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卧龙亚高山公路沿线外来植物入侵风险评估

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摘　要：为探讨卧龙保护区亚高山公路对外来植物的影响以及沿线外来植物的潜在入侵风险，本文采用样线法和样方法，对卧龙保护区 G305 亚高山段沿线(耿达－邓生)进行植物调查，该区域有外来植物 54 种，隶属于 35 科 51 属.其中菊科等 5 科植物占 35.19%.生活型多为草本，占 62.96%.原产地以亚洲最多，占 64.81%，其中非卧龙保护区的中国植物占所调查外来植物的 40.74%.α 多样性指数分析发现，距离公路越远，外来植物分布越少.在此基础上，通过层次分析法构建了卧龙保护区外来植物入侵风险评估体系，并对 54 种外来植物进行评估，结果发现 4 种植物具有高入侵风险，9 种存在中入侵风险，6 种存在低入侵风险.结合外来植物的入侵风险等级，提出了相应的管控措施.

关键词：外来植物；卧龙亚高山公路；风险评估；层次分析法
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Invasive risk issessment of alien plants along Wolong subalpine highway

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Abstract: In order to explore the impact of subalpine highway in Wolong Nature Reserve on alien plants and the potential invasion risk of alien plants along the highway, the plants along the subalpine highway of Wolong Nature Reserve including Gengda to Dengsheng section of G305 were investigated. In the area, 54 alien plants belonging to 51 Genera and 35 families were found. Among them, 5 families including Compositae account for 35.19%. The most of the alien plans was herbaceous, accounting for 62.96%. The plants from Asia except Wolong Nature Reserve accounted for 64.81% and 24.07% were from China except Wolong Nature Reserve. The α-diversity index indicated that the farther away from the highway, the fewer alien plants were distributed. Then, an invasive risk assessment system for alien species of Wolong Nature Reserve was established by Analytic Hierarchy Process, and the invasive risk of 54 alien plants were evaluated. It was confirmed that 4 plants had a potential high risk of invasion, 9 plants had a potential medium risk of invasion, and 6 plants had a potential low risk of invasion. Combined

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with the invasion risk level of alien plants, the corresponding control measures were put forward.
Keywords: Alien plants; Wolong sub-alpine highway; Risk assessment; Analytic hierarchy process

1　引　言

外来植物(alien plants)即非本地乡土植物，是由于环境变迁和人为有意或无意地自国外或国内其他地方引入本地的植物[1]. 当外来物种因高效多样的繁殖机制和对环境因子广泛适应生长等因素，在短时间内占据更大的资源空间或土著种不能利用的生态位时就会成为入侵植物(invasive plants). 入侵物种对本地物种的竞争性、抑制能力是其成功入侵、再生及扩展的关键所在[2]. 入侵物种不仅严重影响原生境生物多样性，影响或改变原生态系统的稳定性及结构和功能，而且造成社会经济乃至人群健康的巨大损失[3].

外来植物的引入多与人为活动相关[4]. 随着经济建设的发展，各种基础建设如交通设施等逐步推进. 然而，道路建设对周边原有环境产生破坏的同时，也会因人类活动的增加和干扰，加剧原生态系统的破坏，导致外来物种的入侵，引起经济损失和生态灾难.

卧龙自然保护区[5]位于西南山地生物多样性热点区的核心，自然条件复杂，珍稀动植物众多，生物多样性丰富，是国家级第三大自然保护区，同时又是川西地区与其他地方经济文化交流的交通枢纽. 因此，国道 G305 修建，满足了川西地区交通运输、旅游的需要，但是也不可忽视公路修建对沿线植物多样性及外来植物迁入的影响. 因此制定外来物种的评价指标体系，对外来物种进行监测、风险评估，加强预警和管理，是维护生态平衡的有效途径. 目前卧龙保护区内的外来植物相关的研究报道较少[6]，并且尚无对卧龙地区外来植物的入侵性评价研究. 为探究公路修建后外来植物对当地生态系统的影响，本研究通过对卧龙自然保护区亚高山公路段(耿达－邓生段)外来植物(国外植物及非卧龙自然保护区的中国植物)组成和分布的实地调查，分析外来植物多样性组成和分布特征，建立适应当地的外来植物入侵风险评估体系，评价外来植物的入侵性，当地公路沿线外来植物防控、保护生物多样性、维护生态平衡和保护区的可持续发展具有重要意义.

2　材料及方法

2.1　研究区域

为四川省卧龙国家级自然保护区内国道G305亚高山公路段(耿达—邓生段公路)沿线，沿垂直于公路方向 300 m 区域范围内开展植物调查. 地理坐标为东经 102°5′～103°24′，北纬 30°45′～31°25′.

