International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:4, No:6, 2010

Effects of Road Disturbance on Plant Biodiversity

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Abstract**—**Urbanization and related anthropogenic modifications cause extent of habitat fragmentation and directly lead to decline of local biodiversity. Conservation biologists advocate corridor creation as one approach to rescue biodiversity. Here we examine the utility of roads as corridors in preserving plant diversity by investigating roadside vegetation in Yellow River Delta (YRD), China. We examined the spatio-temporal distribution pattern of plant species richness, diversity and composition along roadside. The results suggest that roads, as dispersal conduits, increase occurrence probability of new settlers to a new area, meanwhile, roads accumulate the greater propagule pressure and favourable survival condition during operation phase. As a result, more species, including native and alien plants, non- halophyte and halophyte species, threatened and cosmopolitic species, were found prosperous at roadside. Roadside may be a refuge for more species, and the pattern of vegetation distribution is affected by road age and the distance from road verge.

Keywords**—**Native and alien species, Plant diversity conservation, Road construction, Road disturbance

I. Introduction

THE growing anthropogenic modifications frequently disturb and alter natural regimes in every ecosystem and cause extent of habitat loss and fragmentation [1], which can be highly detrimental to the persistence of species, leading to decline of local biodiversity and alternation of ecosystem process [2]. On the one hand, isolated habitat can no longer support viable populations in the long-term [1]. On the other hand, a reduction in landscape connectivity decreases the probability of individuals successfully moving between habitat patches [3], [4]. Therefore, connectivity of habitat patches within a landscape has become a key issue in the conservation of biodiversity [3].

To mitigate the effect of habitat fragmentation, conservation biologists commonly advocate the use of habitat corridor as a conservation tool to increase habitat connectivity in order to sustain and enhance colonization, migration and interbreeding of species between isolated patches [6], [7]. Although corridors have been implemented with the assumption that they will increase biodiversity, not enough research has been done to come to a solid conclusion [4]. Hedgerow has been widely applied in fragmented natural area, however, the empirical evidences currently available are considered to be insufficient to evaluate the effectiveness of hedgerow [1]. Transportation corridors are not traditionally focussed on in conservation issue until Cilliers and Bredenkamp (2000) discussed the importance of railway as dispersal corridor for species between fragmented natural areas. Roads are the most widespread forms of the natural landscape during the past century, correspondingly, the value of road as a corridor, changing the degree of isolation of animals and plant populations in fragmented landscape, should be also considered [5]. The use of road to preserve local biodiversity has been an area of considerable debate over the past two decades. Proponents argue that roads act as conduits, facilitating the movement of individuals between isolated patches of remnant habitat, thereby promoting gene flow, reducing population fluctuations and decreasing extinction risk. Therefore, roadside is sometimes regarded as the last favorable refuge for plant species in many fragmented agricultural areas, such as *Eucalyptus* and *Acacia* plant [6]. However, skeptics point out that the conduit function of roads would accelerate the invasions of alien species and go so far as to advise that these corridors may actually be deleterious to native species, potentially acting as a threaten to local biodiversity [11]-[14], [7]-[10].

The invasions of alien species seems to be the focus of the controversy, however, the factors that influence colonization of alien species along road corridor are not well understood. The distance from road verge may influence the spatial distribution of alien species at roadside. It is believed that areas adjacent to road with greater human disturbance are more likely to be colonized by alien species than areas far away from road, due to greater propagule pressure and increased habitat alternation associated with human activities. For example, the percent cover of alien species was significantly greater at 10m and 100m from roads than that at 1000m from roads in central California [8]. Another factor that may influence propagule pressure and amount of disturbance is road age. If old roads are typically subject to higher cumulative levels of traffic and maintenance than young roads, this might result in an increase in the occurrence of alien species near old roads simply due to the longer period of exposure. Road age is an appropriate factor to evaluate their accumulation effects, including the amount of propagule pressure and disturbance [11], but how to determine it is challenging. Historically, researchers determine road age in terms of cadastral maps or records where and when the roads were constructed, but this simple technique is often unreliable

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because a road may exist there for hundreds to thousands years, additionally, it has been rebuilt for several times. Therefore, the date when a road being built could not be narrowed down to a certain year, alternatively, the construction year is assumed to have occurred in a broad time span within an uncertain range [15],[16].

The distribution of native species may also be responsive to disturbance from road verge and road age. For example, Gelbard and Belnap (2003) found that the cover of native species was significantly higher adjacent to road verge than that far away from road verge. The colonization success of native species in road verge may be constrained by the dispersal function of roads, which promote the migration of human and animals that commonly disperse some native species along roadside [12]. Admittedly, a better understanding of the response of both native and alien species to distance from road verge and road age will help accurate assess the effect of roads as habitat corridors on local biodiversity.

However, other uncontrollable factors, including road attributions (pavemental feature, width, traffic volume and maintenance activities), the biodiversity and community succession of roadside biota, and other anthropogenic activities may influence the spread rate of subsequent migrating species, and mitigate the potential conduit and habitat effects of road on preserving plant species [13]. For example, younger successional aged communities are usually more susceptible to the invasions and older communities are more resistant [14]. To overcome these problems, an ideal road system for the study should be built from a protogenous ecosystem which has never been used as a road, and the anthropogenic activities are monotonous and measurable. Importantly, the road system should have clear historical records and similar attributes. Fortunately, our study area, the Yellow River Delta (YRD) of China, provides a "pure" road ecosystem and an ideal area for studying potential ecological functions of road corridor in plant diversity. The YRD is a protogenous ecosystem, undergoing rapid development. Vegetation succession in this area is primary in nature and experiences rapid changes due to cumulative anthropogenic disturbance. The anthropogenic disturbance in this area is relatively simple and definite, i.e. oil exploitation and associative transportation construction. Apparently different from other areas, road construction in this area is primarily driven by the expansion of oilfield development, so the detailed historical records of oilfield and road construction help us choose associative roads. More importantly, before the road ecosystem has been created, it has never been exploited for other usages.

In the present study, we tested the hypothesis that road as a corridor can preserve and rescue local biodiversity, and it will be affected by the distance from road verge and road age. First, we examined the effect of road corridor on preserve plant species by comparing plant diversity and composition between road and non-road disturbance area. Second, we test the effect of distance from road verge and road age on plant diversity and composition by investigating roadside vegetation at five distances from road verge across four road age groups. Then, we test whether native and alien species have unique response to distance from road verge and road age. If road function as a better dispersal conduit and habitat for plant species, we would find that plant diversity declines with the increasing of distance from road verge or the plant diversity increases over road age. The similar or different responses of native and alien species to distance from road verge and road age would help us to correctly evaluate the ecological effect of road corridor on local biodiversity, that is, threaten or rescue for local biodiversity. These results are expected to provide critical information for decision makers and land managers for managing alien species and maintaining the integrity of biological communities.

