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目 次

基于景观格局理论和理想风水模式的藏族乡土聚落景观空间解析——以甘肃省迭部县扎尕那村落为例·····	史利莎,严力蛟,黄璐,等 (6305)
武夷山风景名胜区景观生态安全度时空分异规律·····	游巍斌,何东进,巫丽芸,等 (6317)
旅游地道路生态持续性评价——以云南省玉龙县为例·····	蒋依依 (6328)
城市空间形态紧凑度模型构建方法研究·····	赵景柱,宋瑜,石龙宇,等 (6338)
丹顶鹤多尺度生境选择机制——以黄河三角洲自然保护区为例·····	曹铭昌,刘高焕,徐海根 (6344)
西南喀斯特区域水土流失敏感性评价及其空间分异特征·····	凡非得,王克林,熊鹰,等 (6353)
流域尺度海量生态环境数据建库关键技术——以塔里木河流域为例·····	高凡,闫正龙,黄强 (6363)
雌雄异株植物鼠李的生殖分配·····	王娟,张春雨,赵秀海,等 (6371)
长白山北坡不同年龄红松年表及其对气候的响应·····	王晓明,赵秀海,高露双,等 (6378)
不同高寒退化草地阿尔泰针茅种群的小尺度点格局·····	赵成章,任珩,盛亚萍,等 (6388)
残存银杏群落的结构及种群更新特征·····	杨永川,穆建平, TANG Cindy Q, 等 (6396)
濒危植物安徽羽叶报春两种花型的繁育特性及其适应进化·····	邵剑文,张文娟,张小平 (6410)
神农架海拔梯度上 4 种典型森林的乔木叶片功能性状特征·····	罗璐,申国珍,谢宗强,等 (6420)
不同植被恢复模式下煤矸石山复垦土壤性质及煤矸石风化物的变化特征·····	王丽艳,韩有志,张成梁,等 (6429)
火烧对黔中喀斯特山地马尾松林分的影响·····	张喜,崔迎春,朱军,等 (6442)
内蒙古高原锦鸡儿属植物的形态和生理生态适应性·····	马成仓,高玉葆,李清芳,等 (6451)
古尔班通古特沙漠西部梭梭种群退化原因的对比分析·····	司朗明,刘彤,刘斌,等 (6460)
白石砬子国家级自然保护区天然林的自然稀疏·····	周永斌,殷有,殷鸣放,等 (6469)
黑龙江省东完达山地区东北虎猎物种群现状及动态趋势·····	张常智,张明海 (6481)
基于 GIS 的马铃薯甲虫扩散与河流关系研究——以新疆沙湾县为例·····	李超,张智,郭文超,等 (6488)
2010 年广西兴安地区稻纵卷叶螟发生动态及迁飞轨迹分析·····	蒋春先,齐会会,孙明阳,等 (6495)
B 型烟粉虱对寄主转换的适应性·····	周福才,李传明,顾爱祥,等 (6505)
利用 PCR-DGGE 方法分析不同鸡群的盲肠微生物菌群结构变化·····	李永洙, Yongquan Cui (6513)
鸡粪改良铜尾矿对 3 种豆科植物生长及基质微生物量和酶活性的影响·····	张宏,沈章军,阳贵德,等 (6522)
铜绿微囊藻对紫外辐射的生理代谢响应·····	汪燕,李珊珊,李建宏,等 (6532)
10 种常见甲藻细胞体积与细胞碳、氮含量的关系·····	王燕,李瑞香,董双林,等 (6540)
冬季太湖表层底泥产毒蓝藻群落结构和种群丰度·····	李大命,孔繁翔,于洋,等 (6551)
城市机动车道颗粒物扩散对绿化隔离带空间结构的响应·····	蔺银鼎,武小刚,郝兴宇,等 (6561)
新疆城镇化与土地资源产出效益的空间分异及其协调性·····	杨宇,刘毅,董雯,等 (6568)
山东潍坊地下水硝酸盐污染现状及 $\delta^{15}\text{N}$ 溯源·····	徐春英,李玉中,李巧珍,等 (6579)
增温对宁夏引黄灌区春小麦生产的影响·····	肖国举,张强,张峰举,等 (6588)
一种估测小麦冠层氮含量的新高光谱指数·····	梁亮,杨敏华,邓凯东,等 (6594)
黄河上游灌区稻田 N_2O 排放特征·····	张惠,杨正礼,罗良国,等 (6606)
专论与综述	
植物源挥发性有机物对氮沉降响应研究展望·····	黄娟,莫江明,孔国辉,等 (6616)
植物种群更新限制——从种子生产到幼树建成·····	李宁,白冰,鲁长虎 (6624)
研究简报	
遮荫对两个基因型玉米叶片解剖结构及光合特性的影响·····	杜成凤,李潮海,刘天学,等 (6633)
学术信息与动态	
科学、系统与可持续性——第六届工业生态学国际大会述评·····	石海佳,梁赛,王震,等 (6641)
期刊基本参数: CN 11-2031/Q * 1981 * m * 16 * 340 * zh * P * ¥70.00 * 1510 * 37 * 2011-11	



封面图说: 鹤立——丹顶鹤是世界 15 种鹤数量极小的一种,主要栖息在沼泽、浅滩、芦苇塘等湿地,以捕食小鱼虾、昆虫、蛙蚺、软体动物为主,也吃植物的根茎、种子、嫩芽。善于奔驰飞翔,喜欢结群生活。丹顶鹤属迁徙鸟类,主要在我国的黑龙江、吉林、俄罗斯西伯利亚东部、朝鲜北部以及日本等地繁殖。在长江下游一带越冬。在中国文化中有“仙鹤”之说。被列为中国国家一级重点保护野生动物名录,濒危野生动植物种国际贸易公约绝对保护的 CITES 附录一物种名录。

彩图提供: 陈建伟教授 国家林业局 E-mail: cites.chenjw@163.com

张喜,崔迎春,朱军,潘德权,杨春华,陈骏,吴鹏. 火烧对黔中喀斯特山地马尾松林分的影响. 生态学报, 2011, 31 (21) :6442-6450.