2.2　研究方法

2.2.1　调查方法　实地调查集中在春秋两季进行. 采用客观取样的样方法，以公路沿线为中心样地进行取样调查，根据公路沿线实际情况，每隔 0.5～1 km 设置一个样地，每个样地沿垂直于公路方向 0 m，150 m，300 m 距离分别设置 3 个投影面积 20 m×20 m 的典型样方，记录样方地理位置、海拔、坡度、坡向、植被类型以及乔木层、灌木层的高度与郁闭度，并对样地内所有乔木层物种的数量、乔木胸径、树高、冠幅等进行测量，其中乔木起测胸径 5 cm，小于 5 cm 记入灌木层. 同时在样方四角及样方中心共设置 5 个 5 m × 5 m 和 5 个 1 m×1 m的小样方，分别用来调查样地内灌木、草本生长状况，详细记录灌木的种类、数量和大于 4 cm 的植株的胸径；记录草本的种类、数量、高度、盖度等.

根据《中国植物志》《四川植物志》等分类学文献对这些外来植物的生物学特性、原产地、管理现状等进行整理分析.

2.2.2　物种 α 多样性测度方法　物种 α 多样性反映群落物种水平的综合数值. α 多样性主要包括物种重要值(IV)、物种丰富度 Margalef 指数(D_{Mg})、Shannon-wiener 多样性指数(H)、均匀度 Pielou 指数(E)、Simpson 指数(D_S)[7-8]等.

1) 物种重要值(IV)＝(相对高度＋相对盖度＋相对频度＋相对多度)/3，

2) 物种丰富度(D_{Mg})＝(S－1)/ln N，

3) Shannon-wiener 多样性指数(H)＝$-\sum_{i=1}^{S}(Pi \times Pi)$，

4) 均匀度 Pielou 指数(E)＝$H/ln\,S$，

式中：S—群落中的物种总数；N—观察到的个体总数；Pi—物种 i 的重要值. 群落的物种多样性分析采用 Excel 软件和 Graphpad 软件处理.

2.2.3　外来物种入侵风险评估体系建立　结合相

关文献[6,9],筛选出研究区内的外来植物.同时实地对筛选出的外来植物的分布现状、危害情况、防治情况等进行观察记录.根据实地调查的外来植物生长繁殖特征以及对生境的影响,并参考相关文献[10],设立了 4 个一级及 14 个二级风险评估指标.通过专家评分法和层次分析法(AHP)[11-12],确定其权重值,建立卧龙国家级自然保护区亚高山公路沿线外来入侵植物入侵风险评估体系(表 1).

表 1 外来植物入侵风险评估体系

Tab. 1 Alien plant invasion risk assessment system

Primary index	Secondary index		Evaluation criteria	Score
Invasiveness(29)	Propagation characteristics P_1(10)		There is no possibility of intentional introduction and diffusion through any media	0
			It may be unintentionally spread by human activities, and it can be spread through a kind of media	1
			It may be unintentionally spread by human activities, and it can be spread through two kinds of media	2
			It may be unintentionally spread by human activities, and it can be spread through more than three kinds of media	3
	Management status P_2(8)		The plant has not been listed as control object and has no intrusion history	0
			The plant has been used as the current quarantine or control object, which is easy to be inspected and identified with complete control procedures or measures	1
			Ithas been listed as the control object, but it is difficult to test and identify.	2
			This plant has a history of invasion butis not listed as the control object. And there is no system or means to control it	3
	Adaptability P_3(6)	Suitability for climate and soil of the area of introduction	The plant is unsuitable for the soil or climate and cannot survive (non-invasive)	0
			The plant is suitable for the soil and climate, but its growth and reproduction are limited	1
			The plant is suitable for soil and climate and can reproduce normally	2
			The plant is suitable for soil and climate, and can grow andpropagate rapidly	3
	Resistance to adversity P_4(5)	Resistance strength: 1. Drought resistance 2. Cold resistance 3. Waterlogging resistance 4. Drug resistance 5. Insect resistance 6. Salt / acid resistance	The plant does not show the above resistance	0
			The plant shows slight resistance but low strength	1
			The plant obviously shows oneto three of the above resistant	2
			The plant obviously showsmore than three of the above resistant	3
Diffusivity (13)	Reproductive characteristics P_5(7)	1. The plant has short reproduction cycle, at least one reproduction in a year. 2. The plant has short development period and can rapidly develop to mature reproduction period. 3. Tiller residues of the plant can be easy to develop into new plants. 4. The seeds of the plant has strong viability, easy preservation and high germination rate. 5. the plant has high reproduction base and can be widely distributed in study area.	The plant does not show the above propagation characteristics	0
			The plant obviously has one of the above propagation characteristics	1
			The plant obviously has the above two reproductive characteristics	2
			The plant obviously has more than the above three reproductive characteristics	3