II. Methods

A. Study area

The study was conducted in northern area of the Yellow River Delta (YRD) (E118°05′-119°15′, N37°25′-38°10′), near Dongying City, Shandong Province of China (Fig. 1) from July to August in 2008. The YRD is a typical alluvial plain and composed of several delta superlobes resulting from shifts in the lower river channel since 1885 (Fig. 1). This area extends with land forming at the speed of 31.3 km^2 per year. This newly-emerging protogeous ecosystem is fragile and sensitive to disturbance because of weak recoverability. Due to serious soil salinization, many lands are abandoned and usually dominated by hygrophytes and halophytes. Totally, plant community composition in this area is monotonous with herbaceous plant [15].

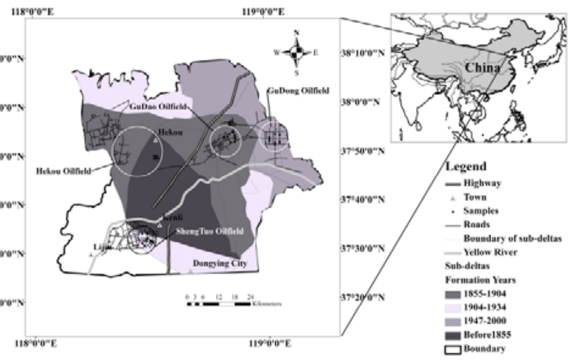

Fig. 1 Location of study area in northern Yellow River Delta (YRD), Shandong Province of China. The polygons filled with different shades represent the sub-deltas formed during different periods. Totally 35 sites along 17 roads were preset in four oilfields.

Petroleum extraction is the primary anthropogenic activity in this area. Historically, Shengtuo, Gudao and Gudong Oilfield were exploited in 1960s, 1970s and 1980s, respectively (Fig. 1). In the meantime, road system was built in different periods to serve for the oilfield construction. Because of the special purpose and the similar maintain activity, the roads have similar pavement, width and traffic volume, additionally, the main vehicles are engineering trucks. More important is that the roads age could be easily estimated in terms of the time when the oilfields were constructed.

B. Site-selection protocol

To examine the effect of road age on plant diversity, 17 roads in 4 oilfields (Fig. 1, Appendix I and II), which were exploited in different years, were selected. According to the road annals [16] and detailed records in Department of Transportation of Dongying City, roads in Gudong, Gudao, and Shengtuo Oilfields represent the age groups of 3-10, 10-20 and >20 years, respectively (Appendix I). Compared to road operation phase, the duration of road construction is transitory, but it causes considerable damage to the adjacent vegetation and environment. This phase is the beginning of road disturbance, however, it is often ignored in road study. In this study, two roads (< 2 years, standing for new road group) in new development district of Hekou Oilfield and one road in Shengtuo Oilfield were selected, aiming to study how vegetation responds in the transitory phase of road construction. To examine the effect of road corridor on preserve plant species, plant diversity and composition between road and non-road disturbance area were compared, so both areas with and without road were selected in each oilfield. However, because it is impossible to find the roadless areas near the oilfields, control plots (standing for non-road disturbance area) were selected on the areas at least 200 m away from any road all around.

C. Vegetation Sampling

The quadrat sampling method was applied to quantify plant diversity in both road and non-road disturbance areas. Preliminary experiments were performed to determine (1) the minimum number and size of quadrat needed to detect most of the plant species present, and (2) the maximum distance of roadside vegetation affected by roads. The preliminary survey illuminated that the most rapid changes in species richness occur within 30 m of the road, especially in the first 10 m, which indicated that the disturbance from roads were most prevalent near roadside and diminished along a gradient from road verge into internal environment. By randomizing the occurrence of species in this study, a species-area and running mean curve were constructed to determine the minimum number and size of quadrat needed for adequate sampling, and six 2× 2 m quadrats appeared adequate to detect at least 95% of species present (Fig. 2).

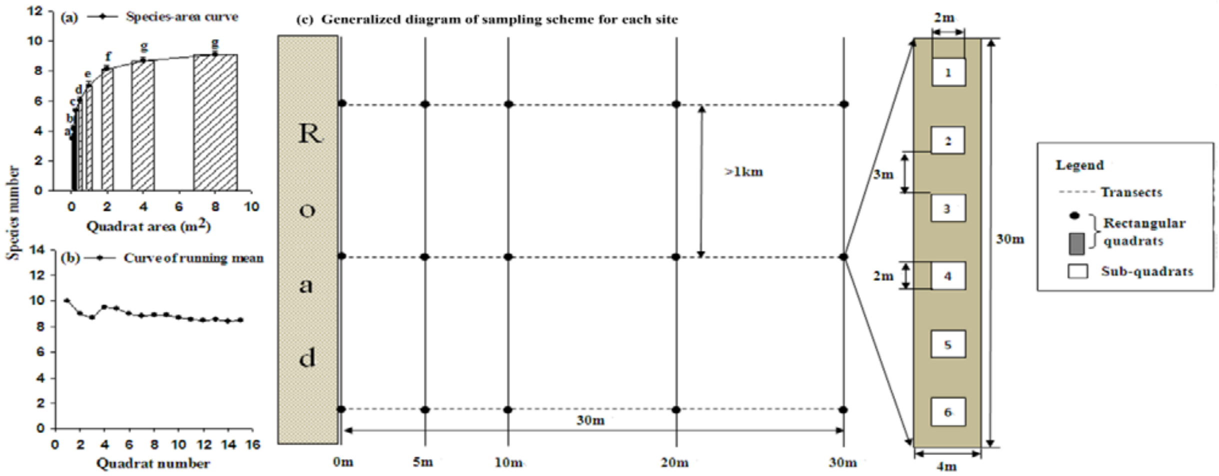

Fig. 2 Vegetation sampling protocol . (a) Species-area curve, (b) Curve of running mean illuminated that six 2 m × 2 m quadrats was adequate to detect majority species present, and (c) Generalized diagram of sampling scheme for each site.

According to our principle, the first to the third transects (depending on road length), at least 1km apart, were located perpendicular to the road along each of the 17 roads (Fig. 2). In order to test the effect of distance from road verge on plant diversity and composition, five rectangular quadrats (2×30 m in size) were arranged parallel to the road at 0 m, 5 m, 10 m, 20 m and 30 m from road in each transects. At each of the 5 rectangular quadrats, six 2 m × 2 m sub-quadrats were randomly placed at 3m intervals (Fig. 2). At each sub-quadrat, the presence of all vascular plants was recorded. Species nomenclature and determination of alien species follow Wang and Zhou (2000).

D. Data analysis

The units used for statistical analysis including species richness, diversity and composition. Species richness was defined by the average number of species per site. Three diversity indices, including Shannon - Wiener diversity index, Margalef's index and species number per plot, were performed to measure species diversity. Additionally, the increased percentage of alien/native species and the percentage of halophyte were performed to measure the species composition. To examine the reliability of our control plots (non-road disturbance areas), one-factor analysis of variance (ANOVA) was used to evaluate the effects of regional disparity on all units, with oilfields as independent variable, and followed by *post hoc* Tukey multiple comparisons ($\alpha = 0.05$). In order to illustrate the discrepancy of plant diversity between road and non-road disturbance areas, *t*-tests was employed to compare all units between road disturbance areas and related control plots. In the same way, ANOVAs and *post hoc* Tukey multiple comparisons (α = 0.05) were performed to analyze the effect of distance from road verge on all units, to determine which distances were significantly different, and to test whether there was an overall effect of road age on all units in all prescribed distances. To determine the responses of alien and native species to long-term road disturbance in spatial and temporal scale, native and alien species were considered separately in above analysis. All the statistical analyses were performed on software package STATISTICA 7.

