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Influence of Anthropogenic Disturbances on Understory Plant Diversity of Urban Forests in Wuhan, Central China

(Pengaruh Gangguan Antropogen terhadap Kepelbagaian Tumbuhan Bawahan di Hutan Bandar di Wuhan, China Tengah)

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ABSTRACT

Relationship between understory plant diversity and anthropogenic disturbances in urban forests of Wuhan City, Central China, was analyzed by diversity analysis and detrended canonical correspondence analysis (DCCA). The results showed that understory species diversity was higher in suburban area than in urban area. From forest center to edge, species diversity of Luojia hill, Shizi hill and Maan hill forests gradually increased, however, that of Hong hill gradually decreased. Anthropogenic disturbances gradient resulted from visitors flowrate, shrub coverage, aspect and adjacent land types had significant effects on species diversity of shrub and herb layers in urban forests. High anthropogenic disturbances might increase similar non-native herb species in urban area and low disturbances might promote co-existence of wood species in suburban area. Further analysis on types of anthropogenic disturbances and plant functional groups in urban-suburban gradient should be taken into a consideration.

Keywords: DCCA; disturbance; edge effect; species diversity; urban-suburban gradient

ABSTRAK

Hubungan antara kepelbagaian tumbuhan bawahan dan gangguan antropogen di hutan bandar Wuhan, China Tengah, telah dianalisis dengan analisis kepelbagaian dan analisis kesetaraan utama nyahtren (DCCA). Hasil kajian menunjukkan bahawa kepelbagaian spesies bawahan adalah di kawasan pinggir bandar yang lebih tinggi daripada di kawasan bandar. Dari pusat hutan ke tepi hutan, kepelbagaian spesies bukit Luojia, bukit Shizi dan hutan bukit Maan beransur-ansur meningkat, walau bagaimanapun, bukit Hong menurun secara beransur-ansur. Antropogen kecerunan gangguan hasil daripada kadar pelawat, liputan pokok renek, aspek dan jenis tanah yang bersebelahan mempunyai kesan yang ketara ke atas kepelbagaian spesies renek dan lapisan herba dalam hutan bandar. Gangguan antropogen yang tinggi mungkin meningkatkan spesies herba bukan asli yang serupa di kawasan bandar dan gangguan rendah mungkin menggalakkan kewujudan bersama spesies kayu di kawasan pinggir bandar. Analisis lanjut mengenai jenis gangguan antropogen dan kumpulan pokok yang berfungsi dalam kecerunan bandar-pinggir bandar perlu diberi perhatian.

Kata kunci: DCCA; gangguan; kecerunan bandar-pinggir bandar; kepelbagaian spesies; kesan pinggir

INTRODUCTION

The world is urbanizing rapidly. Urbanization is a process of a large expanse of impervious surface (Blair & Launer 1997) and simplification of vegetation structure (McKinney 2008) which can create massive anthropogenic disturbances and forest fragmentation. Plant diversity tends to be reduced in central urban core areas with extreme urbanization and fragmentation, compared with the suburban area with moderate levels of urbanization (McKinney 2002, 2008). Increase of anthropogenic disturbances (such as trampling, digging and deforestation) from suburban areas towards urban areas will promote the decrease of plant diversity in urban areas (McKinney 2002). The edge habitats accompanied by forest fragmentation are transition between adjacent habitats (Murcia 1995; Wang et al. 2012b), in which a higher abundance and diversity of species are supported, i.e. the edge effect. However, the edge effects also depend on whether landscape context is urban or suburban habitat. Many previous studies focus on species richness in central urban versus the suburban area (McKinney 2002, 2008) or on edge habitats of forest fragmentation in boreal (Harper & Macdonald 2002), temperate (Baldwin & Bradfield 2005) and tropical forests (Oosterhoorn & Kappelle 2000). However, few studies focus on the influence of anthropogenic disturbances on understory diversity of both urban area and edge habitat.

The aims of this study were to examine whether urbanization has an influence on species diversity and edge habitat of forest and to find which disturbance factors contributed larger to species diversity in urban forest. Therefore, the authors hope to provide the suggestion conservation of species diversity in urbanization process of Wuhan City, Central China.

