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Full Length Research Paper

Impacts of geo-physical factors and human disturbance on composition and diversity of roadside vegetation: A case study from Xishuangbanna National Nature Reserve of Southwest China

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We examined vegetation-disturbance-environment relationships in the Xiaomengyang Section of Xishuangbanna Nature Reserve (XNR) using multivariate analysis to understand the impacts of geo-physical factors and human disturbance on vegetation along the highway corridor. We found that native forests were the best habitat for protected/endangered species and native species. The exotic plants *Eupatorium odoratum* and *Eupatorium adenophora* were found primarily in secondary forests and their presence was positively associated with altitude and soil potassium concentrations. The distribution of two protected plants, *Phoebe nanmu* and *Pometia tomentosa*, was negatively associated with road disturbance. Species richness was correlated with environmental factors but not related to historical land use and road disturbance. Understanding the complex effects of geo-physical factors and anthropogenic disturbance is important for developing and implementing conservation strategies for the protection and restoration of biological diversity and the integrity of roadside ecosystems.

Key words: Vegetation composition, species diversity, gradient analysis, environmental controls, road construction, nature reserve.

INTRODUCTION

With rapid economic development and population growth in China, conservation efforts and environmental quality of many protected areas of the nation are threatened by a variety of human activities (Yang and Li, 2006). Agricultural production, resource exploitation, recreational activities and infrastructure development must be reconciled with the preservation of areas of high scenic and biological conservation value (Gen, 2001; Duan, 2005; Huang and Hu, 2007). Highway infrastructure development presents a particularly challenging balance between conservation and development (Song, 2004; Su and Li, 2005).

The Simao-Xiaomengyang (Sixiao) Highway, China's section of Kunming-Bangkok international road, was recently developed (constructed in 2001 and opened in 2005) to connect the undeveloped southwest frontier of China to the highly developed north China as well as to neighboring countries in Southeast and South Asia. This road was planned to cut through the core zone of the Xiaomengyang Section of Xishuangbanna Nature Reserve (XNR), one of hotspots for tropical biodiversity in China and the world (Yang et al., 2006). To meet the national priority of development, the natural reserve management authority, China's Forest Ministry, designated part of the core zone of XNR as an experimental zone to accommodate the development of the Sixiao Highway (Song et al., 2005).

Although, there has been an intense debate between environmentalists and development planners as to the program impacts of the Sixiao Highway on species and habitats in this area, there is little available evidence to support the arguments of either side due to limited site-specific research in this region. One of the objectives of the present study was to better understand how highway construction has impacted vegetation in the

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Table 1. Environmental conditions of the sampling transects.

Transect number	Plot number	Latitude	Longitude	Altitude (m)	Slope	Aspects	Soil types	Land use types
1	1-3	N22º06'	E100°54'	748-760	10	SW	loam-clay	old fields
2	4-8	N22º10'	E100°53'	790-844	27	W	loam	native forest
3	9-12	N22º10'	E100°53'	760-774	15	NE	loam	native forest
4	13-15	N22º09'	E100°52'	849-859	50	SW	loam	secondary forest
5	16, 17	N22°08'	E100°53'	897-925	20	N	loam	native forest
6	18-20	N22°02'	E100°53'	811-842	26	NE	loam-clay	native forest
7	21-23	N22°08'	E100°53'	817-937	15	SE	loam-clay	old fields
8	24, 25	N22°10'	E100°52'	769-773	10	NW	loam-clay	native forest

XNR.

We quantified vegetation patterns along an 18.5 km length of the highway, and examined the changes in the species composition along disturbance gradients that ran perpendicular from the highway into less disturbed habitats of the reserve.

A simple method was applied needed to analyze and visualize the relationship between many species and many environmental variables (Ter Braak, 1987). Canonical correspondence analysis (CCA), a multivariate method, can provide a means to structure the data by separating systematic variation from noise (Gauch, 1982). Another objective of this study was to testify the feasibility of using the CCA and related multivariate analysis as a tool to infer the species-disturbance-environment relationship along roadside habitats in the protected area of XNR of Southwest China.