III. Results

A. Comparison of plant community in road and non-road disturbance areas

Except for new roads group, roadside habitat harbored higher value of species richness than that in non-road disturbance areas ($p < 0.001$), and the similar results were obtained from three diversity indices, including Shannon - Wiener diversity index, Margalef's index and species number per plot (Fig. 3a). Additionally, totally 100 species (Appendix III) were identified, including 67% native species and 33% alien ones. Amongst these species, 98% species was found at the roadside and only 20% in non-road disturbance areas, which meant that almost 80% of plant species only survived in roadside habitats.

For majority road age groups, the percentage of halophyte in roadside habitat was significantly lower than that in non-road disturbance areas (Fig. 4a). Most non-halophytic plants, such as *Imperata cylindrica (L.) Beauv.*, Herb *Setaria viridis (L.) Beauv.*, *Cynodon dactylon (L.) Pers.*, were often prosperous at roadside habitats. Compared to road disturbance area, rare species were found in non-road disturbance areas, where often dominated by halophytic vegetations, including *Suaeda glauca (Bge.)Bge.*, *Tamarix chinensis Lour.*, *Phragmites australis (Cav.) Trin. ex Steud*, and *Aeluropus sinensis (Debeaux) Tzvel*.

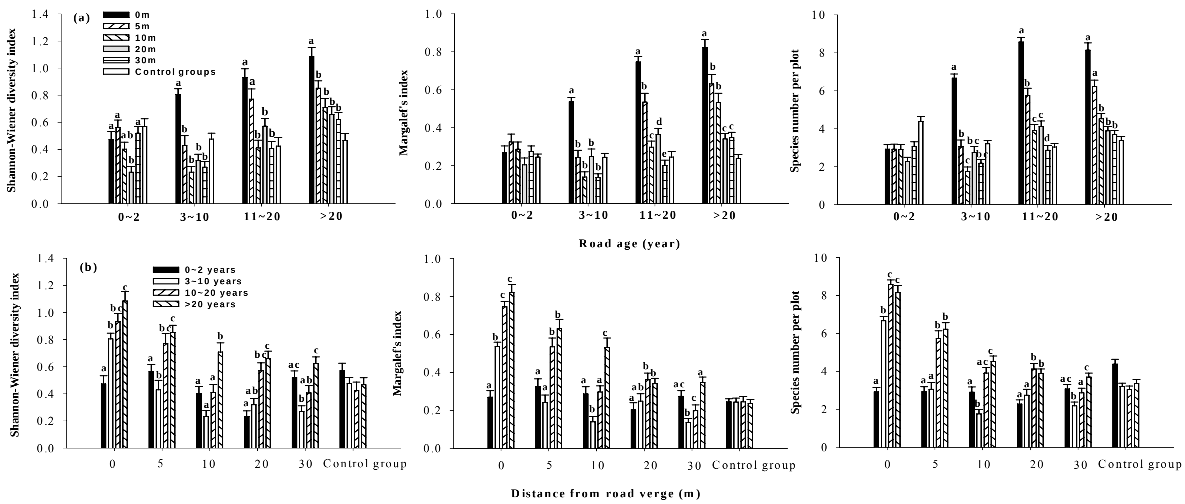

Fig. 3 Changes of species diversity index (Shannon- Wiener diversity index, Margalef's index and species number per plot) across (a) five discribed distance in four age groups and (b) four roads age groups in five discribed distances. Error bars represent 1 SE. Different letters indicate a significant difference at the level (α = 0.05) among different distances from road verge or age gourps as determined by a Tukey's post-hoc test; overall significance of effects were indicated by one-factor analysis of variance (ANOVA).

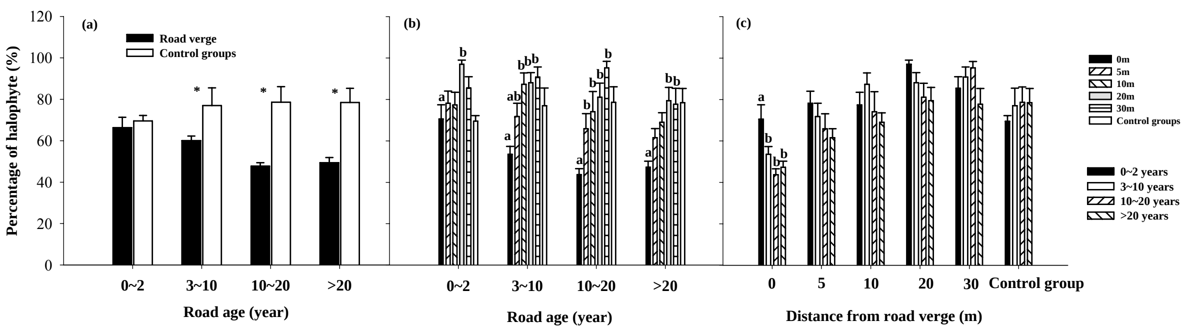

Fig. 4 Changes of percentage of halophyte in road and non-road disturbance area. (a) Comparison of percentage of halophyte between road verge and non-road disturbance areas in four road age groups. Change of percentage of halophyte across (b) five distance from road verge in four age groups and (c) four age groups in five distances. Error bars represent 1 SE. Different letters indicate a significant difference at the level (α = 0.05) among different distances from road verge or age groups as determined by a Tukey's post-hoc test; overall significance of effects were indicated by one-factor analysis of variance (ANOVA).

B. The spatial and temporal distribution pattern of plant diversity in roadside

Species richness (Fig. 5a) and three diversity indices (Fig. 3a) of roadside in new road group is remarkably lower than that in non-road disturbance areas, while no significant difference ($p_{species\ richness}$ = 0.27, $p_{Shannon\text{-}Wiener}$ = 0.27 $p_{Margalef's}$ = 0.21 and $p_{species\ number\ per\ plot}$ = 0.27) was found among different distance groups.

A negative correlation between species richness and distance from road verge was detected in most road age groups, and similar correlation were also found between three diversity indices and distance from road verge. More specifically, species richness (Fig. 5a) and three diversity indices (Fig. 3a) of road verge group (0m from the road) was higher than other distance groups. Contrarily, a positive correlation between percentage of halophyte and distance from road verge was detected in most road age groups (Fig. 4b).

