole region from the landscape level, the patch class level could specifically describe the landscape pattern of each land use type and analyzed its changes before and after the construction of the expressway. From Table 2, the LPI of cropland decreased significantly, grassland and water body decreased slightly, and construction land increased after the construction of the expressway, reflecting the above changes in land use dominance and dominant role. The increase of ED and LSI of grassland and construction land reflected the decrease of stability and increase of dispersion; the decrease of ED and LSI of shrubland and water body indicated the increase of stability and decrease of dispersion. From the change of FRAC_MN, the slight increase of cropland and construction land reflected the increase of complexity and resistance to disturbance. From the change of AI, the aggregation of cropland and water body decreased, while the aggregation of shrubs and construction land increased. In general, the grassland ecosystem was more sensitive to highway construction, which made the grassland type patches more discrete and increase in shape complexity, and had less impact on shrubland and forest.

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Table 2. Comparisons of landscape pattern indies on the patch class level

Land type	Stage	PD	LPI	ED	LSI	FRAC_MN	DIVISION	AI
Cropland	A	0.017	0.27	1.40	20.05	1.08	1.00	93.66
	B	0.009	1.71	1.56	19.28	1.07	1.00	94.75
Forest	A	0.212	0.0035	0.6076	36.07	1.04	1.00	50.94
	B	0.213	0.0035	0.6082	36.10	1.04	1.00	50.92
Grassland	A	0.505	74.06	20.24	40.97	1.0459	0.45	98.20
	B	0.502	76.58	19.72	39.35	1.0457	0.41	98.30
Shrubland	A	3.22	0.48	11.96	117.31	1.0394	1.00	73.51
	B	3.33	0.48	12.40	120.18	1.0396	1.00	73.14
Water body	A	0.06	0.03	0.39	15.13	1.041	1.00	86.99
	B	0.07	0.16	0.51	16.81	1.038	1.00	87.88
Construction land	A	0.01	0.51	1.75	15.13	1.09	1.00	97.17
	B	0.01	0.31	0.54	10.07	1.07	1.00	96.07
Unused land	A	0.03	0.79	6.41	33.29	1.11	1.00	96.35
	B	0.03	0.79	6.41	33.29	1.11	1.00	96.35

(A represented after expressway construction; B represented before expressway construction.)

4. Conclusion

The construction of national highway and railway on the Qinghai-Tibet Plateau has been epoch-making for the economic development of the region, breaking the shackles of severe geographical conditions on industrial development. The interaction between transportation construction and land use has a multifaceted impact on the ecological environment of the regions along the corridors, which can be quantified by studying land use changes, vegetation changes and landscape pattern changes around the corridors. Most of the previous published studies focused on the ecological impacts of the main roads, while ignoring the ecological impacts of different forms of transportation infrastructure. The Qinghai-Tibet traffic corridor is located in the ecologically sensitive and fragile area of the "roof of the world", and most of the national highway and railway are distributed in close proximity to each other.

In the buffer zone of national highway, the results showed an increasing trend of forest and unused land, but a decreasing trend of construction land with increasing distance, while the cropland showed a decreasing trend in 2000 and 2020 and an increasing trend in 2010. As for railway station, results found that the positive correlations between forest, shrub and grassland area and distance were more obvious in the range of 3-8km. In terms of vegetation index, the buffer zone of the railroad station improved significantly with distance in 2010 and 2020, and the buffer zone of the national highway increased with distance in the range of 0-3000m, reflecting the influence of both ecological restoration projects and climate change on regional vegetation. Analysis of expressway construction from landscape pattern changes indicated that further construction caused an increase in landscape fragmentation and complexity, while also increasing landscape diversity and uniformity, suggested that the negative impact on landscape patterns can be mitigated through landscape restoration techniques. For example, roadside ecological protection and restoration of the Nagqu-Golmud section of the highway, based on the natural vegetation succession laws and the basic principles of ecological restoration, contributed to the near-natural recovery of vegetation, while established ecological corridors to promote material transfer and information exchange, accelerated the improvement of ecological coordination and stability of the roadside in alpine regions. This study will also provide reference to the impact of the construction of the corridor in other biological hotspots around the world.

Regarding the study of ecological effects of the Qinghai-Tibet Passage, further analysis could be consider: 1) using remote sensing products from multiple sources for comparative analysis to

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reduce the measurement errors caused by individual products; 2) taking the engineering impacts related to the road into account, adding the analysis of bridges and tunnels to identify the ecological effects generated by different construction methods; 3) combining field surveys with remote sensing analysis for comprehensive research to verify the results of large-scale.

Acknowledgements

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