MATERIALS AND METHODS

Site description

The study site is located in Wild Elephant Valley (22°07′ to 22°23′N, 100°36′ to 101°18′E, and 590 to 1600 m a.s.l) of Yunnan Province, a hilly area in the subtropical to tropical zone of southwest China. Wild Elephant Valley is the central area of the Xiaomengyang Section of XNR, established in the 1950s, one of the earliest nature reserves established in China. The study area covers an 18.5 km length and 1 km wide section along the Sixiao Highway, which cuts through the newly defined experimental zone of the XNR. The area has a subtropical continental climate with a dry and monsoonal wet season. The annual average temperature is 20.8°C and annual precipitation is 1193.7 mm with most of the rain occurring from May to November. The soils are dominated by loam or loam-clay soils, which are fine textured, well drained, and have high organic matter content (Table 1). The seasonal rain forests are dominated by *Antiaris toxicaria,* Canarium album and Gironniera subaequalis, and are the target vegetation for protection in XNR as it was reported to be one of the most important ecosystems with the richest species diversity in the world (Wilson, 1988). The secondary forests and open fields exist along the roadside in some locations due to historical land use activities, including row-crop agriculture, rubber plantations, and selective and clear-cut timber harvests.

Study design and treatment

To assess the role of the various controls on the distribution and abundance of the vegetation in roadside habitats, we measured a suite of plot-level geo-physical factors and human disturbance factors at each site of the road. The geo-physical factors were classified into two types, that is, geographic location and soil characteristics. Geographic location data including longitude, latitude, altitude, slope and aspect, were recorded using a Garmin Global Position System (GPS) and compass. Soil characteristics data including soil type, moisture, pH, organic carbon content, total nitrogen, phosphorus and potassium concentration, were determined using a Time Domain Reflectometry (TDR), pH meter and Elementar Vario analyzer (El Ltd., Germany), respectively. Two types of human disturbance, that is, past anthropogenic practices and recent road construction, were considered in the study. As the intensity and duration of past human disturbances were not well documented, the intensity of historical human practices (HHP) was expressed by the succession stage of the vegetation, that is, primary forests, secondary forests and old fields. The distance to the road (RD) was used as a measure of the disturbance associated with road construction as many studies have shown that disturbance to vegetation is correlated to the distance from the road (Parendes and Jones, 2000; Gelbard and Belnap, 2003; Flory and Clay, 2006).

Field survey and data collection

Field surveys were conducted in 2004 and 2005 during the middle of the dry season from November to January following the modified design from Flory and Clay (2006). Eight transects of 0.3 to 1.0 km in length and 20 m in width were located along the road by a distance determined by a random number table. Transects were at least 20 m apart and at least 50 m from forest openings such as creeks and fields. Transects were set perpendicular to the road and started at the edge of the vegetation along the road, which was either native or planted. The extent of the transect length was determined by the variation of vegetation structure. Along each transect, 10 × 10 m plots were arranged at 10, 50, 200, and 500 m from the road for a total of 25 plots (Table 1 and Figure 1). All plant species within each plot were identified and the species composition and numbers in each plot were quantified.

Based on the data collected from the field survey, the species abundance and diversity were quantified. Species abundance was recorded as number of individuals of each plant. Species richness (Marglef index), diversity (Shannon-Weaver index) and evenness (Pielou index) were calculated following the formulas cited by Dong et al. (1997).

Statistical analysis

Canonical correspondence analysis (CCA) was used to identify the ecological relationships between the vegetation and the

