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Approaches to prediction of impact of Qinghai-Tibet Railway construction on alpine ecosystems alongside and its recovery

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Abstract **With the aid of the Remote Sensing (RS) and Geographic Information System (GIS) technology, the ecosystem pattern and fragility distribution maps of the 50-km-wide zone along the Qinghai-Tibet Railway were compiled and by using the superimposition method, range, area and indexes of the impact of various engineering activities on the ecosystems alongside the railway were studied. By making reference to the ecosystem recovery process of the Qinghai-Tibet Highway, mechanisms of recovery of the alpine ecosystems alongside the Qinghai-Tibet Railway were studied and extents and rates of the recovery were predicted. The results indicate that the impact of the railway engineering on the Alpine ecosystem depends mainly on how much the original surface soil in the zone has been disturbed and how fragile of the ecosystem *per se*. Restoration of vegetation coverage and species abundance shows a significantly reverse relationship with disturbance of the original surface soil but an extremely positive one with the length of the restoration period and mean annual precipitation and annual mean relative humidity in the period and no obvious bearings with altitude and temperature. In sections with an annual precipitation over 200 mm, as long as a certain percentage of original soil is left *in situ*, it takes only 30 years or so for biodiversity to get basically restored to the original level after the construction is completed but at least 45—60 years or more for vegetation coverage.**

Keywords: Qinghai-Tibet Railway, alpine vegetation, ecological impact, prediction of recovery.

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Studies indicate that construction of railroads and highways, as a result of its incision, separation, inhibition or disturbance, generates a varied degree of impact on the wetland biodiversity, amphibious communities, tropical mountain forests, understories of the broad-leaved forest landscape, etc.[1—4]. Rebecca A. Reed et al. picked up the number of patches, mean patch acreage, mean patch perimeter, mean patch shape, variation of patch boundary, Shenon index, etc. as indicators and analyzed the impact of the Rocky Mountain Highway on forest fragmentation with the aid of GIS system[5]. Some scholars have already carried out systematic studies on evaluation of environmental sensitivity of urban highway networks with the help of Analytic Hierarchy Process (AHP), Fuzzy Set Theory (FST), Knowledge-Based Expert Systems (KBES) and GIS[6]. And some have elucidated from different angles the impact of construction of expressways on eco-environment and its restoration with the Jing-Da Expressway, Zhoukou Section of the Expressway in Henan, Huang-Huang Expressway in Hubei and Ning-Xia Expressway separately as a case for study[7—10].

Currently in China, the study on impact of railway construction on eco-environment is mainly concentrated on approaches to predication and assessment of the impact. AHP, Fussy Synthetic Evaluation and matrix semi-quantitative prediction are quite extensively used methods[11,12]. The Qinghai-Tibet Plateau is an area with the highest altitude and the fragilest eco-environment on the earth, but also one of the zones that are so far least disturbed by human activities. Now the construction of the Qinghai-Tibet Railway is under way. The world is very much concerned about how it will affect the alpine vegetation and the eco-environment in the zone and whether they can be restored after damage and disturbance by the construction. The impact of the railway construction on landscape vision and soil erosion were studied by Zhang Hui, Zou Changxin and Shen Weishou et al.[13—15]. In this study, ways and extents of the impact of the construction on the Alpine eco-systems in the zone were analyzed with the aid of RS & GIS technology and extents and rates of restoration of the Alpine eco-system were predicated by means of analogy.

1 General information about the study zone

The Qinghai-Tibet Railway under construction is planned to be 1142 km long stretching southwards from Golmud to Lhasa through Qinghai Province and the Tibet Autonomous Region. The section of the railway in Qinghai Province is 596.58 km (31.75 km already existing), linking Golmud City in Haixi Prefecture and a number of counties in Yushu Prefecture whereas the section on the territory of Tibet is 545.54 km long, running through Anduo County and Naqu County in Naqu Prefecture, Dangxiong County, Duilongdeqing County and Lhasa city.

The entire railway is running on the Qinghai-Tibet Plateau, except for a small section at its northern end from Golmud to the Southern Mountain Pass at the southern edge of the Qaidam Basin. The section from the Southern Mountain Pass to the Kunlun Mountains at the northern end and the one from Yangbajing to Lhasa at the southern tip both go through valley landforms with sharp falling gradients. The middle section from the Kunlun Mountains to Yangbajing is of typical high plain in landform, rather flat in topography and over 4500 m in altitude on average.