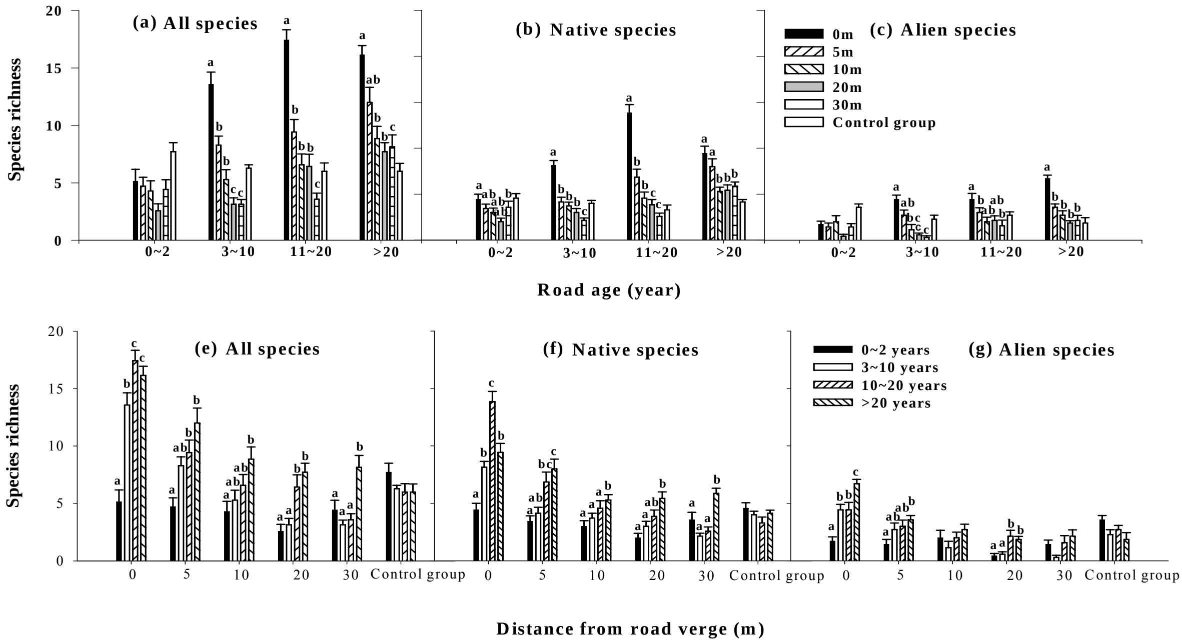

Fig. 5 Changes of species richness in (a) all species, (b) native species, and (c) alien species across five distances from road verge in four roads age groups. Changes of species richness in (d) all species, (e) native species, and (f) alien species across four road age groups in five prescribed distances. Error bars represent 1 SE. Different letters indicate a significant difference at the level (α = 0.05) among different distances from road verge or age groups as determined by a Tukey's post-hoc test; overall significance of effects were indicated by one-factor analysis of variance (ANOVA).

Within-group variance of control group (non-road disturbance areas) did not show significant effect on species richness (Fig. 5b), diversity (Fig. 3b) and percentage of halophyte (Fig. 4c), reflecting our control plots were reliability. In the roadside habitat, species richness (Fig. 5b) and three diversity indices (Fig. 3b) increased over time in all prescribed distances, while the most significant changes were found in road verge. In the road verge, species richness (Fig. 6) and three diversity indices (Fig. 3b) significantly increased with road age and reached the peak at the road age of 20 years and then remained stationary for over 20 years (R^2=0.78, p<0.0001), while the percentage of halophyte declined with road age and then remained stationary for over 20 years (Fig. 4a).

C. Response of alien and native species to long-term road disturbance

Native species, accounting for 76.4% of the total species number, was the main composition of roadside vegetation (Fig. 5). Either native or alien plant, a similar distribution pattern of species richness across five prescribed distances was found, i.e., species richness decreased with increasing of distance from road verge (Fig. 5a). Nevertheless, when road age is considered, different patterns of species richness across four road age groups were found, and the most significant changes were found in road verge (Fig. 6). In the road verge, species richness of alien species linearly increased with road age in all study years (R^2=0.62, p<0.01), while native species richness reached the peak at the road age of 20 years and then decreased (Fig. 6; R^2=0.68, p<0.01). Furthermore, the increased percentage of native species (compared to that in related non-road areas) increased with road age in the first 20 years after road construction and then significantly decreased over 20 years, correspondingly, the opposite pattern was found for increased percentage of alien species (Fig. 7).

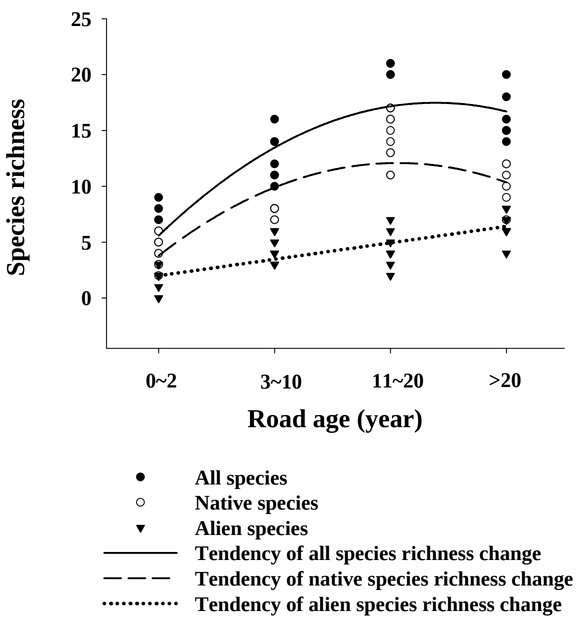

Fig. 6 Changes of native, alien and all species richness in road verge (0m from the road) across four roads age groups.

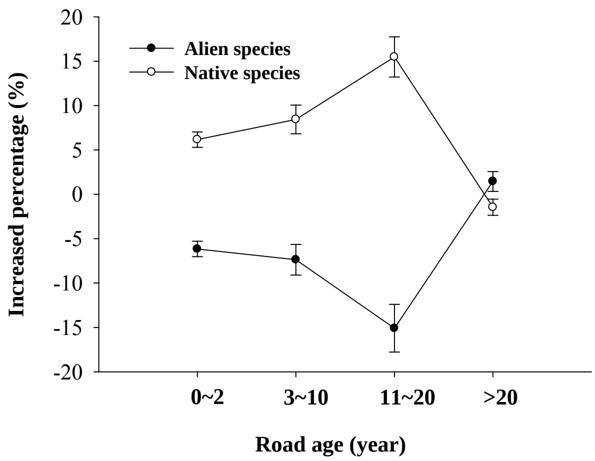

Fig. 7 Changes of increased percentage of native and alien species across four age groups.