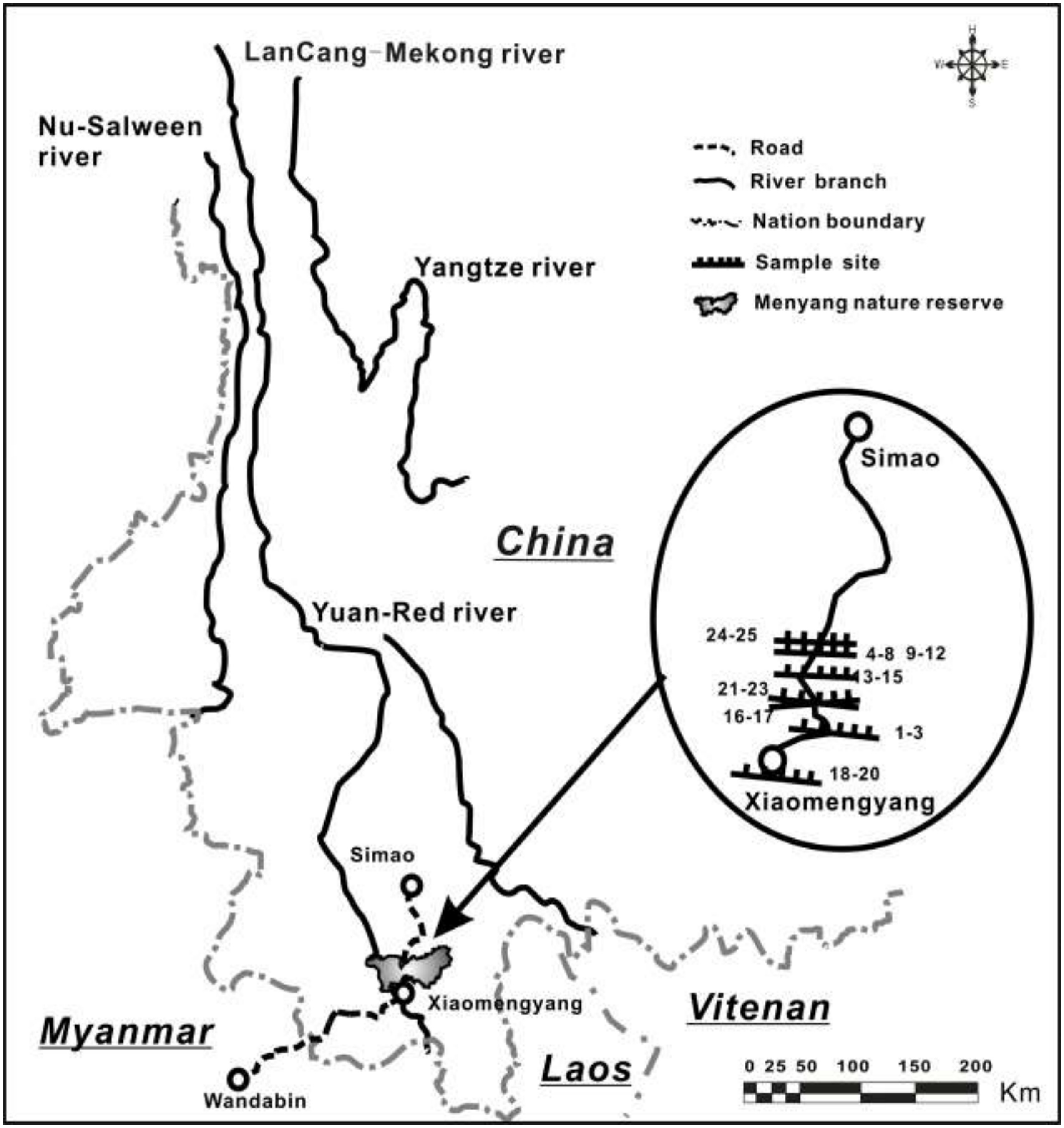

Figure 1. Locations of sample sites and arrays of sampling plots.

environment along the roadside. In order to assure objectivity of the gradient analysis, the species abundance data were used for ordination. This analysis was performed using Software for Canonical Community Ordination (Version 4.5) recently developed by Ter Braak and Smilauer (2002). Multiple regression models were used to investigate the relationship between geographic factors (longitude, latitude, altitude, aspect, and slope), soil factors (type, pH, organic matter content, and nitrogen, phosphorus, and potassium concentration), historical human practices reflected by different land types (primary forest, secondary forest and old fields), road factors (distance to the road) and plant species richness, diversity and evenness, to determine what factors were most closely associated with the variation in species diversity. All analyses were performed using SPSS 12.0 (Huang et al., 2005).

RESULTS

A total of 216 vascular plants, including 72 tree species, 75 shrub species, 58 herbaceous species and 11 vine species, representing 136 genera and 35 families were

Table 2. Canonical coefficients and intraset correlation coefficients derived from the species abundance data.

Axis	**1**	**2**	**3**	**4**
Eigenvalues	0.807	0.760	0.723	0.680
Cumulative percentage variance of species data	6.9	13.4	19.6	25.4
Cumulative percentage variance of species-environment relation	9.7	18.8	27.5	35.6