So the train will go from north to south through a number of mountains, such as the Kunlun Mountains, Kekexili Mountains, Fenghuo Mountains, Wuli Mountains, Kaixinling Mountains, Tanggula Mountains, Touerjiu Mountains, and Sangxiongling Mountains, Jiuzina Mountains and Yangbaling Mountains of the Nianqing Tanggula Mountains. All these mountains look like camel hemps undulating with an average difference in altitude being less than 300 m and show a unique highland landscape "which looks like mountains at a long distance but plains at a short one" because of their smooth round mountain tops and flat slopes, forming a rather flat landform macroscopically.

As the new Qinghai-Tibet Railway goes from north to south, it cuts through Qinghai and Tibet, which are both very diversified in pattern of landforms and climatic condition that changes significantly with the vertical altitude (2800—5600 m) and have well-developed gelisols and unique habitat conditions, thus making the zones alongside the railroad very rich and unique in ecosystem, including typical desert, valley bushwoods, alpine steppe, alpine meadow steppe, alpine meadow, alpine bushwoods, alpine ice and snow, alpine swampy steppe, alpine swamp, lacustrine wetland, fluvial wetland, temperate steppe, etc. As a result of the severe natural conditions on the Qinghai-Tibet Plateau, the alpine ecosystems there are very peculiar and fragile and extremely sensitive to anthropogenic disturbance.

2 Impact of the railway construction on the alpine ecosystems in the zone alongside

(i) Compilation of the alpine ecosystem type map and calculation of fragility of the ecosystems. On the basis of field survey, by making use of the latest Landsat-5 TM and Landsat-7 ETM+ image data, 1∶250000 electronic relief maps, vegetation type maps, land use maps, steppe type maps, soil type maps, etc. an ecosystem type map of the zone 50 km in radius alongside the Qinghai-Tibet Railway was compiled with the aid of the 3S technology.

Fragility is an important measurement of the extent of human disturbance to the ecosystem. In this study, the following equations were used to calculate fragility of each type of ecosystem in the zone[16]:

$$G = 1 - \sum_{i=1}^{n} Pi \cdot Wi \Big/ \left(\max \sum_{i=1}^{n} Pi \cdot Wi + \min \sum_{i=1}^{n} Pi \cdot Wi \right),$$

where G stands for fragility; Pi for initial value of the characteristic index of the fragile ecosystem and environment; and Wi for weighed value of each index.

According to fragility, the ecosystems can be sorted into four categories: $G \geqslant 0.65$ being extremely fragile; $0.65 > G \geqslant 0.45$ being very fragile; $0.45 > G \geqslant 0.3$ bing moderately fragile; $G < 0.30$ being slightly fragile.

Characteristics of the ecosystems and environments of the zone are presented with the following indexes including natural factors such as altitude, precipitation, vegetation coverage, Shanon-Winner diversity, plant species saturation, soil layer thickness, primary productivity, etc. and impact exhibition indexes such as coefficient of the sensitivity of the ecosystem to the engineering disturbance, restorability coefficient, etc. (Table 1).

Table 1 Fragility indexes of the ecosystems alongside the section of railway from the Tanggula Pass to Lhasa

Ecosystem	Natural factor index							Impact exhibition index	
	Altitude/m	Precipitation /mm	Vegetation coverage (%)	Shanon-Winner diversity	Plant species saturation/m^2	Soil layer thickness /cm	Primary productivity/kg·hm^{-2}	Ecosystem sensitivity coefficient	Restorability coefficient
Temperate steppe	3500—4300	300—400	15—45	0.44	5—15	5—10	1320—2800	0.30	0.6
Alpine steppe	4300—5200	100—300	10—50	0.37	5—10	5—20	850—2650	0.35	0.5
Alpine meadow steppe	4300—5200	300—400	20—40	0.42	8—12	10—30	750—2720	0.40	0.4
Alpine meadow	4000—5200	300—500	70—90	0.37	6—14	20—50	950—2350	0.50	0.3
River valleys	3700—5100	300—600	0—15	0.22	—	—	50—1000	0.45	0.3
Lakes	3800—5000	300—600	0—2	0.15	—	—	10—100	0.75	0.1
Alpine swampy meadow	4000—5100	300—600	80—90	0.50	9—16	20—50	850—3500	0.85	0.1
Alpine bushwoods	4000—5000	300—500	30—50	0.53	8—20	20—40	750—1800	0.45	0.5
Farmland	3500—4000	200—400	10—95	0.48	10—15	10—30	7500—15000	0.30	0.4
Alpine ice and snow	4500—6200	300—800	0—2	0.07	0—1	0—10	0—10	0.90	0.2
Weighed	0.07	0.08	0.10	0.05	0.05	0.07	0.08	0.25	0.25

