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•综述•

中国纳入一级保护的极小种群野生植物濒危机制

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摘要: 为科学有效地保护极小种群野生植物, 明确其濒危机制具有重要意义。本文通过分析中国28种极小种群一级保护野生植物的种群特征及其濒危的内在原因和受威胁因素等, 总结了极小种群野生植物的濒危机制。极小种群野生植物的种群特征表现为遗传多样性低(13种)、衰退型种群结构(11种)、聚集型分布(11种)且分布区域狭窄(20种)。极小种群野生植物濒危的内在原因主要是繁殖力低(21种)和竞争能力弱(16种)。受威胁因素主要包括过度采挖等人类活动导致的种群数量减少(15种)和生境破坏(25种)以及气候变化等。因此, 除了保护极小种群野生植物免遭人类活动破坏, 保护策略应加强关注种群规模的维持和遗传多样性的保护。

关键词: 极小种群野生植物; 种群特征; 濒危机制; 人为干扰; 保护遗传多样性

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Endangered mechanisms for the first-class protected Wild Plants with Extremely Small Populations in China

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ABSTRACT

Aims: It is important to clearly identify the mechanisms that leads Wild Plants with Extremely Small Populations to become endangered as a way to effectively protect these WPESP.

Progresses: Here, we review the population characteristics, internal causes, and external threat factors for the first-class protected WPESP (28 species in China) and accordingly discuss the mechanisms leading to plants becoming endangered. Most WPESP displayed at least one of four population characteristics that likely resulted in their current endangered status. First, 20 WPESP species (such as *Parakmeria omeiensis*, *Abies beshanzuensis* and *Cycas changjiangensis*) had a narrow distribution area. Combining a narrow distribution area with low fertility and weak competitive capacity as intrinsic factors results in WPESP species to become endangered. Second, the distribution structure for 11 WPESP species was aggregated (e.g., *Abies ziyuanensis*, *Kmeria septentrionalis*, *Metasequoia glyptostroboides*). Third, there was declining population structures for 11 WPESP (e.g., *Thuja sutchuenensis*, *Metasequoia glyptostroboides*, *Pinus squamaia*). This declining population structure has a negative role in maintaining stable population growth. The fourth population characteristic was that the genetic diversity of 13 WPESP species (46%) was low (e.g., *Manglietia decidua*, *Abies yuanbaoshanensis*, *Cycas debaoensis*). Low genetic diversity is unfavorable for these species to adapt to a changing environment and leads them to face risks of extinction. Twenty-one WPESP species (75%) exhibited low fertility, such as *Acer yangjuechi* and *Abies beshanzuensis*. The poor seed quality and low yield of WPESP species leads to a difficult regeneration of populations. The competitive capacity of 57%

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WPESP species (16) is relatively weak (e.g., *Shaniodendron subaequale* and *Cathaya argyrophylla*), which decreases growth and reproduction for these species. External factors that threaten WPESP mainly include overexploitation decreasing abundance (15 species), human activities and natural disasters destroying habitats (25 species), and geological movements plus climate change affecting the survival of WPESP.
Prospects: In addition to protecting WPESP against destruction from human activities, conservation strategies should focus on the maintenance of population size and the conservation of genetic diversity of WPESP.
Key words: Wild Plants with Extremely Small Populations (WPESP); population characteristics; endangered mechanism; human disturbance; conservation of genetic diversity

中国受威胁植物有3,000多种(覃海宁等, 2017), 其中分布区域狭窄或呈间断分布的野生植物被定义为“极小种群野生植物” (臧润国等, 2016; Yang et al, 2020)。极小种群野生植物长期受外界因素胁迫干扰, 种群呈现衰退和数量持续减少趋势, 种群及个体数量极少, 有些已经低于稳定存活界限的最小可存活种群, 随时面临灭绝的风险(Ren et al, 2012)。极小种群野生植物多为中国特有植物, 在生态和经济上具有重要价值(Ma et al, 2013)。如果不及时保护, 其潜在的基因价值和生物特征就会随物种的绝灭而消失(张则瑾等, 2018)。因此, 明确极小种群野生植物濒危机制, 提高保护成效, 有助于维持生态平衡和促进生态可持续发展, 对我国的生物多样性保护具有重要意义(Guisan et al, 2013; 张则瑾等, 2018)。