Environmental variables	**Canonical coefficients**				**Intraset correlation coefficients**			
	Axis 1	**Axis 2**	**Axis 3**	**Axis 4**	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**
RD	-0.74	1.20	-0.92	-1.33	-0.17	0.67	0.11	-0.11
LOG	0.29	-0.63	0.78	0.17	0.31	0.045	0.076	0.074
LAT	0.14	-0.81	1.18	1.01	-0.20	-0.16	0.0621	-0.022
ALT	-0.94	0.75	0.17	-0.65	-0.41	-0.22	0.31	0.30
SLP	0.21	-0.18	-0.11	1.11	-0.41	-0.13	-0.29	0.44
ASP	0.62	-0.33	-0.53	1.00	-0.11	0.42	-0.13	0.31
ST	-0.58	0.52	-0.0073	-1.01	-0.54	0.34	-0.41	0.3229
SM	0.24	-0.88	1.40	0.23	-0.14	0.444	0.54	-0.076
SpH	0.30	-0.18	-0.21	1.25	-0.07	0.34	0.22	-0.042
SOC	-0.46	0.53	0.36	-1.23	0.12	0.053	0.47	-0.20
STN	0.17	-0.79	0.51	1.97	-0.31	0.32	-0.0060	0.30
SP	0.0091	0.47	-0.24	-0.86	-0.26	0.36	0.14	0.23
SK	0.93	-0.61	-0.49	0.85	0.57	0.027	0.17	-0.037
HHP	0.32	-0.32	-0.12	1.13	-0.35	-0.13	0.33	-0.026

The abbreviations of environmental variables are: LOG, longitude; LAT, latitude; ALT, altitude; SLP, slope degree; ASP, slope aspect; ST, soil type; SM, soil moisture; SpH, soil PH; SOC, soil organic carbon; STN, soil total nitrogen; SP, soil phosphorus; SK, soil potassium; LUT, Historical human practices; RD, distance to road.

collected and identified from the 25 plots. None of the 216 species occurred in all 25 plots. Among these species, 1 cultivated plant, *Cassia siamea*, was recorded in 2 plots, and 2 exotic plants, *Eupatorium odoratum* and *Eupatorium adenophora*, were identified in 11 plots and 1 plot, respectively. Several endangered and protected species were sampled including the following: *Cycas siamensis,* a Grade I species in List of Wild Plants of National Priority Protection in China (LWPNPPC, initiated in 1999) and grade II species in List of Chinese Rare and Endangered Plants for Protection (LCREPP, initiated in 1984) was recorded in 4 plots; *Magnolia henryi*, a Grade II species in LWPNPPC and Grade II species in LCREPP was recorded in 1 plot; *Terminalia myriocarpa*, a Grade II species in LWPNPPC and Grade III species in LCREPP was recorded in 1 plot; *Gmelina arborea*, a Grade II species in LCREPP was recorded in 2 plots; *Phoebe nanmu,* a Grade II species in LCREPP was recorded in 2 plots; *Pometia tomentosa,* another Grade II species in LCREPP was recorded in 3 plots; *Paramichelia baillonii*, a Grade III species in LCREPP was recorded in 1 plot; *Lagerstroimia intermedia*, another Grade III species in LCREPP was recorded in 1 plot.

Ordination of the vegetation

The sign and relative magnitudes of the canonical coefficients and of the intraset correlations indicate the relative importance of each environmental factor in predicting the species composition along the ordination axes. The first four axes of the CCA ordination all had relatively high eigenvalues (Table 2); however, they only explained 25.4% of the total sample variance in the species data and 35.6% of the species-environment relationships. All four axes had similar explanatory power. Axis I was defined primarily by soil type and soil K concentrations; the second by road construction disturbance; the third by soil organic carbon, soil moisture and human disturbance; and the fourth by slope, altitude and soil N concentrations.

It is clear from Figure 2 that historical land use (HHP), road construction (RD), and soil phosphorus (SP) were the most influential environmental factors affecting the vegetation composition along the roadside habitats in XNR as indicated by the length of these vectors. Altitude, slope, aspect and soil K concentrations were positively correlated with HHP. Soil moisture soil organic carbon, soil nitrogen, slope aspect, and soil type were all positively correlated with distance to the road. Only longitude and soil pH were positively associated with soil phosphorus concentrations.