(续表 1)

Primary index	Secondary index		Evaluation criteria	Score
Diffusivity (13)	Population characteristics P_6(3)	Whether the plant establish its own breeding population in the wild	The plant can't build a population	0
			The plant population can be established under artificial conditions	1
			The plant can establish natural population in the wild	3
	Habitat similarity P_7(2)	Climate similarity between the study area and the origin	Less than 20%	0
			21% to 50%	1
			50% to 80%	2
			More than 80%	3
	Diffusion habitat type P_8(2)		Diffusion wetland, serious human disturbance and cultivation site	1
			Sparse shrub tree system	2
			Arbor system with high canopy density	3
Harm fulness(29)	Ecological harmfulness P_9(6)	1. Increase the fire incidence 2. Change the local landform 3. Change the soil characteristics 4. increase the canopy density of the community and affect the light transmittance of the habitat	No impact on the evolution process or ecological factors of the changed or damaged ecosystem	0
			The above effect is slight, but the effect is slow or not obvious	1
			One to three influences above are obvious	2
			More than three influences above are obvious	3
	Harmfulnessto native plants P_{10}(16)	1. strong competition with native species 2. allelopathy and has strong impact on local environment 3. hurt other plant species by climbing and hanging 4. cover the habitat with high density or high frequency in the introduced area . 5. hybridize with native species and destroy the genetic stability of native species	The above effects are not obvious	0
			Slightly show the above impact, but the impact is very small or no impact	1
			The plant influences the local species by one to three ways	2
			The plant influences the local species by more than three ways	3
	Harmfulnessto human P_{11}(7)	1. Thorns 2. Toxic 3. Sensitization 4. Pungentsmell 5. Other hazards	No above harm	0
			One of above harm to human	1
			One to three of above harm to human	2
			More than three of above harm to human	3
Difficulty of control (28)	Control technology P_{12}(17)		Very easy to remove or very little impact on the community	0
			Simple removal method, mature control technology and long maintenance time of control effect	1
			Easy to repeat, so effective control methods and control technology to be improved are needed	2
			There is no effective control technology, and the control effect is poor.	3
	Habitat cost of control P_{13}(8)		no negative effect on the local species	0
			little impact on local species	1
			continuous and serious impact on local plants	3
	Material cost of control P_{14}(3)		The control process is convenient and easy, with low cost or negligible cost.	1
			Need short-term human and capital investment	2
			Need long-term human and large amount of capital investment	3

设外来植物的入侵风险指数为 R,入侵风险指数 R 在 0~3 之间. 物种的入侵风险指数 $R \geqslant 2$,则为高入侵风险物种;$1.5 \leqslant R < 2$;则为中入侵风险物种;$1 \leqslant R < 1.5$,则为低入侵风险物种;$R < 1$,则该物种无入侵风险.

3 结果与分析

3.1 外来植物组成特征

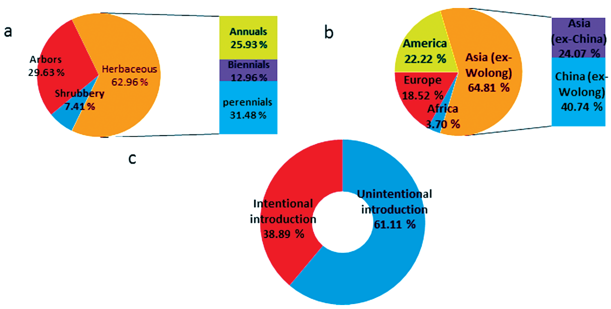

图 1 调查区外来植物的组成特征

a:生活型;b:原产地;c:引入途径.

Fig. 1 Composition characteristics of alien plants in the survey area

a: Life form; b: place of origin; c: introduction pathways.

通过调查分析,研究区域共有 98 科 270 属 402 种植物,其中外来植物 35 科 51 属 54 种. 外来植物中,菊科、禾本科、唇形科、豆科、蔷薇科 5 个科的植物种数占 35.19%. 其中以菊科植物种数最多,这归结于菊科植物的高繁殖力、高适应性、高传播力以及化感作用等特性.