MATERIALS AND METHODS

STUDY AREA

The study site is located in Wuhan (113°41′—115°05′E, 29°58′—31°22′N), Hubei province, Central China. It has a typically subtropical humid monsoon climate with hot and rainy summer and cold winter. The annual average precipitation is 1140–1265 mm, the annual average temperature is 16.6ºC and annual average relative humidity is 77%. The forest types in this region mainly are evergreen broad-leaved forest and coniferous broad-leaved mixed forests. The population density, urbanization and intensity of land use in the urban core are extraordinarily high, while the suburban districts predominantly have a rural landscape and rural land use (Du et al. 2010).

Based on the criteria of urbanization level (McKinney 2002), urban core habitats with a high level of urbanization are mainly landscapes with an area of more than 50% impervious surfaces and suburban areas, represented by the moderate level of urbanization, outside the core but not including the rural areas which usually have 20–50% impervious surface area. Therefore, Luojia hill (site A) and Hong hill (site B) were selected to represent urban habitats (adjacent land types are commercial land and traffic land, respectively); we also selected Shizi hill (site C and adjacent land is for educational and scientific research) and Maan hill (site D and adjacent land type is agricultural land) to represent suburban habitat in middle May 2011 (Table 1). The forest on the site mainly consists of evergreen coniferous tree species *Pinus massoniana* Lamb. and evergreen broad-leaved trees *Cinnamomum camphora*. The typical coniferous broad-leaved mixed forests and similar canopy coverage (76%-80%) are chosen in the above four sites.

Since adjacent land cover might influence the edge effect (Hersperger & Forman 2003), the edges chosen for study were adjacent to impervious pavements in urban areas and to pervious surfaces in suburban areas. On the selected edges, three transects were established towards the center of the forest, perpendicular to the forest boundary. The first transect was placed at the center of the edge and the two others were located 8 m either side. Along each transect, we placed three quadrats of 10 m × 10 m located at 0, 15 and 30 m from the edge and in each quadrat, three random 1 m × 1 m small quadrats were established. Hence a total of 36 quadrats and 108 small quadrats were surveyed.

DATA COLLECTION

In each 10 m × 10 m quadrat, height and coverage of each wood species in shrub layer (including tree saplings and seedlings) were measured. Average height and coverage of each herb species were documented in each 1 m × 1 m small quadrat. Community characteristics: number of broken branches, shrub coverage, litter coverage and thickness and canopy density were measured, photon density (PD) was measured in the center of each quadrat and in open sites on similar overcast days by an illuminometer (TES-1335). Thus, relative photon density (RPD) was calculated. Environmental factors associated with anthropogenic disturbance such as topographical factors (indirect disturbance factors) including slope and aspect were recorded and anthropogenic disturbance factors (direct disturbance factors), including number of rubbishes, stump, human caves, visitors flowrate (the number of visitors), adjacent land types, distance to forest edge, distribution of tiles and path number were documented. These factors (community characteristics, topographical factors and anthropogenic disturbance factors) were included in DCCA ordination.

The classification and evaluation of all factors are listed in Tables 2. In addition 7, 5, 3 and 1 are evaluated to southern slope, eastern slope, western slope and northern slope, respectively, meanwhile 4, 3, 2 and 1 are evaluated to adjacent traffic land, commercial land for educational and scientific research and agricultural land, respectively, 3, 2 and 1 are evaluated to the distance of 30 m, 15 m and 0 m to edge. Other factors are evaluated to measured value.

TABLE 1. Stands characteristics of each site

Sites	Location	Altitude (m)	Slope (º)	Canopy coverage (%)	Forest types	Types of adjacent land	Habitat
Luojia hill	N30°32′15”, E114°22′09”	100	11	82	CBF	Commercial land	Urban area
Hong hill	N30°32′13”, E114°20′18”	80	4	76	CBF	Traffic land	Urban area
Shizi hill	N30°28′50”, E114°21′16”	68	8	74	CBF	Land for education and scientific research	Suburban area
Maan hill	N30°31′09”, E114°26′13”	115	5	80	CBF	Agricultural land	Suburban area

