Harm Situation and Risk Assessment of *Pueraria montana* in the "Four Mountains" Forest Ecosystem in the Central Urban Area of Chongqing

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Abstract *Pueraria montana* is a perennial twining vine species of *Pueraria* in Leguminosae. Because of its fast growth and strong climbing and covering ability, this species has the potential threat of invading forest ecosystem. Based on the investigation of the occurrence and harm of *P. montana* in the "four mountains" forest ecosystem in the central urban area of Chongqing, combined with its growth habits and biological characteristics, we comprehensively evaluated its harm risk. The results show that *P. montana* is widely distributed in the forest ecosystem within the "four mountains" in the central urban area of Chongqing. On average, there was a distribution site of *P. montana* every 1.38 km of forest road with a scale of 0.43 hm^2/survey point and a coverage of about 42.86%. *P. montana* mainly occupy forest land by covering and climbing, threatening the original vegetation of forest land. It grows rapidly, and its ability of diffusion and colonization is very strong. The average length of new branches was 11.52 m/year, and the number of effective tillers was 5.25. According to *National Forestry Pest Risk Analysis Index System*, the risk assessment value of *P. montana* was 2.51, so it is a medium-risk harmful plant to forestry. It is suggested that the forestry department should strengthen the management of *P. montana* to prevent its further spread.

Key words *Pueraria montana*; Forest ecosystem; Harm situation; Risk assessment

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Pueraria montana is a perennial twining vine species. This plant has fast growth speed and strong climbing and covering ability, and is often planted as a forage plant in areas such as mine waste dumps and waste slopes. However, if planted in tree and bush areas, its vines will spread rapidly to the surrounding woodlands, and through winding and covering, the plants they climb will be inhibited, affecting normal growth or even causing death. It has inherent potential as an invasive species and can cause biodiversity loss in the invaded areas and threaten ecological security[1].

Chongqing has a complex landform structure and is famous as a mountain city. Jinyun Mountain, Zhongliang Mountain, Tongluo Mountain and Mingyue Mountain (also known as the "four mountains" in the central urban area of Chongqing) run through the north and south of the main city and are regarded as "natural ecological barriers" in the central urban area of Chongqing[2]. With the process of urbanization and the influence of human activities, *P. montana* has spread rapidly in the "four mountains" in recent years, and occupied and covered forest land in some areas, causing harm to newly planted forests, pine wilt disease control sites and sunroofs of *Pinus massoniana*, and nurseries[1,3]. Due to the lack of systematic investigation and study, the occurrence and harm of *P. montana* in the "four mountains" forest ecosystem in the main city have not been fully grasped, which is extremely unfavorable to the protection of ecological barrier in the central urban area of Chongqing. In order to clarify the occurrence and harm situation of *P. montana* in the "four mountains" forest ecosystem in the central urban area of Chongqing, the habitat types, harm objects and population coverage (or damaged plant rate) of *P. montana* were recorded by on-the-spot survey, and the risk assessment of *P. montana* disaster in the forest ecosystem was completed by combining with a forest pest risk analysis index system, aiming at providing a theoretical basis for the prevention and control of *P. montana* in the "four mountains" forest ecosystem in the central urban area.

Materials and Methods

General situation of study area

The surveyed area was mainly concentrated in the "four mountains" in the central urban area, including Zhongliang Mountain, Jinyun Mountain, Mingyue Mountain and Tongluo Mountain. This area has a mid-subtropical humid monsoon climate, and the vegetation types are mainly *P. massoniana* forest, *P. massoniana* + *Cunninghamia lanceolata* mixed forest and *P. massoniana* + evergreen broad-leaved mixed forest.

Survey routes and investigation methods

Based on satellite map images and forest data, 37 survey routes (with a length of 5 - 8 km per route) were set up. The survey was carried out by "driving + walking" along forest roads based on the survey routes. When *P. montana* was found along the way, it was regarded as a survey point, and the position information, surrounding environment and forest composition of each

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survey point were recorded, and the damage objects of *P. montana*, *the area* (hm^2) of *P. montana* and the population coverage (%) were also recorded. Finally, the damage degree of *P. montana* to forest land was judged through field observation or with the help of aerial image data of unmanned aerial vehicles. According to the occurrence areas (hm^2) and population coverage (%) of *P. montana* at single survey points, the damage degree of *P. montana* was divided into five levels (Table 1).