The species Imperata cylindrica, Solanum xanthocarpum, Hevea brasiliensis and Schizonepeta tenuifolia and to a lesser extent *Digitaria ternata* clustered together in the old fields reflected by their closeness to sample

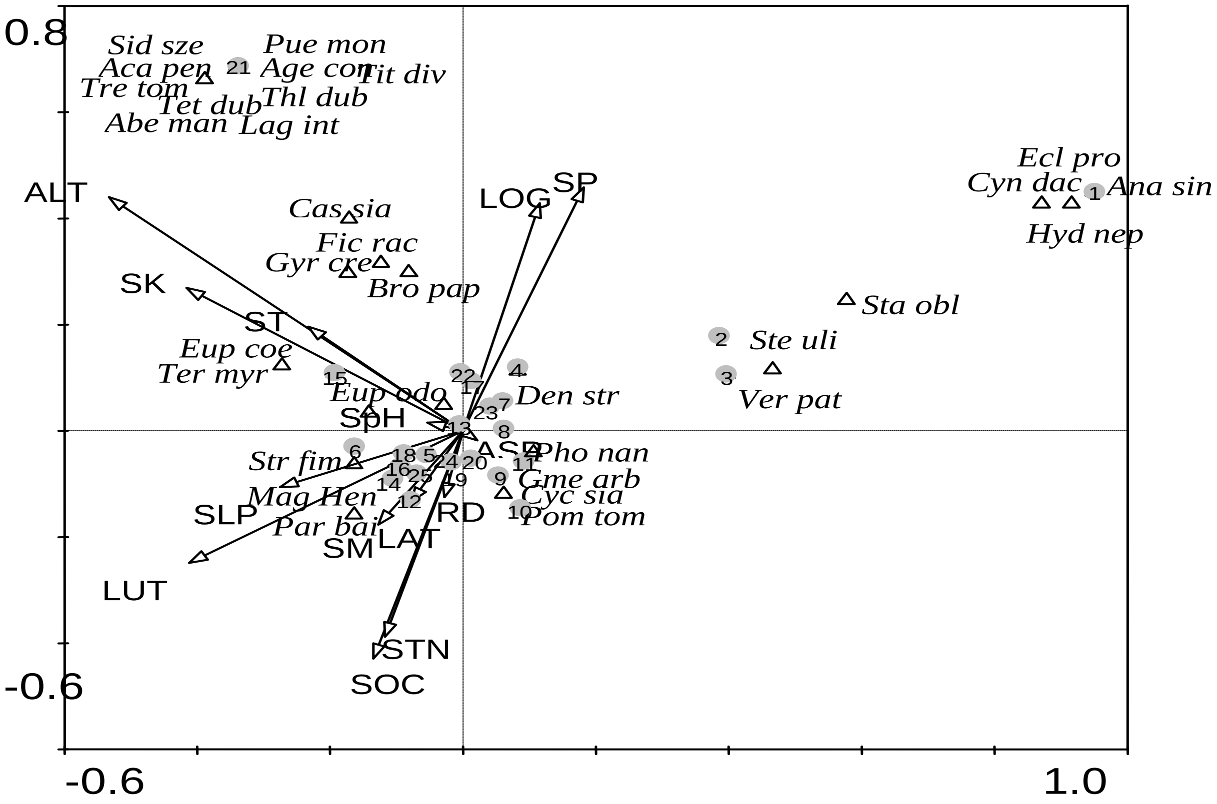

Figure 2. CCA ordination diagram with plant species (△), sample quadrates (●and number 1-25) and environmental variables (arrows) on the basis of species presence; first axis is horizontal, second axis is vertical. To avoid the crowd of the diagram, we only present the species with positions far from center and some important species (protected, exotic and cultivated species) in the diagram using the abbreviations as follows buted as follows: *Abe man=Abelmoschus manihot*, *Aca pen=Acacia pennata*, *Age con=Ageratum conyzoides, Ana sin=Anaphalis sinica*, *Bro pap=Broussonetia papyrifera*, *Cas sia=Cassia siamea*, *Cyc sia=Cycas siamensis*, *Cyn dac=Cynodon dactylon*, *Den str=Dendrocalamus strictus*, *Ecl pro=Eclipta prostrate*, *Eup coe=Eupatorium coelestinum*, *Eup odo=Eupatorium odoratum*, *Fic rac=Ficus racemosn*, *Gme arb=Gmelina arborea*, *Gyr cre=Gyrmra crepidioides*, *Hyd nep=Hydrocotyle nepalensis*, *Mag hen=Magnolia henryi*, *Par bai=Paramichelia baillonii*, *Pho nan=Phoebe nanmu*, *Pom tom=Pometia tomentosa*, *Pue mon= Pueraria montana*, *Sid sze= Side szechuensis*, *Sta obl= Stachys oblongifolia*, *Ste uli=Stellaria uliginosa*, *Str fim=Strophioblachia fimbricalys*, *Ter myr=Terminalia myriocarpa*, *Tet dub= Tetrastigma dubinum*, *Thl dub=Thladiantha dubia*, *Tit div= Tithonia diversifolia*, *Tre tom= Trema tomentosa*, *Ver pat=Vernonia patula.* The abbreviations of environmental variables are present in Table 2.