Using means in the calculation.

From the calculation, it could be found that the ecosystems of alpine ice and snow and lakes are of the category of extremely fragile; the ecosystems of alpine swampy meadow and rivers, the category of very fragile; the ecosystems of alpine steppe, alpine meadow steppe, alpine meadow and alpine bushwoods, the category of moderately fragile; and the ecosystems of temperate steppe and farmland, the category of slightly fragile (Table 2).

Table 2 Fragility of the ecosystems alongside the section of railway from the Tanggula Pass to Lhasa

Ecosystem	Fragility	Assessment
Alpine ice and snow	0.858	extremely fragile
Temperate steppe	0.262	slightly fragile
Alpine steppe	0.413	moderately fragile
Alpine meadow steppe	0.421	moderately fragile
Alpine meadow	0.411	moderately fragile
Alpine swampy meadow	0.610	very fragile
River valleys	0.586	very fragile
Lake	0.830	extremely fragile
Farmland	0.237	slightly fragile
Alpine bushwoods	0.314	moderately fragile

(ii) Ways and extents of the impact of the construction on the alpine eco-systems in the zone. The railway, when put into normal operation, will not have much impact on the ecosystems and biodiversity in the zone, while the disturbance and damage of its construction is rather striking. During the construction of a railway, it is essential to lay out roadbeds (leveling, excavating and filling), set up sites for storage of gravels and sands and for excavation and dumping of earth, and build up temporary roads and working sites (including living quarters), bridges, culverts, tunnels and permanent buildings and facilities. All these engineering activities will certainly cause varied impact on the ecosystems (Table 3).

The construction of the railway is a kind of disturbance to the ecosystems. Based on the ecological succession theory, species diversity declines in the disturbed or damaged ecosystem, but after the disturbance stops, the diversity index will rise with the succession going on and restore its original level[17]. When the damage or disturbance is serious, the species diversity will be reduced to a much lower level in value and then its restoration will take a longer time, and *vice versa*.

In this reseach, impact of the construction on the alpine ecosystems of the zone was calculated by the following formula;

$$CI = \int_0^\infty A(x) \cdot B(x) \cdot C(x) \mathrm{d}x,$$

where CI stands for impact index; x, for the variable of construction nature; $A(x)$ for extent of the damage the original surface soil and vegetation have received; $B(x)$, for the function of engineering work load, expressed in percentage of the acreage affected or damaged; and $C(x)$, for fragility of the eco-system.

In this case, the equation goes like this:

$$CI = (a_1 b_1 + a_2 b_2 + \cdots + a_n b_n) \cdot c_i,$$

where a_i stands for extent of the damage or disturbance construction of different has brought to the original surface soil; b_i, for percentage of the acreage of the affected or damaged part of a certain ecosystem against the whole within the zone; and c_i, for fragility of Ecosystem.

With the GIS technology as a tool and the data of the engineering designing as a basis, all the engineering activities were superimposed on an ecosystem type map, and scale and area of the impact of various engineering activities on the ecosystems in the zone were calculated. And then based on the above-listed equation, indexes for assessment of impact of the construction on the ecosystems and biodiversity in the zone were figured out as listed in Table 4.