3.1.1 外来植物生活型特征 就生活型而言(图 1 a),研究区外来植物主要是草本,占 62.96%,其中多年生草本最多,有 17 种,占 31.48%;一年生和二年生草本分别占 25.93%和 12.96%. 究其原因,草本植物定植能力更强,繁殖速度更快,扩散方式更多,因此外来草本植物更多. 外来植物中的乔木植物种占 29.63%,主要是人工种植,这些树种具有利用价值,如日本落叶松、柳杉等为人工造林树种,加杨用作道路绿化,凹叶厚朴作药用,李作食用等. 外来灌木仅占 7.41%,主要是观赏植物,分布于居民区附近.

3.1.2 外来植物原产地 54 种外来植物(图 1 b)源于亚洲(不含卧龙自然保护区)有 35 种,占 64.81%,其中,有 13 种来自中国以外的亚洲地区,占 24.07%,而来自非卧龙自然保护区的中国植物达 22 种,占 40.74%. 原产美洲的有 12 种,占 22.22%,其中北美和南美分别为 6 种和 5 种. 原产欧洲有 10 种,占 18.52%. 2 种植物原产于非洲,占 3.70%. 由于保护区生境具多样性,使得非乡土植物能快速占据和适应不同生态位,加上对国内其他地方植物的把控力度不如国外植物严格,因此引入种数最多. 来自国外的植物,由于其原产地气候与研究区生态气候相似性较高,同时保护区地处成都平原与青藏高原的过渡带和交通纽带,因此亚洲其它地区的外来植物也较容易进入保护区.

3.1.3 外来植物引入途径特征 就引入途径而言(图 1 c),有意引入外来植物 33 种,占 61.11%,主要是用于人工造林(日本落叶松)、道路和居民区绿化(一串红)、药用(藿香)、饲用(白香草木樨)、食用(芭蕉)等生产和应用目的;无意引入外来植物 21 种,占 38.89%,主要是一些路边、田间杂草,其中不乏一些为恶性入侵植物如牛膝菊、白车轴草等. 保护区外来植物引入途径虽有不同(图 1 c),但公路的发展为外来植物的引入提供了便利.

3.2 外来植物沿公路沿线的分布特征

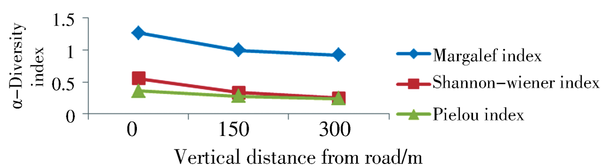

图 2 与公路不同距离的外来植物物种多样性

Fig. 2 Diversity of alien plant species at different distances from the highway

外来植物随着距离公路越远,其 Margalef 丰富度指数、shannon-wiener 多样性指数、Pielou 均匀度指数均为逐渐降低(图 2). 这也表明外来植物与公路的建设和使用有着不可忽视的联系. 一方面,随着原生境与公路的距离越大,人为干扰也随之降低,对于外来植物的有意或无意引入可能性逐渐减小;另一方面,由于随着与公路的距离越远,植物群落的稳定性越强,外来植物扩散的可能性也会越小.

3.3 外来植物的入侵风险评价分析

54 种外来植物中(表 2),高入侵风险物种有 4 种:小飞蓬、牛膝菊、牛筋草、野燕麦. 中入侵风险物种有 9 种:刺苋、一年蓬、黑麦草、聚合草、白车轴草、日本落叶松、繁穗苋、苦苣菜、月见草. 低入侵风险物种有婆婆纳、酢浆草、白香草木樨、胡桃、旱芹、花椒 6 种. 具入侵风险的 19 种植物,隶属于 12 科 18

属，其中菊科最多，有 4 种，高入侵风险和中入侵风险各 2 种.