points 23 on the graph, and their distributions were clearly controlled by RD. The species *Hydrocotyle nepalensis*, *Eclipta prostrate*, Cynodon dactylon and Anaphalis sinica, Stachys oblongifolia and Vernonia patula were clearly separated from the other species and tightly clustered near the SP environmental vector indicated that SP had a strong influence on controlling the distribution of these species. The two exotic species, E. odoratum and E. adenophor*a*, were most abundant in secondary forests as indicated by their closeness to sample points 14 and 15, and were influenced positively by HHP.

Species abundance along environmental and disturbance gradients

The species points and sample points (plots) in Figure 3 jointly represent the dominant patterns of the species abundance insofar as these can be explained by the environmental factors measured in this study. Nearly all endangered or protected species sampled in this study were found in native forest habitat (sample points 6, 8, 11, 16, 18, 20, and 25), except for *P.* baillonii was found in secondary forest (sample site 14). The distribution pattern of endangered or protected species along the gradient of the distance to road shows that *Phoebe nanmu* and *Pometia tomentosa* were abundant in the sites near the roadside and the rest were abundant in the sites far from the roadside. Two exotic species, *E.* odoratum and *E. adenophora* were more abundant in the plots of secondary forest, reflected by their closeness to sample points 14 and 15. The abundance of these two plants was correlated positively with soil potassium and negatively with the distance to road. The cultivated species, *C. siamea*, was more abundant in the plot of old fields, reflected by its location at the sample point 22. The