极小种群野生植物的物种濒危机制研究已从单一的种群生态学和群体遗传学研究发展成多学科交叉的综合性研究, 并取得了令人鼓舞的进展(Aguilar et al, 2006; Lowe et al, 2017)。《全国极小种群野生植物拯救保护工程规划》确定了首批120种重点保护的极小种群野生植物(Ren et al, 2014)。其中, 中国特有的纳入一级保护的极小种群野生植物有33种(http://www.iplant.cn/rep/protlist)。经检索, 目前暂时没有关于玉龙杓兰(*Cypripedium forrestii*)、丽江杓兰(*C. lichiangense*)、斑叶杓兰(*C. margaritaceum*)、小花杓兰(*C. micranthum*)和昌江石斛(*Dendrobium changjiangense*)等5种特有极小种群野生植物的研究报道。故本文将讨论和分析28种极小种群野生植物的特征及濒危因素, 拟为制定极小种群植物的保护对策提供科学依据。从检索到的783篇关于这28种极小种群野生植物的文献中, 选取具有详细分布区域和种群特征的138篇研究性文章。从物种的分布地点可以发现, 这28种极小种群野生植物主要集中分布在我国南方(图1), 具有明显的分布区域狭窄特征。

1 极小种群野生植物的种群特征

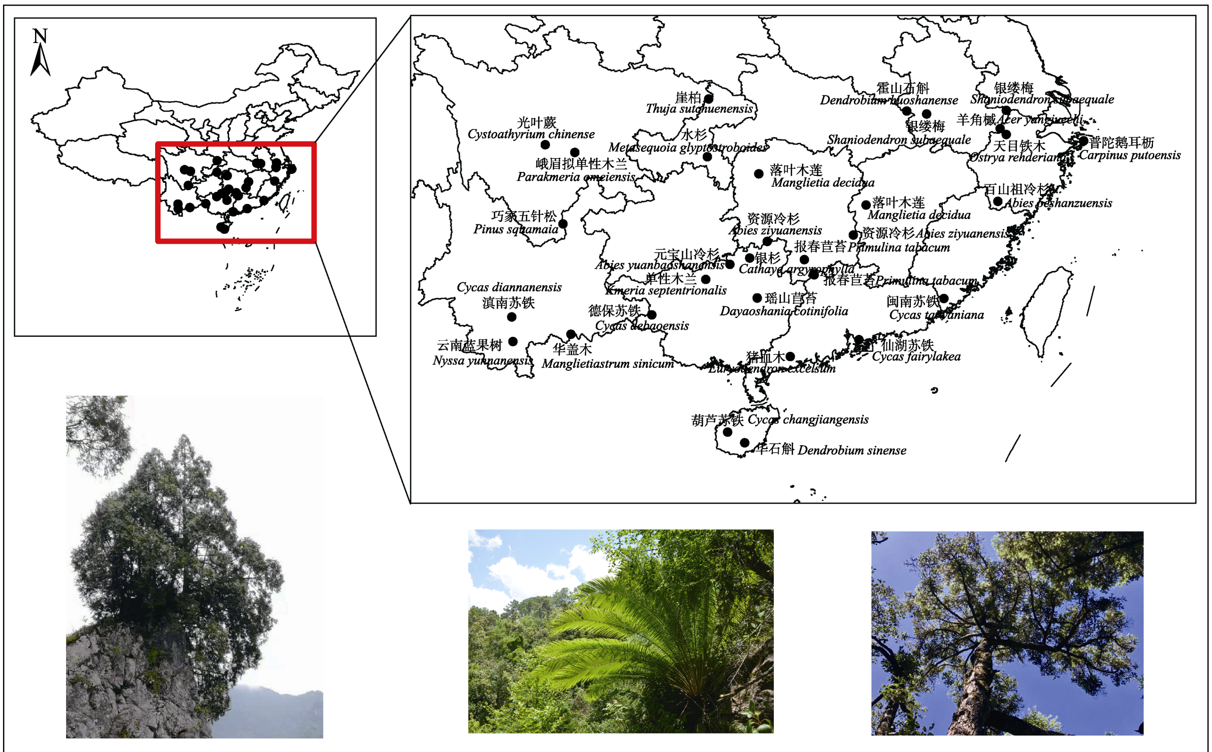
1.1 种群规模小

种群规模小是极小种群野生植物的主要特征, 有15种的种群规模小于1,000株(表1), 例如猪血木(*Euryodendron excelsum*)、天目铁木(*Ostrya rehderiana*)、云南蓝果树(*Nyssa yunnanensis*)等。百山祖冷杉(*Abies beshanzuensis*)野生存活数量只有3株, 是世界上最为濒危的12种植物之一(Zhu et al, 2019); 普陀鹅耳枥(*Carpinus putoensis*)是极小种群野生植物中现存野生植株最少的物种之一, 仅存1株, 有“地球独子”之称(Sheng & Zhu, 2018)。虽然有10个物种的个体数量和种群数量较多, 但多数个体都聚集在一个或两个种群中; 其他18个物种种群规模小, 增加了消失的风险。