Table 1 Classification standards for *P. montana*

No.	Occurrence area (hm^2) and population coverage (%)	Level of damage degree
1	Occurrence area ≤0.013 hm^2 or population coverage ≤5%	Level 0 (no occurrence)
2	Occurrence area ranging from 0.02 – 0.06 hm^2 or population coverage ranging from 6% to 19%	Level 1 (mild)
3	Occurrence area ranging from 0.067 to 0.327 hm^2 or population coverage ranging from 20% to 49%	Level 2 (moderate)
4	Occurrence area ranging from 0.333 to 0.66 hm^2 or population coverage ranging from 50% to 74%	Level 3 (serious)
5	Occurrence area ≥0.667 hm^2 or population coverage ≥75%	Level 3 (severe)

Determination of main biological characteristics of *P. montana*

The growth, tillering, climbing process and spreading rate of *P. montana* were observed and recorded by collecting sample plants. In specific, new branches were collected from the base (including branches) and brought back to the laboratory, and the annual growth of *P. montana* was measured, including length, biomass (fresh weight, dry weight) and so on. Firstly, new branches of *P. montana* were measured for their lengths using a measuring tape with the accuracy to 0.01 m. After the measurement was completed, whole vines (including leaves) were cut into 15 – 20 cm segments, which were tied and weighed with a high-precision electronic scale (model: Yingheng YH-3-6), and then dried in an oven at 80 ℃ until the mass was constant and weighed for dry weights. During the survey, 42 samples of *P. montana* were collected, including 8 samples from Zhongliang Mountain, 8 samples from Jinyun Mountain, 12 samples from Mingyue Mountain and 14 samples from Tongluo Mountain. Before drying, one pinnate compound leaf (including three leaves) was randomly picked from each sample and measured with a ruler for the leaf length (a) and width (b), and the leaf area was measured with an approximate area method.

Calculation formula: $S=\frac{2(a\times b)}{3}$ (Formula 1)

Risk assessment of *P. montana* invasion to forest ecosystem

According to *National Forestry Pest Risk Analysis Index System*, the risk assessment was conducted from four aspects: introduction and colonization risk (P_1), spreading and diffusion (P_2), potential hazards and impacts (P_3) and risk control (P_4). The individual evaluation values P_1, P_2, P_3 and P_4 were calculated according to Formula 2, Formula 3, Formula 4 and Formula 5, respectively, and then, the risk level was divided according to the risk evaluation value P calculated by Formula 6[4]. P_1, P_2, P_3, P_4 and P are calculated according to following formulas as follows:

$$P_1=0.3\times P_{11}+0.3\times P_{12}+0.2\times P_{13}+0.2\times P_{14} \quad \text{(Formula 2)}$$

$$P_2=\sqrt[4]{P_{21}\times P_{22}\times P_{23}\times P_{24}} \quad \text{(Formula 3)}$$

$$P_3=\max(P_{31}, P_{32}, P_{33}) \quad \text{(Formula 4)}$$

$$P_4=(P_{41}+P_{42}+P_{43})/3 \quad \text{(Formula 5)}$$

$$P=\sqrt[4]{P_1\times P_2\times P_3\times P_4} \quad \text{(Formula 6)}$$

The risk level was divided according to the value of risk P. If $2.8\leqslant P<4.0$, the evaluated object is at the risk level I, and it is a high-risk harmful organism; if $1.2\leqslant P<2.8$, it is at the risk level II, and it is a medium-risk harmful organism; and if $0\leqslant P<1.2$, it is at the risk level III, and it is a high-risk harmful organism.

Data processing and mathematical statistics

SPSS Statistics 22.0 was employed to analyze the survey data by One-way ANOVA, and the least significant difference (*LSD*, $P<0.05$) was used for multiple comparisons of the average. Before the analysis, the coverage (%/point) of *P. montana* population was subjected to arcsine square root transformation.

Results and Analysis

Survey results of occurrence and harm of *P. montana*

Results and analysis of encounter frequency Thirty seven routes were surveyed, with a total mileage of 192.30 km, involving 266 survey points. In terms of encounter frequency, *P. montana* was most widely distributed in Tongluo Mountain with 1.58 points/km, followed by Zhongliang Mountain with 1.40 points/km, Mingyue Mountain with 1.39 points/km and Jinyun Mountain with 1.16 points/km (Table 2).

Table 2 Statistical analysis on the occurrence frequency of *P. montana* in the "four mountains" forest ecosystem in the central urban area of Chongqing

Survey area	Route	Total mileage//km	Survey point	Encounter frequency//points/km
Zhongliang Mountain	10	51.2	81	1.58
Zhongliang Mountain	11	52.8	74	1.40
Mingyue Mountain	7	38.1	53	1.39
Jinyun Mountain	9	50.2	58	1.16
Total	37	192.3	266	1.38