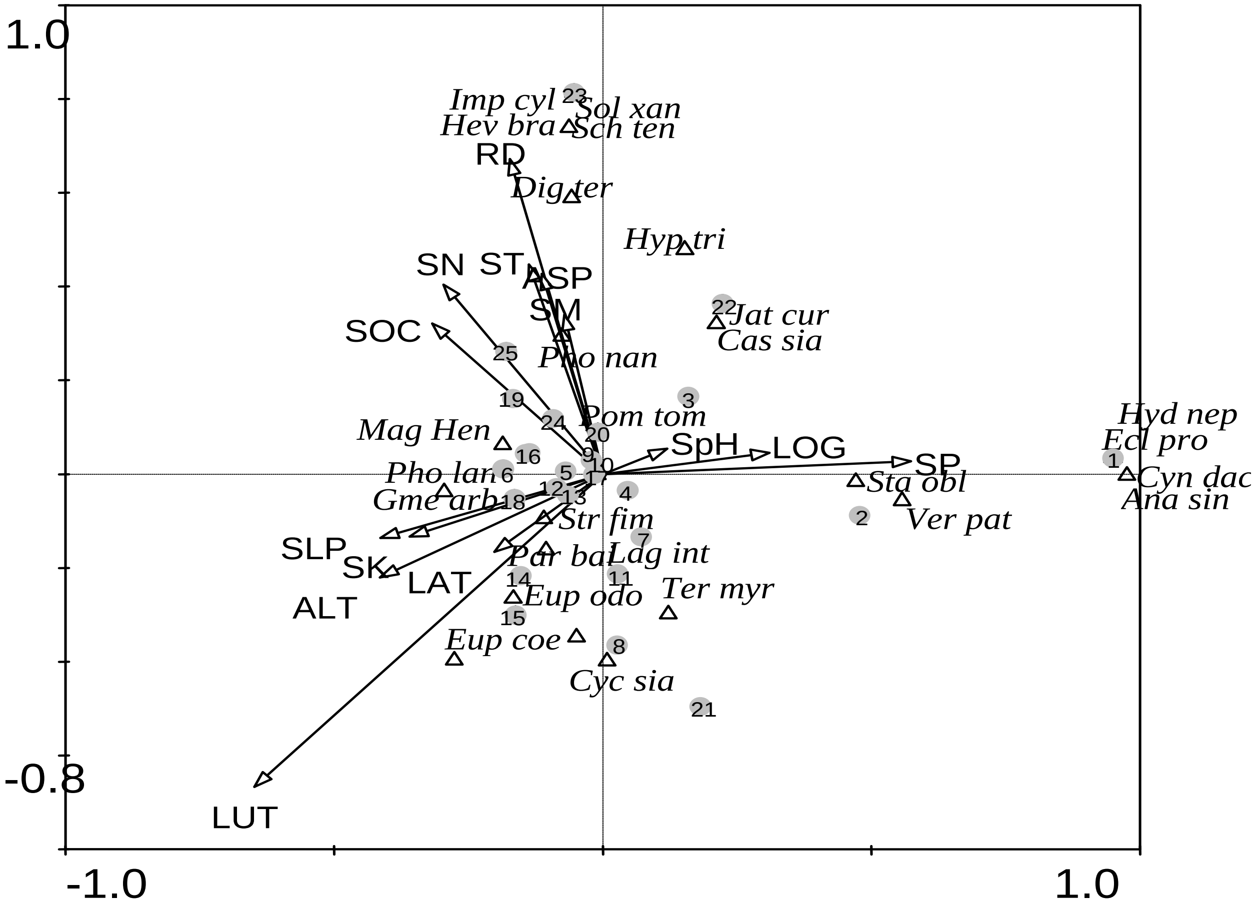

Figure 3. CCA ordination diagram with plant species (△), sample quadrates (●and number 1 to25) and environmental variables (arrows) on the basis of species abundance; first axis is horizontal, second axis is vertical. To avoid the crowd of the diagram, we only present the species with positions far from center and some important species (protected, exotic and cultivated species) in the diagram using the abbreviations as follows buted as follows: *Ana sin=Anaphalis sinica*, *Cas sia=Cassia siamea*, *Cyc sia=Cycas siamensis*, *Cyn dac=Cynodon dactylon*, *Dig ter=Digitaria ternata*, *Ecl pro=Eclipta prostrate*, *Eup coe=Eupatorium coelestinum*, *Eup odo=Eupatorium odoratum*, *Gme arb=Gmelina arborea*, *Hey bra=Hevea brasiliensis*, *Hpy tri= Hypoestes triflora*, *Imp cyl=Imperata cylindrica*, *Jat cur= Jatropha curcas*, *Lag int=Lagerstroimia intermedia, Mag hen=Magnolia henryi*, *Par bai=Paramichelia baillonii*, *Pho lan=Phoebe lanceolata*, *Pho nan=Phoebe nanmu*, *Pom tom=Pometia tomentosa*, *Sch ten=Schizonepeta tenuifolia*, *Sol xan= Solanum xanthocarpum*, *Sta obl= Stachys oblongifolia*, *Str fim=Strophioblachia fimbricalys*, *Ter myr=Terminalia myriocarpa*, *Ver pat=Vernonia patula.* The abbreviations of environmental variables are present in Table 2.

abundance of this plant was positively associated with the distance to road, that is, closer to the road had more C. siamea.

Relationship between plant diversity and environmental and disturbance factors

It can be seen from Table 3 that species richness represented by the Margalef index correlated negatively to longitude ($p < 0.05$) and slope aspect ($p < 0.01$), but positively to soil organic carbon ($p < 0.05$). There were no significant correlations between any of the measured environmental variables and species evenness as measured by the Pileou or species diversity estimated by the Shannon-Weaver index.

DISCUSSION

The present study examined the correlation between environmental factors, human disturbance and vegetation composition and plant diversity in different roadside habitats along international highway in a protected area, XNR in Southwestern China. Overall, the vegetation in the XNR has not been affected to a great extent by the construction of the road. Habitat types, geographic locations and soil factors were the key factors affecting the species vegetation compositions and plant diversity along the roadside habitats in XNR.

Table 3. Spearman correlations between species diversity and environmental variables.