As shown in Table 4, the degrees of impact of the construction on the various ecosystems, i.e. C values, were arranged in a decreasing order of alpine meadow > temperate steppe > alpine meadow steppe > alpine steppe > farmland > alpine swampy meadow > river valleys. The lake ecosystems, alpine ice and snow ecosystems and al

Table 3 Impact and disturbance coefficients of the construction on the ecosystems

Item	Way of impact	Disturbance coefficient[a)]
Roadbeds, permanent buildings and facilities	The vegetation and plant species in the site are thoroughly destroyed and the vegetation coverage and plant species diversity are reduced to zero. It leads to linear scission of the ecosystems and landscapes and fragmentation of the habitat.	1.0
Excavation and dumping of earth	The vegetation and soil structure are thoroughly destroyed and the vegetation coverage and plant species diversity are reduced. The damaged vegetation and species diversity will begin their slow natural recovery after the construction is completed.	0.9
Temporary roads	Rolling of transport machinery (vehicles) destroys surface vegetation and soil structure and reduces vegetation coverage and species diversity. The damaged vegetation and species diversity will begin their slow natural recovery after the construction is completed. The restoration rate depends on how much the original soil and vegetation is damaged.	0.7
Bridges and culverts	The soil structure and vegetation is not seriously damaged and the surface vegetation and species diversity will naturally rehabilitate at considerable rates.	0.3
Tunnels	The soil structure and vegetation is not very much damaged, except for at the entrance and exit of a tunnel.	0.1
Temporary living quarters	The soil structure and vegetation is damaged to a certain extent and natural restoration of the damaged surface vegetation and species diversity will proceed at a fairly high rate.	0.5

a) Obtained from two circulations of questionnaire with the Delphi method and after normalization.

Table 4 Indexes for assessment of impact of the construction on the ecosystems and biodiversity in the zone

Type of ecosystem	Land coverage of the project /hm^2	% of the ecosystem n the zone 2 km wide alongside the railway	% of the ecosystem in the zone 50 km wide alongside the railway	Impact index	Standardized value on the basis of 100 being the highest	Order in terms of impact degree
Alpine ice and snow	0.0	0.000	0.000	0.0000	0.0000	8
Temperate steppe	313.7	1.922	0.096	0.4857	87.3884	2
Alpine steppe	127.7	1.064	0.081	0.4000	71.9619	4
Alpine meadow steppe	251.0	1.041	0.044	0.4165	74.9372	3
Alpine meadow	1729.5	1.526	0.061	0.5558	100	1
Alpine swampy meadow	115.4	0.378	0.032	0.2191	39.4183	6
River valleys	39.9	0.004	0.000	0.1230	22.1321	7
Lake	0.0	0.000	0.000	0.0000	0.0000	8
Farmland	106.8	0.011	0.194	0.002	45.0971	5
Alpine bushwoods	0.0	0.000	0.000	0.0000	0.0000	8

pine bushwoods ecosystems are often located quite far away from the railway and basically out of the reach of its direct impact.

The alpine meadow ecosystem is the one that is the most extensively distributed in the zone, and also the one that is the most extensively under the impact of the construction. In terms of the indexes for assessment of impact of the construction on the ecosystems and biodiversity, the alpine meadow ecosystem ranks first with a total of 1729.5 hm^2 being occupied or destroyed by the construction, accounting for 1.526% of the ecosystem in the zone 2 km wide alongside the railway and 0.061% of the ecosystems in the zone 50 km wide alongside the railway. Obviously, although the alpine meadow ecosystems has the largest acreage being occupied or damaged, the proportion is rather limited as is against the total of the ecosystems in the zone. Besides, the impact of linear scission of the alpine meadow ecosystems caused by the roadbedding engineering is relatively small in comparison with that of the alpine swamp and swampy meadow ecosystems, because the former is a zonal ecosystems[18], distributed almost everywhere in the Qinghai-Tibet Plateau, except for depressions. It is not easily degraded on a large scale as a result of change in landform of some local sections.

In light of the land areas of the temperate steppe ecosystems, alpine meadow steppe ecosystems and alpine steppe ecosystems occupied by the railway project, the construction renders relatively great impact on the three types of ecosystems. But in terms of fragility of the ecosystems in the zone, the temperate steppe ecosystems is in the category of slight fragile, the alpine steppe ecosystems and alpine meadow steppe ecosystems in the category of moderate fragile, while the lake and river ecosystems are in the category of very fragile, and the alpine swamp and swampy meadow ecosystems and alpine ice and snow ecosystems in the category of extremely fragile. On the whole, although the impact of the construction is relatively great on the temperate steppe ecosystems, alpine meadow steppe ecosystems and alpine steppe ecosystems, they are more capable of standing the disturbance of human activities and also relatively more capable of getting recovered at a high rate after the construction is completed. As long as strict vegetation preserving and restoring measures are adopted during and after the construction, it seems unlikely for the construction to cause any irreversible damage to the three types of ecosystems.