CBF: Coniferous- broad leaved mixed forest

TABLE 2. The environmental factors included in DCCA of the quadrats

Type	Factors	Abbr.	Range
	Slope(°)	Slope	Measure values
Topography	Aspect	Aspect	7, 5, 3, 1
	Rubbish(no.)	Rubbish	Measure values
	Stump(no.)	Stump	Measure values
	Adjacent land types	Adj Lan	4, 3, 2, 1
	Human cave(no.)	Hum Cav	Measure values
Disturbance	Visitors flowrate (person/day)	Vis Flo	Measure values
	Distance to forest edge (m)	DTFE	3, 2, 1
	Tile (no.)	Tile	Measure values
	Path number (no.)	Pat Num	Measure values
	Canopy density (%)	Can Den	Measure values
	Broken branches (no.)	Bro Bra	Measure values
Community structure	Relative photon density (%)	RPD	Measure values
	Shrub coverage (%)	Shr Cov	Measure values
	Litter coverage (%)	Lit Cov	Measure values
	Litter thickness (cm)	Lit Thi	Measure values

DATA ANALYSIS

The important value (IV) of the species is calculated using the following formulas (Wang et al. 2009, 2012c):

IV shrub and herb = (relative height + relative coverage + relative frequency) ×100/3.

Detrended canonical correspondence analysis (DCCA) of CANOCO4.5 soft was used to analyze the relationship between quadrats (based on importance values of species) and environmental variables and to discuss key disturbance factors (Wang et al. 2009, 2012c).

Shannon-Wiener index $H = -P_i \ln P_i$; Simpson index $D = 1 - \sum P_i^2$; Pielou evenness index $J = (-\sum P_i \ln P_i)/\ln S$; Richness index S. P_i is the relative IV of the species and S is the total species (Wang et al. 2012a).

The similarity among communities (β-diversity) is calculated by Jaccard's index: $C_s = \frac{c}{a+b-c}$, C_s is the similarity index, a and b is the species number of community A and B, respectively, c is number of common species between community A and B. The figures were drawn by Origin 7.0 (software) and all statistical analyses were carried out using SPSS (SPSS 11 Copyright: SPSS Inc.). A multiple comparison was used to determine significant differences among 3 quadrats with different distances to edge.

RESULTS

UNDERSTORY SPECIES DIVERSITY DYNAMICS FROM FOREST CENTER TO EDGE

A total of 114 species were sampled in study sites, including 61 tree species, 24 shrub species, 21 herb species and 8 vine species.

Shannon-Wiener, Simpson and Richness indices of shrub layer, herb layer and total richness index of forest understory in site A, C and D significantly increased from forest interior to the edge (p<0.05) except for Simpson index in site C and D of herb layer. On the contrary, these indices in site B significantly decreased from forest interior to the edge (p<0.05). Evenness index of shrub layer indicated significantly changed from forest interior to the edge in urban forest. The index significantly increased from forest interior to the edge in site A (p<0.05), which showed opposite trend in site B (Figure 1).

UNDERSTORY SPECIES DIVERSITY BETWEEN URBAN FOREST AND SUBURBAN FOREST

When compare urban forest (site A and B) with suburban forest (sites C and D), Shannon-Wiener diversity, Simpson diversity and Richness indices of urban forests are much lower than suburban forests (Table 3). These indices of Maan hill (site D, suburban) are the highest and that of Hong hill (site B, urban) are the lowest among four sites. In addition, Jaccard's index (β diversity) of shrub layer in urban forest is lower than suburban forest, which is the highest between Maan hill and Shizi hill and is the lowest between Hong hill and Maan hill. However, the index of herb layer in urban forest is higher than that in suburban forest, which is the highest between Luojia hill and Hong hill and is the lowest between Hong hill and Shizi hill (Table 4).