Occurrence and harm results of *P. montana* The survey results showed that 81 growing points of *P. montana* were found when walking along 51.2 km of forest road in Tongluo Mountain. The average occurrence area was (0.519 ± 0.057) hm^2/survey point, and the coverage reached (48.98 ± 3.07)%. Among them, 36 points reached the serious and above levels (Table 3), and the plant mainly encroached on forest land by covering and climbing, threatening the original vegetation of forest land. When passing through 52.8 km of forest road in Zhongliang Mountain, 74 growing points of *P. montana* were found, with an average occurrence area of (0.454 ± 0.053) hm^2/survey point and a coverage of (44.1 ± 12.70)%. Among them, 37 points reached the serious and above levels, and the plant also encroached on forest land by covering and climbing, threatening the original vegetation of forest land. When passing through Mingyue Mountain and Jinyun Mountain, 53 and 58 growing points of *P. montana* were found respectively, and 20 and 31 of them reached the serious and above levels, respectively. The average occurrence area and coverage were (0.331 ± 0.045) hm^2/survey point and (33.13 ± 3.30)% for the former, respectively, and the values were (0.365 ± 0.048) hm^2/survey point and (41.64 ± 3.42)% for the later, respectively. The damage mode was also covering or climbing the forest land.

Table 3 Statistical table of the damage degree of *P. montana* in the "four mountains" forest ecosystem in the central urban area of Chongqing

Survey area	Occurrence area hm^2/point	Population coverage %/point	Damage degree				
			Level 0	Level 1	Level 2	Level 3	Level 4
Zhongliang Mountain	0.519 ± 0.057 b	48.98 ± 3.07 a	7	17	21	12	24
Zhongliang Mountain	0.454 ± 0.053 ab	44.11 ± 2.70 a	3	8	26	22	15
Mingyue Mountain	0.331 ± 0.045 a	33.13 ± 3.30 a	9	7	17	13	7
Jinyun Mountain	0.365 ± 0.048 ab	41.64 ± 3.42 a	2	4	21	22	9

Different letters following data in the same column indicate that there is significant difference between the treatment groups ($P < 0.05$, *LSD*, ANOVA).

Determination and analysis of *P. montana* growth The measurement results of new branch length, number of branches, number of nodes, approximate leaf area, fresh weight and dry weight are shown in Table 4. According to the investigation results, *P. montana* grew fast. The length of new branches was between 4.35 and 21.62 m (11.52 m averagely), and the base was stout and lignified. The tillering ability was very strong, and the number of effective tillers was between 2 and 9 (5.25 averagely). Averagely, each new branch had 47.35 nodes, which could develop to new individuals and start to grow independently when conditions were suitable, so *P. montana* has strong natural spread and colonization ability. *P. montana* has pinnate compound leaves with 3 leaflets, and the measured approximate leaf area was in the range of 88.17 – 268.40 cm^2, with an average of 183.25 cm^2. The fresh weight and dry weight of new branches were 3.27 and 0.26 kg, respectively, indicating that the biomass of *P. montana* was large. Therefore, it was judged that *P. montana* might have a certain degree of loss effect on soil fertility. No significant differences were found in the length of new branches, number of branches, number of nodes, approximate leaf area, fresh weight and dry weight between different regions.

Conclusions and Discussion

P. montana is often widely planted as a forage plant in large areas such as bare land, mine waste dumps and waste slopes, because of its rapid growth, adaptability and strong reproduction[5]. However, due to the lack of control in the later period, its vines will quickly spread to the woodland, and inhibit the normal growth of the plants they climb by winding and covering and releasing allelochemicals, resulting in the loss of biodiversity in the invaded areas. Compared with other forestry harmful plants, such as *Eupatorium adenophorum*[6], *Mikania micrantha*[7] and *Cuscuta chinensis*, researchers generally pay less attention to the growth habits, harm and control methods of *P. montana* [8-9], and its harm is often underestimated. According to the assessment results, the risk assessment value of *P. montana* was 2.51, so it is a medium-risk harmful plant to forestry. It is suggested that the forestry department should strengthen the management of *P. montana* to prevent its spread.

Table 4 Determination results of *P. montana* growth

Survey area	Number of samples	Length//m	Number of tillers	Number of nodes	Leaf approximate area//cm^2	Fresh weight//kg	Dry matter weight//kg
Zhongliang Mountain	8	12.18 ± 0.91	5.25 ± 0.49	44.13 ± 7.55	186.27 ± 16.39	3.46 ± 0.38	0.24 ± 0.05
Zhongliang Mountain	8	11.43 ± 1.50	5.08 ± 0.62	48.83 ± 2.99	182.30 ± 11.46	3.75 ± 0.53	0.28 ± 0.06
Mingyue Mountain	12	10.56 ± 0.89	5.75 ± 0.37	50.00 ± 3.53	172.79 ± 8.43	3.15 ± 0.48	0.23 ± 0.03
Jinyun Mountain	14	11.91 ± 1.32	4.93 ± 0.47	46.43 ± 4.44	191.65 ± 13.45	2.72 ± 0.29	0.29 ± 0.05
Total/average	42	11.52 ± 0.65	5.25 ± 0.26	47.35 ± 2.26	183.25 ± 6.43	3.27 ± 0.22	0.26 ± 0.03