The alpine swamp and swampy meadow ecosystems is the most important ecosystems on the Qinghai-Tibet Plateau. Judging from the indexes for assessment of impact of the construction project on the ecosystems and their biodiversities in the zone, the ecosystems should rank sixth in terms of the extent of the impact they are under. However, it is also a very fragile ecosystems and the most affected one by the roadbedding project among the ecosystems in the zone. Besides the damage to the vegetation and soil in the ecosystems by direct land occupation, the bedding project also break up the ecosystems, which might lead to shrinkage and degradation of the ecosystems. Even though the railway just passes by the ecosystems, it will still interferes with its hydraulic conditions, thus causing shrinkage and degradation of the ecosystems of this type. The construction of temporary roads will also cause relatively great impact on the ecosystems. To pave roads in the ecosystems, it is necessary to use large amounts of pebbles and sands as fillings, which is very destructive to the ecosystems, and meanwhile temporary roads also result in linear scission and fragmentation of the ecosystems, thus leading to shrinkage and degradation of the wetlands.

Judging from the indexes for assessment of impact of the construction project on the ecosystems and their biodiversities in the zone, the river ecosystems are the one under the least impact besides the alpine bushwood ecosystems, alpine ice and snow ecosystems and lake ecosystems and ranks the seventh in the order of impact degree. But bridge and culvert engineering and extraction of sands and pebbles from the river ecosystems will inevitably affect the ecosystems. Although bridge and culvert engineering will not cause much disturbance to the hydraulic processes of the ecosystems, during the construction, the engineering will not only seriously damage the vegetation and landscape of the ecosystems, but the construction site, worker encampment, and daily garbage and sewage from the encampment will also undermine or pollute the ecosystems and affect to a certain extent the health of the ecosystems. Moreover, extraction of sands and pebbles from rivers will damage the vegetation and landscape on the river banks and leave a certain impact on the hydraulic processes of the ecosystems as well.

3 Prediction of restoration of alpine vegetation after being disturbed by the engineering

(i) Prediction method. The Qinghai-Tibet Railway from Golmud to Lhasa goes basically in parallel with the Qinghai-Tibet Highway. Taking into account similarities between the two in alpine vegetation in the zone and in impact of the engineering, an analogous investigation method is adopted in this study, that is, by surveying restoration of the alpine vegetation along the highway, prediction of natural restoration of the alpine vegetation after being disturbed by the construction of the Qinghai-Tibet Railway.

It is over 3 decades since the original soils and alpine vegetations were damaged or disturbed by the construction of the highway. Their natural restoration was investigated with a quadrat investigation method. Sampling lots were set up in typical road sections and sections typical in vegetation type. Some were of damaged or disturbed vegetation under restoration and some of intact original vegetation cited for comparison. The items covered by the quadrat investigation included vegetation coverage, abundance of species, native vegetation type, years of restoration after destruction, mechanical composition and organic matter content of the 0—10 cm surface soil, and natural conditions of the sites, such as altitude, mean annual precipitation, tempreture and relative humidity (Table 5).

In Table 5, the item of extent of restoration of the vegetation coverage (Y1) and the item of extent of restoration of the species abundance are the results of dividing the related value of the sampling lots of vegetation under restoration by that of the sampling lots of native vegetation, i.e. percentage of the restoration as against the original before disturbance; and the item of destructiveness of the original soil (X1) is the proportion of silt, clay particles and organic matter in the disturbed soil against that in the original soil. The lower the percentage, the more serious the damage of the soil.

(ii) Results of the prediction. Through correlation analysis of the data gathered from a total of 168 sampling lots distributed in 21 typical sections along the Qinghai-Tibet Highway, the following correlation matrix (Table 6) was worked out reflecting the relations of the restoration degrees of vegetation coverage and species abundance with the destructiveness of the original soil, dura-tion of the restoration and natural conditions of the sampling lot section. The table indicates that the restoration degrees of vegetation coverage and species abundance are in significantly negotive relation with destructiveness of the original soil and significantly positive relation with duration of the restoration, mean annual precipitation and annual mean relative humidity, but has little relation with altitude and annual temperature, which suggests that restoration of the alpine vegetation depends to a large extent on destructiveness of the original surface soil and the local moisture conditions, rather than altitude and temperature of the locality.