IV. Discussion

A. Roads promote plant dispersal and colonization along roadside

Road construction is considered as the most widespread forms of anthropogenic modification during the past century [22],[23]. Skeptics reported that one of the major changes associated with these modification is the fragmentation of habitat, which may be the barrier for species migration and dispersal [11], [24], [25]. Besides it is a typical anthropogenic disturbance, road is also a corridor acts as a conduit, which can increase habitat connectivity in order to sustain and enhance the population viability of some species [1]. Our results illustrated that road as a important habitat corridor harbored more plant species than non-road disturbance areas, and it helps to rescue and preserve local biodiversity to some extent. According to the theories of plant invasion, transport of propagules over long distance is the first step for invasion, and consequent change of propagule pressure strongly influences colonization success of alien species [2]. Flory and Clay (2006) formulates the hypothesis that if a road functions as an important dispersal corridor and the roadside edges provide good habitats for plant growth, plant diversity is predicted to decrease with increase of distance from roads. Similar evidences were observed by many researchers [12], [19], [27], [28], but their works focused on alien plants. Our results argue that dispersal function of road corridor is not monopoly for alien species, but also for native species.

It is widely accepted that roads are typical linear corridors and function as important dispersal conduits for plants [3]. Roads not just allow easier movement of wild or human vectors, meanwhile vehicle tires and imported road-building materials also increase the probability of propagule transport [17], [30]-[32]. Moreover, animals such as birds, whose activities are limited to roadside, help seeds to distribute along roadside [4]. Furthermore, drainage ditches of roads can facilitate the spread of aquatic plants along roadside [5]. From this point, roads can facilitate the dispersal of at least three types of plants over long distance, including anemophilous, hydrophilae and zoidogamae plant. For example, majority gramineous plant, *Phragmites australis (Cav.) Trin. ex Steud* and *Xanthium sibirium Patrin.* are often found prosperous at roadside. Furthermore, similar demonstrating of native and alien species in relation to distance from roads implies that road function of helping plants to disperse is not exclusive for specific species. It means that species with adaptable dispersal mechanism have fair chance to spread along road, no matter whether they are native or alien. Continual seeds and propagules transport along road, however, it is difficult to determine where they are deposited. Similarly, roadside vegetation in our study is a mosaic flora constituted by various species with low frequency of presence. However, native species is still the main component of roadside vegetation (Fig. 5). According to record by Wang and Zhou (2000), this finding on composition of roadside vegetation is comparable to the species composition in this area where native species pool is larger than alien species pool and account for 61% of the total species pool. It also partly explains why native and total species have similar spatial and temporal distribution pattern in roadside habitat (Fig. 5). It also suggests that the presence of road can only increase the opportunity for species' spreading to remote areas, which cannot fundamentally change the original species pool.

B. The accumulative effect of roads to preserve high species diversity

Unlike other habitat corridors, road is maintained by people and characterized by frequent disturbance in a extended period from construction to abandon, additionally, their ecological functions change over time [6]. Few studies have tracked the long-term effects of road corridor, our result provides the rare piece of evidence about how the plant diversity at roadside habitat changes over time. Our results suggest that whether a road can rescue or threaten local plant diversity is affected by road age. Generally, with the road development, roadside vegetation experiences three stages, i.e., destroy, transport and colonization, and establishment analogous to invasion process of alien species. Although road construction phase is a relatively transitory term, the disturbance is destructive, and the consequence is obvious, including a direct removal of habitats and vegetations [3]. Compared to non-road disturbance areas, lower plant coverage and species richness, and more open space were detected within the area 30 m far from road verge (Appendix II). Similar to the consequence of wildfire [7], disturbance from road construction may stimulate seeds germination and seedling establishment by providing patches of bare soil where competition is low, and meanwhile provide a refuge for survival of rapid growth plants after road has been built. Therefore, new settlers and remaining propagules in seed bank may benefit from the increased compete-free niches and light availability [8]. Generally, road system construction is making provision for colonization of migration species in this phase.

Our result also implies that road disturbance plays a potential positive role in short-term operation phase, and this stage is the period for transport of plant propagules and colonization of new settlers. In our study, the total species richness and diversity increased over time, including both native and alien species. We outline several possible mechanisms for these changes. First, heritage from historical disturbance in road construction, including more edges and niches, increases the vulnerability of community to establish of new species by providing location for migration species [11], [31], [34]. Second, roads provide dispersal conduits for many plants and increase the possibility for species' arrival in remote areas, and at the same time, roads experience cumulative amount of vehicular traffic and other maintenance disturbances [9]. As a result, more seeds or other propagules accumulate at roadside over time, leading to a large species pool at roadside. Third, disturbances from roads change the physicochemical conditions of adjacent environments, and usually increase availability of nutrients and water [11], [31], [34]. Therefore, old road with high level of propagule pressure, continuous input of energy and nutrient is a more favorable habitat for plants than young roads [24], [37], [38]. Thus, the trend that species richness increases over time is found in the first 20 years after road construction.

To establish and expand population, migration species must colonize a site and develop themselves sustaining. The establishment may last longer than colonization and occur in the long-term operation phase. The theories of plant invasion suggest that biotic factor is the major filter to control population growth and establishment [2]. When the number of species increases, inter-specific competition for resources become more intense because roads are still subsidized heterotrophic ecosystems [31], [39], [40]. Thus, species with stronger competitiveness are allowed to survive at roadside. For example, alien plants with high seed production and broad germination requirement are more competitive than native species, and they quickly colonize and threaten survival of native species, especially when resource is scarce [10]. Based on our results, when connecting to road age, the performance of native and alien species is significantly different, especially after 20 years when road were built. In this phase, native plant significantly decreases in species richness while alien plant increases, but the total species richness does not show significant change. Furthermore, our study area is undergoing serious soil salinization, supporting the survival of few salt-tolerant plants, thus the total species richness would reach a ceiling due to the restrictions of environmental condition.

Whether road as a corridor can rescue and preserve local biodiversity? The conclusion is controversial, pro and con conclusions are reported in previous studies [19], [28], [41]. In our study, positive and negative effect of road on plant diversity were observed from road construction to long-term operation phases. Our results emphasize the importance of taking both short- and long-term temporal scale into account when evaluating roads effect on environment and vegetation, and combining both historical and present effects as integration to assess accumulative impact. Additionally, our result supports the viewpoint that roads as a typical corridor can function as a conservation tools to rescue and preserve variable plants for a long duration. Therefore, the following measures may available for roadside vegetations protection. First, minimize disturbance as possible in short-term after road construction, for example, road maintenance activities includes trim or cutting of roadside vegetation. Second, the timing of 10 years after road construction is optimal for controlling and/or eradicating the noxious invasive species. Third, create buffer zones in roadside, which on the one hand benefits the existed high local biodiversity, and on the other hand avoids invasion of alien species into internal natural areas. Fourth, regular moderate disturbance may be necessary in long-term operation stage, because it can mitigate biological competition and restrain population expansion of alien species.