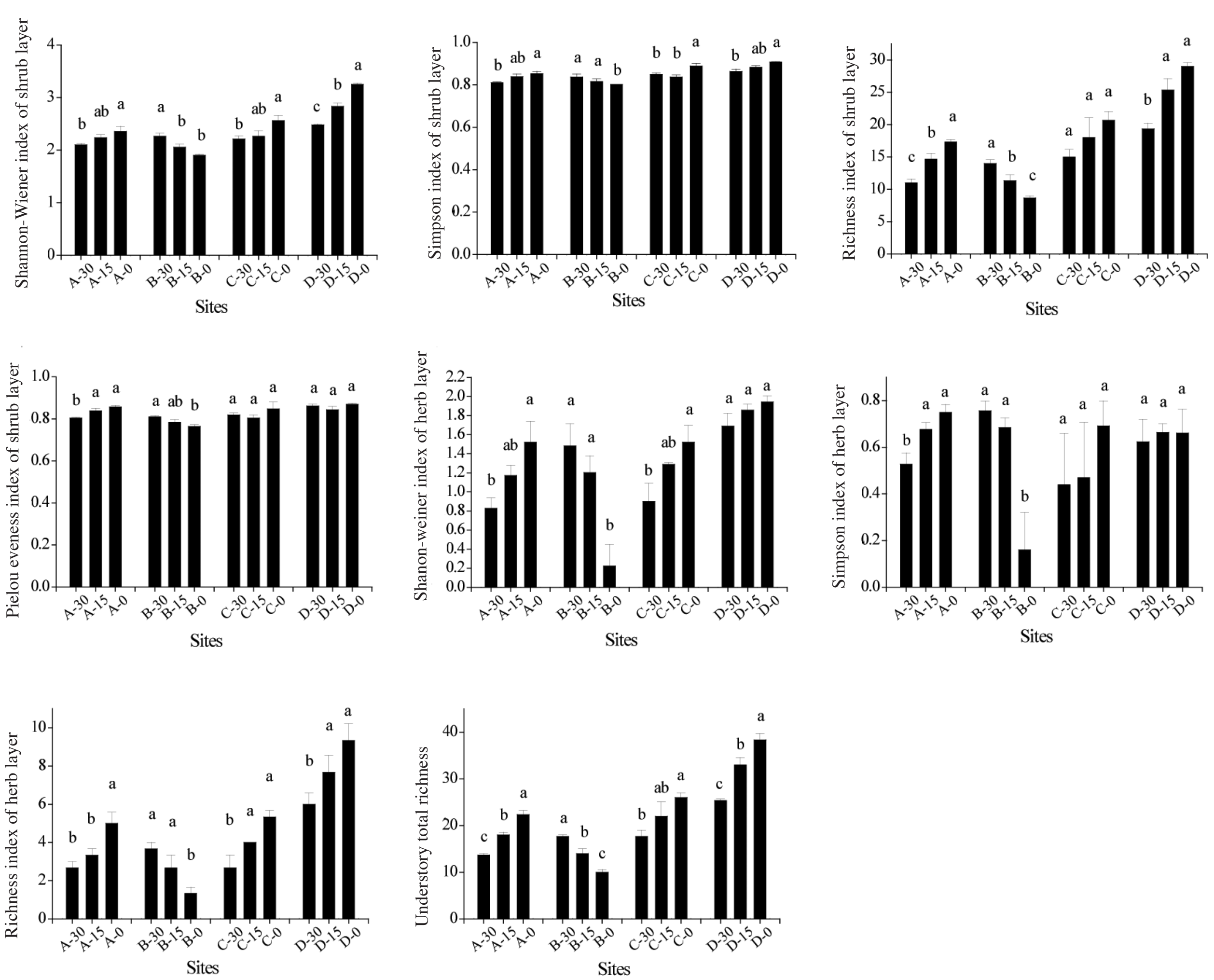


FIGURE 1. Species diversity dynamics of shrub, herb and total understory from forest center to edge in four sites
Site A, B, C and D represented Luojia hill, Hong hill, Shizi hill and Maan hill, respectively. A-30, A-15 and A-0 represented central area (30 m distance to edge), middle area (15 m distance to edge) and edge (0 m distance to edge) in site A (Luojia hill), respectively. The same as in site B, C and D. Bars indicate S.E. from the mean. Different letters (a, b and c) mean significant differences (p<0.05) among species diversity indices and evenness index of each layer

TABLE 3. Species diversity of shrub and herb layer in different sites

Sites	Layer	*S*	*H*	*D*	*J*
Luojia hill	Shrub	34	2.658	0.884	0.754
	Herb	13	2.319	0.882	0.904
Hong Hill	Shrub	34	2.555	0.852	0.725
	Herb	10	2.145	0.868	0.932
Shizi Hill	Shrub	50	2.938	0.896	0.751
	Herb	15	2.484	0.895	0.917
Maan Hill	Shrub	55	3.163	0.931	0.789
	Herb	18	2.701	0.923	0.934