例如瑶山苣苔(*Dayaoshania cotinifolia*), 除了2个40株以上的较大种群外, 大部分为10株以下的小种群(王玉兵等, 2008); 在德保苏铁(*Cycas debaoensis*)的15个种群中, 除了扶平种群为800株左右外, 其余种群规模都不足10株, 其中平泮种群与下泮种群个体数量分别只有2株和6株, 具有消失的风险(王超红, 2007[①]; 潘光波和赵峰磊, 2011)。

1.2 种群多为零星或岛状狭域分布

根据28种极小种群野生植物已有的地理分布现状, 崖柏(*Thuja sutchuenensis*)、百山祖冷杉、峨眉拟单性木兰(*Parakmeria omeiensis*)等20个物种呈零星或岛状的狭域分布(表1)。例如葫芦苏铁(*Cycas changjiangensis*)仅分布在海南省昌江县坝王岭约70 km^2的狭小范围内(简曙光等, 2005); 百山祖冷杉现存野生植株仅3株, 占地面积不足2 km^2 (Zhu et al, 2019); 巧家五针松(*Pinus squamaia*)只分布在云南

① 王超红 (2007) 德保苏铁居群生物学及其保护生物学研究. 硕士学位论文, 广西师范大学, 广西桂林.



崖柏 *Thuja sutchuenensis*　　滇南苏铁 *Cycas diannanensis*　　百山祖冷杉 *Abies beshanzuensis*

图1　27种极小种群野生植物地理分布图(灰干苏铁无分布点数据)。崖柏图片由姚志提供，滇南苏铁图片由龚洵提供，百山祖冷杉图片由向巧萍提供。

Fig. 1　Distribution of 27 Wild Plants with Extremely Small Populations (No distribution data of *Cycas hongheensis*). The picture of *Thuja sutchuenensis* is provided by Zhi Yao, *Cycas diannanensis* is provided by Xun Gong, and *Abies beshanzuensis* is provided by Qiaoping Xiang.