C. Important species present in roadside

As mentioned above, the YRD area is threatened with serious soil salinization, and only saline tolerant plants can survive in profuse abandoned lands. Under this situation, road corridor acts as an important refuge for many species. Besides the constructive species, such as *S. glauca (Bge.)Bge.*, *T. chinensis Lour.*, *Apocynum venetum L.*, *Phragmites australis (Cav.) Trin. ex Steud*, and *A. sinensis (Debeaux) Tzvel.*, various non-salt-tolerant species are often found prosperous in roadside. For example, Leguminosae plants scarcely occur in non-road disturbance areas due to high level of soil salinity, while abundant Leguminosae are easy to be found at roadside. The Leguminosae, such as wild soybean *Glycine soja Sieb. Et Zucc.* and Japan clover herb *Kummerowia striata (Thunb.) Schindl.*, quickly colonize at roadside after road construction. It is well known that Leguminosae can improve soil structure and fertility by fix dissociative nitrogen into absorb nitrate for plant. Plenty of Leguminosae plants at roadside help to improve the habitat environment and provide a suitable condition for migration of subsequent plants. It is worth noting that, roadside environments provides vital habitat for some threatened species with global biodiversity conservation importance. For instance, *Glycine soja Sieb. et Zucc.*, an important gene resources for cultivated soybean, is an unique wild panax resource in China [11]. The wild soybean has been listed as the nationally primarily protected wild plant in second class since 1999, because their natural distribution area reduced increasingly due to overexploitation of land [12].

APPENDIX

APPENDIX I LIST OF ROADS SURVEYED IN THE YELLOW RIVER DELTA, CHINA

No.	Grade	Pavement material	Width (m)	Location	Construction (year)	Length (m)	Number of sites sampled
1	4	Macadamize	7	Shengtuo Oilfield	1965	6854	2
2	4	Macadamize	6	Shengtuo Oilfield	1965	4463	3
3	4	Macadamize	6	Shengtuo Oilfield	1965	4563	1
4	4	Macadamize	6	Shengtuo Oilfield	1967	4538	3
5	4	Asphalt concrete	10	Gudao Oilfield	1988	7378	1
6	4	Asphalt concrete	10	Gudao Oilfield	1988	2504	2
7	3	Asphalt concrete	12	Gudao Oilfield	1988	2867	3
8	3	Asphalt concrete	9	Gudao Oilfield	1984	16861	1
9	4	Asphalt concrete	6	Gudao Oilfield	1986	5187	2
10	4	Macadamize	7	Gudong Oilfield	1998	6271	3
11	4	Macadamize	9	Gudong Oilfield	1996	4835	3
12	4	Macadamize	7	Gudong Oilfield	2000	17204	3
13	4	Asphalt concrete	12	Shengtuo Oilfield	2006	992	1
14	4	Macadamize	12	Hekou Oilfield	2005	81	1
15	4	Macadamize	8	Hekou Oilfield	2006	1639	3
16	4	Macadamize	12	Hekou Oilfield	2005		1
17	4	Macadamize	8	Hekou Oilfield	2006		2

International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:4, No:6, 2010

APPENDIX II ILLUSTRATIONS OF PLANT COMMUNITIES

Age (year)	0-2	3-10	10-20	>20
Road disturbance areas				
Non-road disturbance areas				

APPENDIX III LIST OF PLANT SPECIES SURVEYED IN THE YRD, CHINA BETWEEN 2006 AND 2009

Scientific name	Life history	Life form	Propagation type	Place of origin
Humulus scandens (Lour.) Merr.	Annual	Herbage	seed propagation	
Roegneria kamoji Ohwi	Perennial	Herbage	seed/vegetative propagation	
Metaplexis japonica (Thunb.) Makino	Perennial	Liane	seed/vegetative propagation	
Kochia scoparia (L.) Schrad	Annual	Herbage	seed propagation	Europe, Asia
Salsola. collina Pall.	Annual	Herbage	seed propagation	
Suaeda glauca (Bge.) Bge.	Annual	Herbage	seed propagation	
Setaria viridis (L.) Beauv.	Annual	Herbage	seed propagation	
Phragmites australis (Cav.) Trin. ex Steud.	Perennial	Herbage	seed/vegetative propagation	
Datura stramonium L.	Annual	Herbage	seed propagation	America
Sonchus oleraceus L.	Annual	Herbage	seed propagation	Europe, Asia
Messerschmidia sibirica L.	Perennial	Herbage	seed/vegetative propagation	
Aster subulatus Michx.	Annual	Herbage	seed propagation	North America
Artemisia mongolica (Fisch. ex Bess.) Nakai	Perennial	Herbage	seed propagation	
Atriplex centralasiatica Iljin	Annual	Herbage	seed propagation	
Abutilon theophrasti Medicus	Annual	Herbage	seed propagation	Tropics
Echinochloa crusgali (Linn.) Beauv.var.mitis (Pursh) Peterm.	Annual	Herbage	seed propagation	North America
Pharbitis nille (L.) Choisy	Annual	Herbage	seed propagation	Tropical America
Aeluropus sinensis (Debeaux) Tzvel.	Perennial	Herbage	vegetative propagation	
Ixeris denticulata (Houtt.) Stebb.	Annual	Herbage	seed propagation	
Chenopodium serotinum L.	Annual	Herbage	seed propagation	Siberia, Japan, Europe
Imperata cylindrica (L.) Beauv.	Perennial	Herbage	vegetative propagation	Southeast Asia
Polygonum aviculare L.	Annual	Herbage		
Chenopodium. Album L.	Annual	Herbage	seed propagation	
Eragrostis minor Host	Annual	Herbage	seed propagation	
Chenopodium glaucum L.	Annual	Herbage	seed propagation	
Tamarix chinensis Lour.	Annual	Shrub	seed/vegetative propagation	West Mediterranean Sea
Tripolium vulgare Nees	Annual	Herbage	seed propagation	
Conyza canadensis (L.) Cronq.	Annual	Herbage	seed propagation	North America