H: *Shannon-Wiener* diversity index; D: *Simpson* index; J: Evenness index; S: Richness index. The same below

DCCA ORDINATION AND ANTHROPOGENIC DISTURBANCES IN URBAN TO SUBURBAN AREA

Based on the species and environment data matrix, the quadrats distribution was recognized by detrended canonical correspondence analysis (DCCA). The first axis is largely associated with slope (correlations coefficient 0.4933) and broken branches (0.3802), which represents topographical gradient. The second axis is mainly associated with visitor flowrate (-0.6760), aspect (0.6169), shrub coverage (-0.4743) and land types (-0.3813), which

TABLE 4. β-diversity index of shrub and herb layer in four sites

Items		Luojia hill	Hong hill	Shizi hill	Maan hill
Shrub	Luojia hill	1.000	0.360	0.333	0.290
	Hong hill	/	1.00	0.313	0.290
	Shizi hill	/	/	1.000	0.382
	Maan hill	/	/	/	1.000
Herb	Luojia hill	1.000	0.438	0.333	0.290
	Hong hill	/	1.000	0.250	0.273
	Shizi hill	/	/	1.000	0.269
	Maan hill	/	/	/	1.000

represents disturbance gradient gradients. From left to right along the first axis, slope becomes abrupt and the number of broken branches tends to be increasing. From the top to the bottom along the second axis, visits becomes more frequent and intensive, quadrats tends to be urban land, slope is facing south and the shrub cover tends to be decreasing (Table 5 and Figure 2).

The DCCA ordination (Figure 2) demonstrated anthropogenic disturbance gradient decreased along the direction of site B, A, C and D. Quadrats (including sample 1 to sample 18) of urban habitats have extremely higher visitors flow rate than those (including sample 19 to sample 36) of suburban habitats, especially when compared with sample 10, 11, 12, 13, 14 and 15 of site B (Hong Hill) with quadrats of site C (Shizi Hill) and site D (Maan Hill). The similar results were exhibited in other variables such as land types. Therefore, urban forests could be subjected to more intense and frequent anthropogenic disturbances than suburban forests.

DISCUSSION AND CONCLUSION

Urbanization produced anthropogenic disturbances gradient (McKinney 2002), such as disturbances from the adjacent land and human frequentation. Adjacent land use and human frequentation have been shown to modify understory diversity in forests (Gibb & Hochuli 2002; Jacquemyn et al. 2001). In this study, we have found that visitor frequentation and adjacent land use are the key factors affecting the understory diversity (Table 5 and Figure 2), and these factors in the urban forest are more intensive and frequent than suburban forest, this is consistent with previous studies (Medley et al. 1995; Pickett et al. 2008).

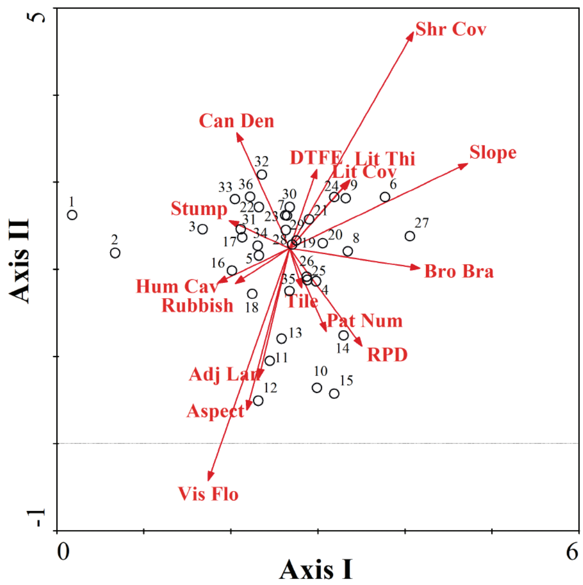
Previous study indicates anthropogenic disturbances gradient from urbanization will reduce the species diversity and increase the similarity of urban forest (McKinney 2002). Indeed, in our study, the understory diversity in urban forest are much lower than that in suburban forest, the similarity of herb in urban forest are higher than suburban forest. Anthropogenic disturbances produce a comprehensively physical changes strongly and reducing available habitat for native species (McKinney 2002), such as human population density, road density, air and soil pollution, average ambient temperature ('heat island' effect), average annual rainfall, soil compaction, soil alkalinity and other indicators of anthropogenic disturbance (Medley et al. 1995; Pickett et al. 2008). Furthermore, anthropogenic disturbances create the habitat for exotic species. In this study, the visitor flow rate and adjacent land type are negative with the canopy density and shrub coverage (Table 5), so direct anthropogenic disturbances in forests can create open areas, which favor exotic species by increasing light availability and reducing competition with forest plants (Deconchat & Balent 2001). Therefore, high anthropogenic disturbances might increase similar non-native herb species in urban area and low disturbances might promote co-existence of wood species in suburban area.