东北部巧家县新华镇杨家湾一个山脊的东西两个坡面上，分布面积仅5 km^2 ①。

1.3　种群呈聚集型分布格局

在28种极小种群野生植物中，种群分布格局呈聚集型的有资源冷杉(*Abies ziyuanensis*)、单性木兰(*Kmeria septentrionalis*)、水杉(*Metasequoia glyptostroboides*)等11种(表1)，不利于种群的维持和发展。有些物种的分布格局在不同生长阶段和生境条件下会表现出差异，例如元宝山冷杉(*Abies yuanbaoshanensis*)在幼苗、幼树阶段为聚集分布，中龄阶段向随机分布发展，大树呈均匀分布(李先琨等，2002a)；银杉(*Cathaya argyrophylla*)在银杉–亮叶青冈(*Cyclobalanopsis phanera*)林中为典型的聚集分布，而在银杉–甜槠(*Castanopsis eyrei*)林中因个体数量不均衡死亡而出现随机分布的格局(谢宗强，1999)。

1.4　极小种群野生植物遗传多样性低

有13种极小种群野生植物的遗传多样性较低，这些物种对环境的适应力较差，影响了物种的进化潜力(表1)。例如，廖文芳等(2004)利用ISSR分子标记研究落叶木莲(*Manglietia decidua*)的遗传多样性，并与同科的其他物种以及其他特有植物的遗传多样性进行了比对，发现落叶木莲的遗传多样性极低(Nei’s基因多样性0.0637，Shannon多样性指数0.0936，多态位点百分率17.28%)；王燕等(2004)使用AFLP分子标记方法，发现元宝山冷杉种群的遗传多样性较低(Nei’s基因多样性0.1510，Shannon多样性指数0.1735，多态位点百分率50.96%)。

一般认为濒危植物的遗传多样性水平较低，但仙湖苏铁(*Cycas fairylakea*)、猪血木、崖柏等7个极小种群野生植物的遗传多样性较高(表1)。例如，王晓明等(2006)应用ISSR分子标记研究了仙湖苏铁野