Melilotus officinalis (L.) Desr.	Annual	Herbage	seed propagation	Europe
Limonium sienense (Girard) O. Kuntze	Perennial	Herbage	seed propagation	Europe
Apocynum venetum L.	Annual	Shrub	seed propagation	
Suaeda salsa (L.) Pall.	Annual	Herbage	seed propagation	
Convolvulus arvensis L.	Perennial	Herbage	seed/vegetative propagation	Europe
Eclipta prostrata (L.) L. Mant.	Annual	Herbage	seed propagation	
Eleusine indica (L.) Gaertn.	Annual	Herbage	seed propagation	India
Hibicus trionum L.	Annual	Herbage	seed propagation	Africa
Potentilla. supina L.	Annual	Herbage	seed propagation	
Plantago asiatica L.	Perennial	Herbage	seed propagation	
Plantago depressa Willd.	Annual	Herbage	seed propagation	North America
Portulaca grandiflora L.	Annual	Herbage	seed/vegetative propagation	Brazil
Taraxacum mongolicum Hand. -Mazz.	Perennial	Herbage	seed propagation	
Polygonum orientale L.	Annual	Herbage	seed/vegetative propagation	
Glycine soja Sieb. et Zucc.	Annual	Herbage	seed propagation	
Hippochaete ramosissima (Desf.) Boerner	Perennial	Herbage	vegetative propagation	
Helianthus annuus L.	Annual	Herbage	seed propagation	North America
Kummerowia striata (Thunb.) Schindl.	Annual	Herbage	seed propagation	
Hemistepta lyrata (Bge.) Bge.	Biennials	Herbage	seed propagation	
Cirsium segetum Bge.	Perennial	Herbage	seed propagation	
Amaranthus lividus L.	Annual	Herbage	seed propagation	America
Cucurbita moschata (Duch. ex Lam.) Duch. Ex Poiret	Annual	Herbage	seed propagation	Central America
Cynodon dactylon (L.) Pers.	Perennial	Herbage	vegetative propagation	
Cyperus rotundus L.	Annual	Herbage	seed propagation	India
Inula japonica Thunb.	Perennial	Herbage	seed propagation	
Chloris virgata Swartz	Annual	Herbage	seed propagation	
Setaria glauca (L.) Beauv.	Annual	Herbage	seed propagation	
Euphorbia supina Rafin.	Annual	Herbage	seed propagation	North America
Carex tristachya	Perennial	Herbage	seed propagation	
Puccinellia tenuiflora (Griseb.) Scribn. et Merr.	Perennial	Herbage	seed propagation	European Mediterranean Sea area
Corispermum declinatum var. tylocarpum	Perennial	Herbage	seed propagation	
Amaranthus retroflexus L.	Annual	Herbage	seed propagation	North America
Euphorbia humifusa Willd.	Annual	Herbage	seed propagation	
Medicago sativa L.	Perennial	Herbage	seed propagation	Europe
Artemisia rubripes Nakai	Perennial	Herbage	seed propagation	
Leonurus japonicus Houtt.	Annual	Herbage	seed propagation	
Gaura lindheimeri Engelm. et Gray	Perennial	Herbage	seed propagation	America
Calamagrostis epigeios (L.) Roth	Perennial	Herbage	seed propagation	
Rubia cordifolia L.	Perennial	Liane	seed propagation	
Melilotus dentatus (Waldst. Et Kit.) Pers.	Annual	Herbage	seed propagation	
Amygdalus persica L.	Perennial	Arbor	seed propagation	
Viola prionantha Bge.	Perennial	Herbage	seed propagation	
Dictamnus dasycarps Turcz.	Perennial	Herbage	seed propagation	
Mulgedium tataricum (Linn.) DC.	Perennial	Herbage	seed propagation	
Polygonum lapathifolium L. var. salicifolium Sibth.	Annual	Herbage	seed propagation	
Bidens frondosa L.	Annual	Herbage	seed propagation	North America
Xanthium sibiricum Patrin.	Annual	Herbage	seed propagation	
Artemisia capillaris Thunb.	Perennial	Herbage	seed propagation	
Artemisia argyi Lévl. et Vant .	Perennial	Herbage	seed propagation	

Bromus japonicus Thunb.	Annual	Herbage	seed propagation	
Astragalus scaberrimus Bge.	Perennial	Herbage	seed propagation	
Equisetum pratense Ehrh.	Perennial	Herbage	seed propagation	
Conyza canadensis (L.) Cronq.	Perennial	Herbage	seed propagation	North America
Acorus calamus L.	Perennial	Herbage	seed/vegetative propagation	
Cuscuta chinensis Lam.	Annual	Cancerroot	seed propagation	
Parthenocissus tricuspidata (Sieb. et Zucc.) Planch.	Perennial	Liane	seed/vegetative propagation	Eastern Asia, North America
Amaranthus tricolor L.	Annual	Herbage	seed propagation	India
Conyza bonariensis (L.) Cronq.	Annual	Herbage	seed propagation	Europe
Artemisia fauriei Nakai	Perennial	Herbage	seed propagation	
Artemisia lancea Van.	Perennial	Herbage	seed propagation	
Scirpus triquter L.	Perennial	Herbage	seed Vegetative propagation	
Artemisia lavandulaefolia DC.	Perennial	Herbage	seed/vegetative propagation	
Scorzonera mongolica Maxim.	Perennial	Herbage	seed	
Triarrhena sacchariflora (Maxim.) Nakai	Perennial	Herbage	seed/vegetative propagation	
Tragus beteronianus Schult.	Annual	Herbage	seed	
Deschampsia caespitosa (L.) Beauv.	Perennial	Herbage	seed	
Diplachne fusca (L.) Beauv.	Annual	Herbage	seed	
Digitaria sanguinalis (L.) Scop.	Annual	Herbage	seed	
Gueldenstaedtia stenophylla Bge.	Perennial	Herbage	seed	
Lespedeza cuneata (Dum. Cours) G. Don	Perennial	Shrub	seed	
Amaranthus hybridus L.	Annual	Herbage	seed	Tropical America
Typha orientalis Presl.	Perennial	Herbage	seed/vegetative propagation	

ACKNOWLEDGEMENTS

This research was supported by the grant from the National Natural Science Foundation of China (grant No. 2006CB403305) and the Program for New Century Excellent Talents in University (NCET-06-0364) through the Ministry of Education of China.

REFERENCES

[1] Z.G. Davies and A.S. Pullin, "Are hedgerows effective corridors between fragments of woodland habitat? An evidence-based approach". *Landscape Ecology*. vol. 22, no. 3, pp. 333-351,2007.

[2] S.L. Flory and K. Clay, "Effects of roads and forest successional age on experimental plant invasions". *Biological Conservation*. vol. 142, no., pp. 2531-2537,2009.

[3] B.C. Klein, "Effects of Forest Fragmentation on Dung and Carrion Beetle Communities in Central Amazonia". *Ecology*. vol. 70, no. 6, pp. 1715-1725,1989.

[4] M. Baguette, S. Petit, and F. Que´va, "Population Spatial Structure and Migration of Three Butterfly Species within the Same Habitat Network: Consequences for Conservation". *Journal of Applied Ecology*. vol. 37, no., pp. 100-108,2000.

[5] I.A. Hanski, "Island Biogeography : Ecology, Evolution and Conservation". *Nature*. vol. 398, no., pp. 387-388,1999.

[6] D. Simberloff, "The contribution of populations and community biology to conservation science". *Annual Review of Ecology and Systematics*. vol. 5, no., pp. 473-511,1988.

[7] P.F. Brussard, D.D. Murphy, and R.F. Noss, "Editorial: Strategy and Tactics for Conserving Biological Diversity in the United States". *Conservation Biology*. vol. 6, no., pp. 157-159,1992.

[8] E.I. Damschen, N.M. Haddad, J.L. Orrock, J.J. Tewksbury, and D.J. Levey, "Corridors increase plant species richness at large scales". *Science*. vol. 313, no. 5791, pp. 1284-1286,2006.

[9] S.S. Cilliers and G.J. Bredenkamp, "Vegetation of road verges on an urbanisation gradient in Potchefstroom, South Africa". *Landscape and Urban Planning*. vol. 46, no. 4, pp. 217-239,2000.

[10] D.A. Saunders and R.J. Hobbs, *The role of corridors* Chipping Norton, NSW, Australia: Surrey Beatty 1991.