Based on multiple regression analysis of the restoration degree of vegetation coverage and species abundance, destructiveness of the original soil, duration of the restoration, and mean annual precipitation, the following models for prediction were figured out:

$$y1 = 0.416 - 0.797x1 + 1.777\times10^{-2}x2 + 5.820\times10^{-5}x4, \quad R=0.985;$$

$$y2 = -0.255 + 5.181\times10^{-2}x1 + 3.609\times10^{-2}x2 + 1.808\times10^{-4}x4, \quad R=0.933;$$

where $y1$ and $y2$ stand for restoration degree of vegetation coverage and species abundance, respectively; $x1$ destructiveness of the original soil; $x2$ duration of the restoration; $x4$ mean annual precipitation; R multiple correlation coefficient.

Results of the above-described prediction models and the field surveys revealed that the restoration of species abundance proceeded at a quicker pace than that of vegetation coverage. In sections with mean annual precipitation beyond 200 mm, 30 years are long enough for species abundance to restore to its former level before it was destroyed. In comparison, the restoration of vegetation coverage did at a much slower pace. In these sections, when the soil destructiveness reached 30%, i.e. about 70% of the contents of silt, clay particles and organic matter in the original soil were left, vegetation coverage could come back to 70% of the native vegetation coverage after 30 years of restoration, and at least after 45 years or more, the vegetation coverage could then be completely restored. When the soil destructiveness reached 70%, vegetation coverage could only be restored to 40% of the original level after 30 years and to 100% after at least 60 years. What needs illustrating is that the restoration of vegetation to the level before destruction does not mean that the vegetation is completely restored in vegetation composition and relative quantity ratio, let alone renewal of the native type of vegetation. It refers to establishment of vegetation approximate to the native one in type and composition, species diversity and vegetation coverage.

4 Conclusion and discussion

Although the alpine meadow ecosystems is the one

Table 5 Vegetation restoration and natural conditions at various sampling lots along the Qinghai-Tibet Highway

No. of sampling lots	Type of native vegetation	Number of sampling lots	Extent of vegetation restoration	Extent of restoration of species abundance	Extent of soil damage	Duration of restoration/a	Altitude /m	Mean annual precipitation /mm	Annual mean tempera-ture/℃	Annual mean rela-tive humid-ity (%)
			Y1	Y2	X1	X2	X3	X4	X5	X6
1	Barren Gobi desert	8	0.13	0.312	0.725	16	2820	41.8	6.7	6.1
2	Reaumuria kaschgarica desert	6	0.1	0.5	0.762	18	3210	41.8	6.7	6.1
3	Salsola abrotanodes desert	4	0.567	0.583	0.549	22	3670	290.9	6.7	51
4	Kobresia pygmaea meadow	12	0.305	0.602	0.605	21	4670	290.9	-5.2	32
5	Kobresia pygmaea meadow	6	0.268	0.589	0.634	22	4715	41.8	–5.2	32
6	Flow-rock slope parse vegetation	8	0.333	0.692	0.622	22	4630	290.9	–5.2	32
7	Stipa pururea steppe	14	0.455	0.636	0.459	21	4610	248.5	–4	51
8	Kobresia pygmaea meadow	10	0.042	0.219	0.804	15	4520	248.5	–4	6.1
9	Kobresia pygmaea meadow	6	0.365	0.478	0.578	20	4540	248.5	–4	32
10	Stipa pururea steppe	6	0.223	0.556	0.618	19	4940	428.4	–2.9	6.1
11	Kobresia little-dalei meadow	8	0.859	0.666	0.099	25	4810	428.4	–2.9	57
12	Kobresia pygmaea Meadow	6	0.189	0.58	0.707	19	4730	293.4	–2.9	6.1
13	Kobresia pygmaea meadow	6	0.605	0.714	0.254	23	4650	293.4	–1.3	53
14	Kobresia little-dalei meadow	10	0.588	0.625	0.264	21	4520	428.4	–1.3	53
15	Kobresia pygmaea meadow	4	0.543	0.558	0.314	20	4450	293.4	–1.3	51
16	Stipa pururea steppe	12	0.627	0.727	0.266	23	4215	468.1	1.6	53
17	Kobresia pygmaea meadow	10	0.824	0.769	0.096	25	4410	468.1	1.6	57
18	Artemisia younghusbandii steppe	6	0.798	0.788	0.169	27	3680	406.8	7.8	54
19	Orinus thoroldii steppe	8	0.887	0.902	0.061	30	3685	468.1	1.6	53
20	Pennisetum flaccidum steppe	10	0.834	0.782	0.106	28	3670	406.8	7.8	54
21	Stipa bungeana steppe	8	0.923	0.845	0.039	30	3650	406.8	7.8	57