① 陶翠 (2013) 中国五针松组濒危植物的濒危机制探究．硕士学位论文，北京林业大学，北京．

表 1　28 种极小种群野生植物主要性状表

Table 1　Main characters of 28 Wild Plants with Extremely Small Populations

物种 Species	现存数量 Existing numbers (ind.)	IUCN 濒危等级 Endangered status in IUCN	种群特征 Population characteristics				濒危因素 Endangered factors				参考文献 References
			分布类型 Distribution type	分布格局 Distribution pattern	年龄结构 Age structure	遗传多样性 Genetic diversity	种子发芽率 Germination rate of seeds	人为采挖 Human activities	生境破坏 Habitat destruction	自然灾害 Natural disasters	
百山祖冷杉 *Abies beshanzuensis*	3	CR	岛状分布 ID			低 L	1%–2%		✓	✓	Hu et al, 2004; Wu et al, 2010
资源冷杉 *Abies ziyuanensis*	494	CR	岛状分布 ID	聚集型 AD	稳定型 SP	低 L	2%–4%	✓	✓		Ning et al, 2005; Ning & Tang, 2005; Zhang et al, 2007; Zhang, 2009; Liu et al, 2011; Wang et al, 2013
元宝山冷杉 *Abies yuanbaoshanensis*	小于 900 Less than 900	CR	岛状分布 ID	聚集型 AD	稳定型 SP	低 L	2.5%		✓	✓	Tang et al, 2001; Li et al, 2002b, c; Wang et al, 2004; Wu et al, 2010; Liang & Pan, 2012; Yang J et al, 2019
葫芦苏铁 *Cycas changjiangensis*	约 7,300 About 7,300	CR	星散分布 SD			高 H		✓	✓		Li, 2004; Jian et al, 2005; Sun XL et al, 2019
德保苏铁 *Cycas debaoensis*	1,085	CR	星散分布 SD		衰退型 DP	低 L		✓	✓	✓	Ma et al, 2003; Pan & Zhao, 2011; Zhan et al, 2011; Luo et al, 2013; Xu et al, 2015; Wang YH et al, 2018
仙湖苏铁 *Cycas fairylakea*	1,500	CR	星散分布 SD	聚集型 AD	衰退型 DP	较高 RH	33.3%		✓		Jian et al, 2006; Wang XM et al, 2006; Wang DB et al, 2007, 2009; Sun YJ et al, 2019
滇南苏铁 *Cycas diannanensis*	219	CR	星散分布 SD			较低 RL					Liu et al, 2015
灰干苏铁 *Cycas hongheensis*		CR	星散分布 SD								Wu & Zhang et al, 2008; Zheng et al, 2017
闽南苏铁 *Cycas taiwaniana*	1	EN	星散分布 SD								Liu & Xie, 2007; Nong et al, 2011; Wang et al, 2019
银杉 *Cathaya argyrophylla*	约 3,500 About 3,500	EN	岛状分布 ID	聚集型 AD	衰退型 DP	较低 RL	21%		✓		Xie & Chen, 1994, 1999a, b; Wang et al, 1996; Xie et al, 1999a, b; Xie & Li, 2000
光叶蕨 *Cystoathyrium chinense*	58	EW	星散分布 SD				57.8%		✓	✓	Wei & Zhang, 2014; Yu et al, 2015; Wen et al, 2016
瑶山苣苔 *Dayaoshania cotinifolia*	9,600	CR				较高 RH	28%		✓	✓	Wang YB et al, 2008
霍山石斛 *Dendrobium huoshanense*		CR				低 L	10.6%	✓	✓		Chen et al, 2013
华石斛 *Dendrobium sinense*		EN	星散分布 SD		衰退型 DP		0.6%	✓	✓		Jiang et al, 2011; Wang TX et al, 2018; Bian et al, 2017
猪血木 *Euryodendron excelsum*	179	CR	岛状分布 ID	聚集型 AD	稳定型 SP	较高 RH	42.7%	✓	✓	✓	Shen et al, 2007, 2008; Cui & Su, 2015; Wang et al, 2015; Li et al, 2019
单性木兰 *Kmeria septentrionalis*	309	VU	星散分布 SD	聚集型 AD	稳定型 SP	较高 RH	0.05%				Pan et al, 2008; Zeng, 2007; Jin et al, 2013; Peng et al, 2015, 2016
落叶木莲 *Manglietia decidua*	约 27,000 About 27,000	VU	岛状分布 ID		衰退型 DP	较低 RL		✓	✓	✓	Yu et al, 1999; Yuan, 2005; Zhan et al, 2013; Yang et al, 2017
华盖木 *Manglietiastrum sinicum*	18	CR	星散分布 SD		衰退型 DP	较低 RL	2%–7%		✓	✓	Tian et al, 2003; Yuan, 2009; Zheng et al, 2008; Chu et al, 2012; Ding et al, 2014
云南蓝果树 *Nyssa yunnanensis*	8	CR	星散分布 SD			较低 RL	7%	✓	✓		Zhang et al, 2014, 2019; Wu et al, 2015; Yang XC et al, 2019
天目铁木 *Ostrya rehderiana*	5	CR			衰退型 DP	低 L	16.2%	✓	✓	✓	Wang ZL et al, 2008; Luo et al, 2018; Yang et al, 2018

表1 (续) Table 1 (continued)