Adjacent land type and human frequentation also modulate the edge effects and understory plant species diversity (Guirado et al. 2006). Understory diversity

TABLE 5. Correlations of environmental variables to the first two DCCA axis

Environmental variables (Abbr.)	Correlations axis Ⅰ	Coefficient axis Ⅱ
Slope	**0.4933**	0.2099
Aspect	-0.0848	**-0.4743**
Can Den	-0.1801	0.3603
Shr Cov	0.3051	**0.6169**
Bro Bra	**0.3802**	-0.0933
Vis Flo	-0.1794	**-0.6760**
RPD	0.2323	-0.3118
Adj Lan	-0.0573	**-0.3813**

Shr Cov: Shrub coverage; Bro Bra: Broken branches; Can Den: Canopy density; Vis Flo: Visitors Flowrate;
Adjacent land types: Adj Lan; RPD: Relative photon density



Shr Cov: Shrub coverage; Bro Bra: Broken branches; Can Den: Canopy density; Vis Flo: Visitors Flowrate; Adj Lan: Adjacent land types; Pat Num: Path number; DTFE: Distance to forest edge; Lit Thi: Litter thickness; Lit Cov: Litter coverage; RPD: relative photon density; Hum cav: Human caves. Quadrats 1-9, 10-18, 19-27 and 28-36 mean Luojia hill, Hong hill, Shizi hill and Maan hill, respectively. 1, 4, 7, 10, 13, 16, 19, 22, 25, 28, 31 and 34 mean samples at distance of 30 m to edge, 2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 32 and 35 mean samples at distance of 15 m to edge, 3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33 and 36 means samples at distance of 0 m to edge

FIGURE 2. DCCA ordination based on the understory species matrix of 41 species and 36 quadrats and on the environment matrix of 16 factors and 36 quadrats

increases with decreasing distance from the forest edge in forests (Sites A, C and D) adjacent to commercial land, crops land and land for educational and scientific research, but converse in Hong hill adjacent to traffic land (Table 1 and Figure 1). Different adjacent land type and human frequentation have different effects on forest edges: agricultural activity might modify some forest edge properties, causing eutrophication (Dumortier et al. 2002) and enhancing the arrival and spread of many weed and crop species into forests (Koerner et al. 1997). In contrast, urban land use would determine more intense soil compaction due to pedestrian traffic, soil compaction associated has been proven to determine the plant diversity reduction (Godefroid & Koedam 2004). Our study also highlights human frequentation playing a central role on understory plant species diversity. Frequentation was concentrated significantly near the edge of forest (site B) adjacent to traffic land, and this pattern essentially coincides with the positive relationship between adjacent land type and visitor frequentation (Table 5 and Figure 2).

In addition, anthropogenic disturbances, including coverage (rubbishes and tiles), trampling (paths, visitors coming from different adjacent lands and the distance to edge) and deforestation (anthropogenic caves and stumps) and indirect anthropogenic disturbances (terrain, such as slope and aspect) might have integrated effect on composition and plant diversity of forest (Wang et al. 2012c).

As the response of different functional groups to anthropogenic disturbances is varied, we suggest further analysis on types of anthropogenic disturbances and plant functional groups in urban-suburban gradient should be taken into consideration. That will help to understand the effect of anthropogenic disturbances on plant diversity and will provide more detailed supports for conservation of plants.

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