[11] P.G. Spooner, I.D. Lunt, and S.V. Briggs, "Spatial analysis of anthropogenic disturbance regimes and roadside shrubs in a fragmented agricultural landscape". *Applied Vegetation Science*. vol. 7, no. 1, pp. 61-70,2004.

[12] R.T.T. Forman and L.E. Alexander, "Roads and their major ecological effects". *Annual Review of Ecology and Systematics*. vol. 29, no., pp. 207-231,1998.

[13] J.L. Gelbard and J. Belnap, "Roads as conduits for exotic plant invasions in a semiarid landscape". *Conservation Biology*. vol. 17, no. 2, pp. 420-432,2003.

[14] S.J. Milton and W.R.J. Dean, "Alien plant assemblages near roads in arid and semi-arid South Africa". *Diversity and Distributions*. vol. 4, no. 4, pp. 175-187,1998.

[15] P.M. Tikka, H. Hogmander, and P.S. Koski, "Road and railway verges serve as dispersal corridors for grassland plants". *Landscape Ecology*. vol. 16, no. 7, pp. 659-666,2001.

[16] E.K. Cameron and E.M. Bayne, "Road age and its importance in earthworm invasion of northern boreal forests". *Journal of Applied Ecology*. vol. 46, no. 1, pp. 28-36,2009.

[17] P.G. Spooner and L. Smallbone, "Effects of road age on the structure of roadside vegetation in south-eastern Australia". *Agriculture Ecosystems & Environment*. vol. 129, no. 1-3, pp. 57-64,2009.

[18] D.J. Hodkinson and K. Thompson, "Plant dispersal: the role of man". *Journal of Applied Ecology*. vol. 34, no. 6, pp. 1484-1496,1997.

[19] A.E. Lugo and H. Gucinski, "Function, effects, and management of forest roads". *Forest Ecology and Management*. vol. 133, no. 3, pp. 249-262,2000.

[20] S.L. Flory and K. Clay, "Invasive shrub distribution varies with distance to roads and stand age in eastern deciduous forests in Indiana, USA". *Plant Ecology*. vol. 184, no. 1, pp. 131-141,2006.

[21] J. Zhang, S. Xing, Q. Sun, J. Chi, and Y. Song, "Study on flora resources and its features in Yellow River Delta Region". *Research of soil and water conservation*. vol. 13, no., pp. 100-102,2006.

[22] Compiling committee of records of roads in Dongying, *Records of roads in Dongying*. Beijing: Chinese Literature and History Press 2003.

[23] R. Wang and G. Zhou, *Shandong vegetation*. Jinan: Shandong Science and Technology Publishing House 2000, pp. 373.

[24] R.F. Noss and A.Y. Cooperrider, "Saving nature's legacy: protecting and restoring biodiversity", in *Saving nature's legacy: protecting and restoring biodiversity*, R.F. Noss and A.Y. Cooperrider, Editors. Washington, D.C.: Island Press: 1994. pp. xxvii+416p.

[25] A.F. Bennett, "Roads, roadsides, and wildlife conservation: a review", in *Nature conservation conservation 2: the role of corridors*, D.A. Saunders and R.J. Hobbs, Editors. New South Wales, Australia: Surrey Beatty and Sons: 1989. pp. 99-118.

[26] N.A. Auerbach, M.D. Walker, and D.A. Walker, "Effects of roadside disturbance on substrate and vegetation properties in arctic tundra". *Ecological Applications*. vol. 7, no. 1, pp. 218-235,1997.

[27] S.C. Saunders, M.R. Mislivets, J.Q. Chen, and D.T. Cleland, "Effects of roads on landscape structure within nested ecological units of the Northern Great Lakes Region, USA". *Biological Conservation*. vol. 103, no. 2, pp. 209-225,2002.

[28] K.A. Theoharides and J.S. Dukes, "Plant invasion across space and time: factors affecting nonindigenous species success during four stages of invasion". *New Phytologist*. vol. 176, no., pp. 256-273,2007.

[29] R.W. Tyser and C.A. Worley, "Alien flora in grasslands adjacent to road and trail corridors in Glacier National Park, Montana (USA)". *Conservation Biology*. vol. 6, no. 2, pp. 253-262,1992.

[30] R.Z. Watkins, J.Q. Chen, J. Pickens, and K.D. Brosofske, "Effects of forest roads on understory plants in a managed hardwood landscape". *Conservation Biology*. vol. 17, no. 2, pp. 411-419,2003.

[31] A.W. Coffin, "From roadkill to road ecology: a review of the ecological effects of roads". *Journal of Transport Geography*. vol. 15, no., pp. 396-406,2007.

[32] W.M. Lonsdale and A.M. Lane, "Tourist vehicles as vectors of weed seeds in Kakadu-National-Park, Northern Australia". *Biological Conservation*. vol. 69, no. 3, pp. 277-283,1994.

[33] C.H. Greenberg, S.H. Crownover, and D.R. Gordon, "Roadside soils: a corridor for invasion of xeric scrub by nonindigenous plants". *Natural Areas Journal*. vol. 17, no. 2, pp. 99-109,1997.

[34] S.C. Trombulak and C.A. Frissell, "Review of ecological effects of roads on terrestrial and aquatic communities". *Conservation Biology*. vol. 14, no. 1, pp. 18-30,2000.

[35] Y. Jodoin, et al., "Highways as corridors and habitats for the invasive common reed Phragmites australis in Quebec, Canada". *Journal of Applied Ecology*. vol. 45, no. 2, pp. 459-466,2008.

[36] I.F. Spellerberg, "Ecological effects of roads and traffic: a literature review". *Global Ecology and Biogeography*. vol. 7, no. 5, pp. 317-333,1998.

[37] L. Borghesio, "Effects of fire on the vegetation of a lowland heathland in North-western Italy". *Plant Ecology*. vol. 201, no. 2, pp. 723-731,2009.

[38] L.A. Parendes and J.A. Jones, "Role of light availability and dispersal in exotic plant invasion along roads and streams in the H. J. Andrews Experimental Forest, Oregon". *Conservation Biology*. vol. 14, no. 1, pp. 64-75,2000.

[39] T. Frissell, "Review of ecological effects of roads on terrestrail and aquatic communities". *Conservation Biology*. vol. 14, no., pp. 18-30,2000.

[40] M.M. Abd El-Ghani and N.A. El-Sawaf, "The coastal roadside vegetation and environmental gradients in the arid lands of Egypt". *Community Ecology*. vol. 6, no. 2, pp. 143-154,2005.

[41] P.G. Angold, "The impact of a road upon adjacent heathland vegetation: effects on plant species composition". *Journal of Applied Ecology*. vol. 34, no. 2, pp. 409-417,1997.

[42] A.M. Farmer, "The effects of dust on vegetation - a review". *Environmental Pollution*. vol. 79, no. 1, pp. 63-75,1993.

[43] R.T.T. Forman, et al., *Road ecology: science and solutions*. Washington, D.C.: Island Press 2002.

[44] R. Huang, "Resources value and cultivation techniques of Glycine soja". *Resource Development & Market*. vol. 24, no., pp. 771-772, 814,2008.