表 2　外来植物入侵危害风险评分

Tab. 2　Risk score of alien plant invasion

Alien plant	Family	Origin	R-value	Alien plant	Family	Origin	R-value
Musa basjoo	Musaceae	A	0.80	*Oenothera biennis*	Onagraceae	M	1.51
Agastache rugosa		A	0.75	*Portulaca grandiflora*	Portulacaceae	M	0.86
Salviasplendens	Lamiaceae	M	0.61	*Aconitum carmichaelii*	Ranunculaceae	C	0.82
Perilla frutescens		C	0.71	*Aconitum vilmorinianum* var. *altifidum*		C	0.82
Ilex chinensis	Aquifoliaceae	C	0.64	*Magnolia officinalis* subsp. *biloba*	Magnoliaceae	C	0.8
Trifolium repens		E	1.7	*Prunus salicina*		C	0.64
Melilotus albus	Fabaceae	A,E	1.17	*Photinia serrulata*	Rosaceae	C	0.65
Caragana sinica		C	0.58	*Cerasus pseudocerasus*		A	0.69
Rhododendron simsii	Ericaceae	C	0.68	*Viburnum plicatum* var. *tomentosum*	Caprifoliaceae	C	0.77
Tropaeolum majus	Tropaeolaceae	M	0.62	*Angelica sinensis*	Apiaceae	A	0.72
Phyllostachys sulphurea		C	0.89	*Apium graveolens*	Theaceae	A	1.03
Eleusine indica	Poaceae	A	2.04	*Camellia japonica*	Taxodiaceae	C	0.7
Avena fatua		E	2.08	*Cryptomeria fortunei*		C	0.63
Lolium perenne		E	1.87	*Metasequoia glyptostroboides*		C	0.68
Juglans regia	Juglandaceae	A,E	1.15	*Nasturtium officinale*	Brassicaceae	E	0.52
Malva crispa	Malvaceae	A	0.66	*Larix kaempferi*	Pinaceae	A	1.61
Althaea rosea		C	0.65	*Cedrus deodara*		A,F	0.86
Sedum lineare	Crassulaceae	E	0.59	*Amorphophallus rivieri*	Araceae	A	0.87
Codonopsis pilosula	Campanulaceae	M	0.61	*Amaranthus spinosus*	Amaranthaceae	M	1.98
Sonchus oleraceus		E	1.56	*Amaranthus paniculatus*		M	1.68
Galinsoga parviflora		M	2.12	*Veronica didyma*	Scrophulariaceae	A	1.22
Cosmos bipinnata	Asteraceae	M	0.65	*Paulownia fargesii*		C	0.81
Conyza canadensis		M	2.31	*Populus × canadensis*	Salicaceae	M	0.95
Cyanus segetum		E	0.5	*Zanthoxylum bungeanum*	Rutaceae	C	0.97
Erigeron annuus		M	1.79	*Sassafrastzumu*	Lauraceae	C	0.72
Ailanthus altissima	Simaroubaceae	C	0.84	*Symphytum officinale*	Boraginaceae	E	1.88
Toona sinensis	Meliaceae	C	0.73	*Oxalis corniculata*	Oxalidaceae	M,F	1.2

A：亚洲(不包含中国)；C：中国(不包含卧龙自然保护区)；E：欧洲；F：非洲；M：美洲

A：Asia (ex-China) C：China (ex-Wolong National Nature Reserve) E：Europe F：Africa M：America

4　讨　论

公路的修建和使用，为外来植物引入和入侵提供了便利. 通过对外来植物随着距离道路越远其数量越低的调查分析，也说明人为活动会直接影响外来植物的分布. 因此对交通道路使用人群及居民进行植物多样性和生态环境保护的宣传，提高对入侵植物的认识，使防治成为社会性的工作，才能有效

遏制外来植物人为的引入和蔓延.

目前,卧龙自然保护亚高山公路沿线外来植物达54种,多为经济目的有意引入栽培.这些植物在发挥其经济价值的同时,也不能忽视其对保护区生境的影响.盲目的引入和无限制的引种都可能影响保护区内原有的生物多样性和生态系统的稳定性,与保护区管理局的相关保护工作背道而驰.因此,本研究综合考虑外来物种的入侵性、扩散性、危害性以及防治难易性,建立外来物种入侵风险评估体系,客观、准确地量化外来物种的潜在入侵风险.通过评估,对具有高入侵风险的植物因分布广,排挤或杀死本地植物,可形成单优群落,应该进行及时防治处理,防止危害扩大.同时研究利用乡土植被的恢复方案,建立以本地物种为主的稳定的生态系统,增强群落对外来入侵植物的抵抗力,达到对入侵有害植物长期控制的目标.对中入侵风险植物,主要分布在路边、撂荒地,应严格控制其传播途径,加强监控,防止其进一步发展成高入侵风险植物.对低入侵风险植物,零星分布,对当地生物多样性暂时未造成明显危害,应以预防为主,优先考虑发掘其综合利用价值,但也应当进行有效地监控.对于上述具有入侵风险的植物,人为活动对其传播扩散有极大的促进作用,对其应加大宣传力度,提高防控意识.对于外来植物入侵性的不同,采取合理的监控力度.

综上所述,建立并完善防治植物入侵的机构和体系;科学评估并预测外来植物风险性,权衡利弊,制定科学的引种计划;对具有潜在入侵性的外来植物严格管理和监控;综合防治,以确保保护区的生态平衡.

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