物种 Species	现存数量 Existing numbers (ind.)	IUCN 濒危等级 Endangered status in IUCN	种群特征 Population characteristics 分布类型 Distribution type	分布格局 Distribution pattern	年龄结构 Age structure	遗传多样性 Genetic diversity	濒危因素 Endangered factors 种子发芽率 Germination rate of seeds	人为采挖 Human activities	生境破坏 Habitat destruction	自然灾害 Natural disasters	参考文献 References
峨眉拟单性木兰 *Parakmeria omeiensis*	20	CR	星散分布 SD		稳定型 SP		0.08%	✓	✓		Yu et al, 2011, 2019; Chen et al, 2015
银缕梅 *Shaniodendron subaequale*	超过2,000 More than 2,000	CR	岛状分布 ID	聚集型 AD	衰退型 DP		20%	✓	✓		Hu et al, 2011; Gong et al, 2012; Li et al, 2012; Zhang et al, 2016; Wang L et al, 2018; Ye, 2019
巧家五针松 *Pinus squamata*	34	CR		聚集型 AD	衰退型 DP		55%		✓	✓	Lu et al, 1999; Zhang et al, 2005; Wang et al, 2020
报春苣苔 *Primulina tabacum*	约1万 About 10,000	EN		聚集型 AD		高 H			✓	✓	Ren, 2003; Miao et al, 2013; Dai et al, 2018
崖柏 *Thuja sutchuenensis*	约4,500 About 4,500	EN	岛状分布 ID	聚集型 AD	衰退型 DP	较高 RH	24%	✓	✓		Liu et al, 2004, 2005, 2013; Liu & Xiao, 2008; Zhu et al, 2014; Ma et al, 2017
水杉 *Metasequoia glyptostroboides*	5,746	CR		聚集型 AD	衰退型 DP	较低 RL	19.73%		✓	✓	Cheng et al, 2007; Xiong et al, 2010; Lin et al, 2017; Zhu & Xu, 2019; Wu et al, 2020
普陀鹅耳枥 *Carpinus putoensis*	1	CR				低 L	2.18%	✓	✓	✓	Li et al, 2010; Zhang et al, 2011a, b; Sheng & Zhu, 2018
羊角槭 *Acer yangjuechi*	1	VU					36.19%	✓	✓	✓	Xu et al, 2012; Chen et al, 2017, 2019

CR: 极危; EN: 濒危; VU: 易危。
CR, Critically Endangered; EN, Endangered; VU, Vulnerable; ID, Island distribution; SD, Scattered distribution; AD, Aggregation distribution; SP, Stabling population; DP, Decaying population; L, Low; H, High; RH, Relatively high; RL, Relatively low.

生种群遗传多样性，发现其遗传多样性高于其他苏铁类植物和濒危植物(Nei’s基因多样性0.2196, Shannon多样性指数0.3445，多态位点百分率87.01%)；张仁波等(2007)采用RAPD分子标记对崖柏天然种群遗传多样性进行研究，发现崖柏种群的遗传多样性与其他濒危植物相比较为丰富(Nei’s基因多样性0.3015，Shannon多样性指数0.4360，多态位点百分率72.09%)，表明遗传多样性不是造成这些物种濒危的首要因素，反而是人类活动和生境破坏等因素导致其面临较高的灭绝风险(刘建锋和肖文发, 2008；苏金源等, 2020)。

1.5 种群结构多为衰退型

在28种极小种群野生植物中，德保苏铁、崖柏、水杉等11个物种的种群年龄结构表现为衰退型(表1)，即幼龄个体少而老龄个体多、死亡率大于萌发率等，这种种群结构由于难以维持种群增长可能会导致种群灭绝。例如因幼龄个体存活率较低，导致水杉种群幼龄个体不断减少，老龄个体逐渐增加，难以维持种群整体的长期稳定(林勇等，2017)；银缕梅(*Shaniodendron subaequale*)种群年龄结构差异较大，大部分种群缺乏幼龄个体，各个年龄段都有着较高的死亡率，有些种群衰退严重(龚滨等，2012)。

2 导致极小种群野生植物濒危的因素

2.1 繁殖力低使种群更新缓慢

在自然条件下，物种濒危的关键环节是种子向幼苗的转化过程，这个过程涉及果实成熟、种子萌发等，没有足够数量的幼苗，种群就难以更新。有21种濒危植物的种子品质差且产量很少(表1)，导致种子向幼苗的转化率较低，形成的幼苗数量较少①②③④。百山祖冷杉野生植株仅有3株，人工繁育的后代能结实嫁接的植株也不多，种子发芽率仅有1%–2% (吴友贵等，2010)；羊角槭(*Acer yangjuechi*)种子内没有胚乳，饱满种子生活力仅有20.53%，在其果实生长期间，果序脱落率高达