that has the largest land area being occupied and damaged by the railway construction, it suffers relatively less impact due to its extensive distribution in the zone. Moreover, the major constructive and common accompanying species of the ecosystems are those extensively distributed on the plateau and consequently the construction will not result in extinction of certain species and diminution of species diversity of the ecosystems. As long as rigid measures are taken to protect and restore the vegetation

Table 6 Correlation matrix between restoration degree of vegetation and destructiveness of the original soil and natural conditions of the sampling lot section

*y*1							
0.841**	*y*2						
−0.977**	−0.820**	*x*1					
0.913**	0.927**	−0.873**	*x*2				
−0.113	−0.013	0.073	−0.159	*x*3			
0.733**	0.653**	−0.744**	0.622**	0.249	*x*4		
0.389	0.258	−0.344	0.384	−0.883**	0.065	*x*5	
0.907**	0.752**	−0.876**	0.773**	0.035	0.599**	0.202	*x*6

** At 0.01 significance level.

during and after the construction, the impact of the con struction on the alpine meadow ecosystems and its species diversity may be reduced to an acceptable level.

The alpine swamp and swampy meadow ecosystems is a very fragile type of intrazonal ecosystems, which would readily degrade even if it is subjected to the slightest artificial disturbance[19]. It is essential for the designing and construction of the railway to minimize their disturbance and impact on the ecosystems. In sections with concentrated distribution of the ecosystems it is advisable to substitute road with bridges as much as possible to minimize impact of the construction on the ecosystems. When the line passes by the ecosystems, especially through a piedmont plain or the lower part of an alluvial-diluvial fan, bedding of the railway will seriously affect the wetland ecosystems by intercepting its water supply in the form of underground stream or surface overflow. It is, therefore, essential to use permeable soil for bedding so as to reduce the impact of the construction on the alpine swamp and swampy meadow ecosystems to the lowest possible level.

Within the scope of the alpine swamp and swampy meadow ecosystems, it is in principle not advisable to set up earth extracting or dumping sites, sand and pebble storage sites, worker barracks or some other temporary working sites. And at the same time, as little temporary roads as possible should be built. When it is a must, the roads should be removed after the completion of the construction so as to restore its original landform and hydraulic processes.

The results of the research on mechanisms for restoration of alpine vegetation after disturbance by the construction and extent of its restoration indicate that recovery of the disturbed or damaged alpine vegetation depends mainly on extent of the damage the original surface soil has suffered and the local moisture conditions and has nothing obviously to do with altitude of the site. Therefore, to keep a certain proportion of original surface soil during the construction is key to restoration of the alpine vegetation after the construction is completed.

An analogous investigation method is adopted in this study, that is, by surveying restoration of the alpine vegetation along the Qinghai-Tibet Highway, prediction of the extent and rate of natural restoration of the alpine vegetation species abundance and vegetation coverage after being disturbed by the construction of the Qinghai-Tibet Railway. In view of the similarities of roadside vegetation and impact of the construction between the railway and highway, the prediction based on the natural processes of restoration of the alpine vegetation in the past 30 years or more is held to be quite reliable. Nevertheless, owing to severity, fragility and complexity of the natural conditions of the Qinghai-Tibet Plateau and limitation of number of sampling lots and prediction factors in this study, further studies need to be carried out on the natural processes of restoration of the alpine vegetation after its being disturbed or damaged by the construction of the Qinghai-Tibet Railway.

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