Environmental variable	Species diversity					
	Margalef index		Shannon-Weaver index		Pielou index	
	Coefficient	Sigificance	Coefficient	Significance	Coefficient	Significance
RD	0.189	0.365	0.205	0. 326	0.03	0.886
LOG	-.399*	0.048	-0.028	0. 895	0.104	0.622
LAT	0.197	0.346	-0.055	0. 796	-0.169	0.419
ALT	0.092	0.66	-0.2	0. 338	-0.332	0.105
SLP	-0.043	0.837	0	1.00	-0.028	0.895
ASP	-.539**	0.01	-0.156	0.489	-0.08	0.722
ST	0.033	0.876	0.011	0.958	-0.031	0.883
SM	0.305	0.139	0.218	0.295	0.106	0.615
SpH	-0.187	0.371	-0.14	0.505	0.007	0.972
SOC	.456*	0.022	0.109	0.604	-0.095	0.651
STN	0.382	0.06	0.083	0.692	-0.101	0.63
SP	-0.06	0.774	0.093	0.657	0.158	0.451
SK	0.085	0.686	-0.091	0.665	-0.135	0.521
HHP	0.244	0.241	-0.212	0.308	-0.321	0.118

The abbreviations of variables are similar to Table 2; ** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed).

Species-sites relationship in CCA ordination diagram indicates that the habitat types strongly influenced the presence and abundance of key plant species. Native forest was the best habitat for most protected/endangered species and primitive species. This means that native forest should be the priority for roadside habitat protection in this area. Secondary forest, as habitats with high human interventions, may serve as source for invasion of exotic species into more pristine environments (Tyser and Worley, 1992; Hobbs, 2000). Higher light and bare soil exposure may have favored alien plant establishment (Parendes and Jones, 2000; Flory and Clay, 2006).This is why two alien plants, *E. odoratum* and *E. adenophora* were found abundant there. One protected species *P. baillonii* was also abundant in secondary forest. Restoration of secondary forest is necessary to facilitate the growth of protected species and to control the invasion of exotic species. Old fields was abounded rubber forest or farm land, on which *C. siamea* has been planted to form a highly appreciated fuelwood used by the local people due to quick regrowth of the branches of this plant. A better control of upperstorey timber cutting is required to maintain this land use type.

Species-environment relationship in CCA ordination diagram indicates that altitude and soil potassium were most important factors affecting the presence of *E. odoratum* and *E. adenophora* and historical land use was one of the most influential factors that determines the abundance of these two alien plants. That is in agreement with other researchers' reports that the distribution of alien species was highly related to land use patterns (Hobbs, 2000; Sax and Brown, 2000) and our preliminary finding that *E. adenophora* (also named *Ageratina adenophora*) was more susceptible to total soil potassium (unpublished data). Better land use and reduced soil potassium may be the solutions to control the invasion of alien species. In present study, it was found that road disturbance played very important role in determining the distribution of two protected plants of P. nanmu and *P. tomentosa*. Higher abundance of these two protected species near roadside means that moderate disturbance derived from road construction and traffic may favor their survival and growth. This is a proof to support the view that the effects of roadwork on the vegetation and its environment were complex and sometimes positive (Forman and Alexander, 1998).

Although, previous researchers have noted the incremental effects of road developments (Forman and Alexander, 1998) and argued the loss of biological diversity (Southerland, 1995; Angold, 1997) and the fragmentation of natural habitats (Heilman et al., 2002; Spellerberg, 1998) resulted from road construction and traffic, the correlation analysis in this study showed that species richness was solely related significantly to some geographic and soil factors while not to land use and road disturbance. This may be mainly attributed to three reasons according to Sixiao Road Planning Report (Song et al., 2005; Zhuang, 2007): (1) the protective strategies including choosing the shortest route, evading key habitats and minimizing ecosystem damage were adopted during road planning period to reduce the potential negative effect of roadwork; (2) the construction projects of ecological protection including viaduct, and tunnels have been dramatically used during road construction to avoid the clearance of plant, fragmentation of habitat and alteration of hydrological flows and soil condition; (3) the protective measures including enclosure of road system, bio-protection of slope and limitation of traffic were strictly implemented during road service period.

The results of this study are important for several practical reasons. First, they identify the effects of environmental factors, land use and road disturbance, on the species composition and diversity along roadside habitats in the protected area of XNR. Hence, they are very meaningful for maintaining vegetation structure and distribution pattern in this protected area and other similar sites. Second, they reveal how key species (endangered species, exotic species and cultivated species) respond to environmental factors, land use and road disturbance. So, they give a good indication to better key species management (protect the endangered species, control exotic species and maintain cultivated species) and improve their environment. Third, they show the clear relationships between species, environment and sites (habitats). Therefore, they can provide a baseline to formulate the plans of roadside habitats protection or restoration. Indeed, the results appear to indicate understanding complex effects of environmental factors, land use and road disturbance is very important to develop and implement the strategies to protect or restore elements of biological diversity and integrity of roadside ecosystems.

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