① 哀建国 (2005) 百山祖冷杉濒危机制与保护对策研究. 硕士学位论文, 浙江大学, 杭州.
② 翟月婷 (2010) 霍山石斛试管丛生芽及原球茎继代增殖措施的研究. 硕士学位论文, 安徽农业大学, 合肥.
③ 许小连 (2012) 濒危植物羊角槭生殖生物学的初步研究. 硕士学位论文, 浙江农林大学, 杭州.
④ 付迪 (2019) 珍稀濒危植物天目铁木的生殖生物学研究. 硕士学位论文, 杭州师范大学, 杭州.

67.7%，落果率高达87.3%，而且果实败育率高(石柏林等, 2006; 肖志成和高捍东, 2008)，这些特征均导致种群更新缓慢。

2.2 种间竞争能力差

物种在群落内的竞争能力差，获得资源就少，从而直接或间接地影响其生长发育。有16种极小种群野生植物在种间竞争中处于不利地位，多表现为生长缓慢(表1) (莫耐波等, 2012; 陶翠, 2013[①]; 王鑫等, 2017)。银杉由于对光的需求大，只有在群落的林窗内光照充足的条件下其幼苗才有机会发展，当它们进入成年期后，在群落竞争中则处于不利地位(谢宗强等, 1998, 谢宗强和陈伟烈, 1999a, b)；银缕梅与青冈(*Cyclobalanopsis glauca*)和其他阔叶树种之间的生态位重叠程度较高，在争夺光照、水分、土壤养分时处于弱势，导致其在群落中居于次要和从属地位(方顺清等, 2004; 黄绍辉等, 2006)。

3 极小种群野生植物的受威胁因素

3.1 动物取食影响极小种群野生植物种群更新

动物取食野生植物的叶片、果实、种子等不仅影响植物的生长发育，也阻碍了种群的更新(表1) (潘光波和赵峰磊, 2011; 梁凌林和潘庆宝, 2012; 赵燕, 2018)。例如，鼠类在单性木兰种子散播初期至种子萌发期均有取食现象，包括地表和土壤中的种子，导致单性木兰天然更新过程中由种子转化成幼苗时存在严重障碍(赖家业等, 2007; 潘春柳等, 2008)；银杉球果产量很少，成熟后被昆虫、鸟类、哺乳类动物取食达到15%，落到地表的种子几乎全被鸟类和鼠类取食，只有埋于土壤较深层(3 cm以下)的种子才得以保留，存活种子数量极小，成为银杉种群更新的主要障碍(谢宗强等, 1998; 谢宗强和陈伟烈, 1999a; 谢宗强和李庆梅, 2000)。

3.2 人为过度采挖和砍伐降低种群规模

在28种极小种群野生植物中，有15种由于经济价值、观赏价值和商业价值高而被人为大量采挖和砍伐，直接导致数量快速减少，成为其濒危的直接因素(表1)。例如崖柏因木材质地坚硬而长期被砍伐用作建筑材料，现在重庆城口县的建筑中仍能发现用于建筑材料的崖柏木材(Guo et al, 2019)。德保苏铁由于具观赏性而有较高的经济价值，被当地居民肆意采挖，导致其数量从2001年的2,200多株锐减到2010年的1,100多株，特别是成年德保苏铁的数量减少更为严重(潘光波和赵峰磊, 2011; 农安, 2014)。

3.3 人为开发利用破坏极小种群野生植物的生境

工程建设、旅游开发和过度垦荒等因素破坏了24种极小种群野生植物生存的原有生境(表1)，具体表现为生境破碎化或面积变小，从而使得种群规模减小。瑶山苣苔由于人为活动对其原生境的破坏，个体数由1999年的9,600株锐减到2006年的1,000株左右，减少了近90% (王玉兵等, 2008)。灰干苏铁(*Cycas hongheensis*) 2020年的个体数量比1992年减少了47%；水杉原生种群母树由1983年的5,779株减少至2003年的5,393株(王希群等, 2005; 程丹丹等, 2007)。