Risk assessment of *P. montana* to forest ecosystem

According to *National Forestry Pest Risk Analysis Index System*, the risk assessment was conducted from four aspects: introduction and colonization risk (P_1), spreading and diffusion (P_2), potential hazards and impacts (P_3) and risk control (P_4). According to Formulas 1, 2, 3 and 4, the individual evaluation values $P_1 = 3.39$, $P_2 = 2.36$, $P_3 = 2.48$ and $P_4 = 1.99$ were calculated respectively, and then the risk evaluation value P was calculated to be 2.51 according to Formula 5. According to the classification standards, the risk level of *P. montana* the four mountains forest ecosystem in Chongqing was level II. That is to say, it belongs to medium-risk harmful organisms to forestry.

Table 6 Results of risk assessment of *P. montana* to forest ecosystem within the "four mountains" in the central urban area of Chongqing

First-class index (criterion layer)	*P*	Second-class index (target layer)	Specific parameter and scoring interval (specific evaluation index)	Assigned value/points Mean ± *SD*
P_1: Introduction and colonization risk	P_{11}	Suitability of environmental factors	The climate and water environment in the area are highly suitable.	3.70 ± 0.45
	P_{12}	Suitability of food (matrix) factors	The animal food/insects and microbial hosts/soil in the evaluation area are highly suitable for plant survival.	3.56 ± 0.15
	P_{13}	Growth and reproduction characteristics	It has strong reproductive ability (3 – 4).	3.48 ± 0.18
	P_{14}	Natural enemy situation	There are few kinds of natural enemies and the natural control level of this species is low (1 – 3).	2.90 ± 0.26
P_2: Spreading and diffusion	P_{21}	Distribution	It is widely distributed (1 – 3).	2.74 ± 0.32
	P_{22}	Existing management measures	There are no corresponding management measures or methods at present (0 – 1).	0.92 ± 0.11
	P_{23}	Spreading and diffusion capability	It has strong diffusion ability, and is capable of spreading by natural means and artificial means such as biological carrying, transportation tools and packaging carrying (3 – 4).	3.52 ± 0.22
	P_{24}	Suitable growth range	The proportion of the occurrence range in the assessment area is greater than 35% (3 – 4).	3.52 ± 0.22
P_3: Potential hazards and impacts	P_{31}	Impact on social economy	It has caused great economic losses to the local area (1 – 3).	2.40 ± 0.27
	P_{32}	Impact on ecological environment	It can harm a variety of ecosystem types, including forests, grasslands and wetlands (1 – 3).	2.48 ± 0.15
	P_{33}	Importance of harm object	The harm objects have certain economic value, and it has certain impact on society and ecological environment (1 – 3).	2.42 ± 0.19
P_4: Potential hazards and impacts	P_{41}	Difficulty of inspection and identification	It is easy to inspect and identify the species (1 – 3).	1.14 ± 0.22
	P_{42}	Difficulty of monitoring and investigation	The difficulty of monitoring and investigation is at a medium level (1 – 3).	2.20 ± 0.19
	P_{43}	Difficulty of control management	The existing methods mainly include manual control and chemical application, with low efficiency of 30% – 85% (1 – 3).	2.62 ± 0.13

The results of this study show that *P. montana* is common in the forest ecosystem within the "four mountains" in the central urban area of Chongqing. On average, there was a distribution site of *P. montana* every 1.38 km of forest road with a scale of 0.43 hm^2/point and a coverage of about 42.86%, and sometimes, even the whole hill was covered. The scale of *P. montana* may be related to the following two factors. First, there is a remarkable feature in the occurrence areas of *P. montana*, that is, most of them are located in the forest and agriculture ecotone, showing a trend of expanding to woodland, such as abandoned land, barren hills and slopes, nurseries and orchards that have not been managed for a long time. These areas are easily invaded by *P. montana*, which can be introduced into adjacent forest ecosystems after many years. Second, it is related to the growth characteristics and adaptability of *P. montana*. The results show that *P. montana* grows rapidly (the average length of new branches was 11.52 m^2/year), and its ability of diffusion and colonization is very strong (the number of effective tillers of new branches was 5.25). In addition, on each vine of *P. montana*, there were 47.35 nodes that could serve as independent root tillers to form new individuals. According to the comprehensive investigation and research results, *P. montana* has the potential ability to invade forest ecosystem, and it is suggested that the management of *P. montana* should be strengthened in relevant areas to prevent its further spread.

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