3.4 气候变化和自然灾害威胁物种的生存

气候变化和自然灾害等严重威胁物种的生存，迫使它们或者改变自身性状以适应环境，或者迁移到其他适生区域。在28种极小种群野生植物中有15种孑遗植物(表1) (李晓笑, 2013[②]; Zhu et al, 2019; 邓莎等, 2020)，这些物种在经历过晚第三纪气候变冷以及第四纪冰期的影响后，世代周期变长，繁殖能力降低，如银杉、崖柏、资源冷杉等。崖柏由260万年前的山西榆社盆地南迁到现存分布区——大巴山山区，该区温暖湿润的气候条件对崖柏起到了“避难所”的作用(陈冬梅等, 2011; 邱迎君等, 2011; Cui et al, 2015)。现存的5株天目铁木中，有一株高7 m、有300多年寿命的植株主干顶部遭受过雷击(管康林和陶银周, 1988)；百山祖冷杉生长在水沟边，曾在20世纪60年代被大水冲倒一株[③]；瑶山苣苔在2008年由于冻害而导致直接死亡的有100多株(王玉兵等, 2008)。

4 极小种群野生植物的濒危机制

基于前文对28种极小种群野生植物的种群和个体特征以及受威胁因素分析，发现导致其濒危的原因有4个。(1)在种群尺度上，衰退型种群结构和聚集狭域分布特征是导致其濒危的原因之一，这使得

① 陶翠 (2013) 中国五针松组濒危植物的濒危机制探究. 硕士学位论文, 北京林业大学, 北京.

② 李晓笑 (2013) 中国 5 种冷杉属植物生态濒危机制研究. 硕士学位论文, 北京林业大学, 北京.

③ 哀建国 (2005) 百山祖冷杉濒危机制与保护对策研究. 硕士学位论文, 浙江大学, 杭州.

其遗传多样性过低，从而对环境的适应力和进化潜力降低，进一步提高了濒危的风险。(2)在个体尺度上，大多数极小种群野生植物的种子品质差且产量少，繁育力低，形成的幼苗数量少，导致种群变小且难以更新；加上极小种群野生植物在种间竞争中处于弱势地位，直接或间接影响其生长发育，进一步影响了种群大小。(3)人为过度采挖、自然灾害等因素导致个体数量降低，工程建设、旅游开发和过度垦荒等导致的生境破坏或消失使得野生植物种群数量减少，是极小种群野生植物濒危的主要原因。(4)宏观尺度的全球气候变化等是导致极小种群野生植物濒危的历史原因。

5 保护建议

极小种群野生植物因其分布地域狭窄、种群衰退严重，个体数量低于其稳定存活界限，是急需优先拯救的国家重点保护濒危植物。优先保护极小种群野生植物有助于延缓物种多样性的流失、维护生态平衡以及促进生态可持续发展，对我国生物多样性保护具有重要意义。就地保护是其保护的主要措施之一(张文辉等, 2002; Kramer et al, 2008)，在必要时候建立保护区或植物园，对种质和生物资源进行迁地保护是全球植物保护战略的重点(Larkin et al, 2016)。

在就地保护和迁地保护措施的基础上，基于28种极小种群野生植物的濒危机制分析，我们建议：(1)对自身繁育力低的极小种群野生植物，开展人工繁育并加强野外回归工作，提高种群的自我更新能力(Ren et al, 2014); (2)修复栖息地内破坏的生态系统，提高群落生态系统的稳定性，改善其生境条件；(3)除了采取措施增加个体数量之外，应加强对极小种群野生植物的种群结构和遗传多样性的研究，保护整个种群的遗传多样性。

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综述