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火烧对黔中喀斯特山地马尾松林分的影响

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摘要: 采用样地比较法在黔中喀斯特山地上覆第四纪粘土的马尾松人工次生林内, 研究了林火对马尾松林分的影响, 结果表明过火马尾松林不同部位的受害率为树皮 (95.51%) > 树枝 (71.49%) > 树冠 (62.95%), 不同层片的植物死亡率为草本层 (100.00%) > 灌木层 (30.43%) > 乔木层 (29.09%)。马尾松树皮受害率不因径级而变化, 树枝和树冠受害率及植株死亡率随径级增高而降低, 灌木层物种或全部死亡、或部分死亡、或全部存活, 草本层物种或死亡、或萌生。过火马尾松林地生物量的潜在损失量 (68.7755 t/hm²) > 直接损失量 (12.1818 t/hm²)、直接损失率 22.41%, 直接损失量中乔木层 (6.9382 t/hm²) > 枯物层 (3.3441 t/hm²) > 灌木层 (2.4964 t/hm²) > 草本层 (0.8861 t/hm²), 直接损失率中草本层或枯物层 (100.00%) > 灌木层 (33.36%) > 乔木层 (23.59%)。过火马尾松林不同层片的 Patrick 指数、Gleason 指数、Simpson 指数和 Hurlbert 指数损失量为草本层 > 灌木层 > 乔木层、潜在损失量 > 直接损失量, 直接损失率中乔木层的相应值为 14.29%、14.29%、17.85%、-11.29%, 灌木层的相应值为 26.76%、26.76%、37.63%、-18.53%, 草本层为 100.00%。

关键词: 喀斯特山地; 火烧; 马尾松林; 生物量; 植物多样性

Influence of fire on stands of *Pinus massoniana* in a karst mountain area of central Guizhou province

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Abstract: The effects of fire on artificial secondary forests of *Pinus massoniana* with an average diameter at breast height (DBH) from 5.5958 cm to 19.3900 cm, average height from 4.11 m to 18.60 m, and average density from 500 clumps hm⁻² to 2400 clumps hm⁻², were investigated by comparison of burnt and non-burnt plots in a karst mountain area covered by Quaternary clay in central Guizhou province, China. The percentage damage to *P. massoniana* trees differed among plant organs and followed the order bark (95.51%) > branches (71.49%) > crown (62.95%). The percentage plant death in different forest layers was highest in the herbaceous layer (100%), intermediate in the arbuscular layer (30.43%) and lowest in the arboreal layer (29.09%). With increasing DBH of *P. massoniana* in the arboreal layer, the percentage damage to bark was unchanged, whereas damage to branches and the crown decreased, and the percentage death of plants also decreased. At *P. massoniana* DBH < 5 cm, the percentage damage to bark, branches and the crown, percentage plant death and direct loss of biomass were all 100%, whereas at DBH ≥ 25 cm the percentage damage to bark, branches and the crown were 85.00%, 25.00% and 15.00%, respectively, and percentage plant death and direct loss of biomass were zero. In the arbuscular layer, either all individuals of a plant species died, such as *P. massoniana*, *Betula alnoides* and *Camellia oleifera*, all plants survived, such as *Prunus serrulata*, *Myrsine africana* and *Rhamnus leptophylla*, or only some plants died, such as *Cunninghamia lanceolata*, *Castanea seguinii* and *Aralia chinensis*. Plant species in the

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herbaceous layer either died or germinated after death of aboveground branches and leaves because of fire. In burnt forest, the potential biomass loss (68.7755 t/hm^2) was higher than direct biomass loss (12.1818 t/hm^2 ; percentage direct loss 22.41%). Direct biomass loss differed among the layers and followed the order arboreal layer (6.9382 t/hm^2) > litter layer (3.3441 t/hm^2) > arbuscular layer (2.4964 t/hm^2) > herbaceous layer (0.8861 t/hm^2); in terms of the corresponding percentage direct biomass loss, the order was herbaceous layer (or litter layer, 100.00%) > arbuscular layer (33.36%) > arboreal layer (23.59%). Decreases in the Patrick, Gleason, Simpson and Hurlbert indices followed the order herbaceous layer > arbuscular layer > arboreal layer, and reflected potential losses were higher than direct losses of plant diversity in the different layers of burnt forests. The range and average values of direct diversity loss in the arboreal layer indicated by the Patrick, Gleason, Simpson and Hurlbert indices were 0—1 and 0.1429, 0—0.1669 and 0.0238, 0—1.0000 and 0.1586, and -0.1098—0 and -0.0166, respectively; the corresponding range and average values of percentage direct biodiversity loss were 0—100 and 14.29, 0—100 and 14.29, 0.66—100 and 17.85, and -18.61—-3.98 and -11.29, respectively. The range and average values of direct loss of diversity in the arbuscular layer as measured by these indices were 0—5 and 1.8571, 0—0.6948 and 0.4301, 0—0.2987 and 0.1115, and -0.3477—0 and -0.1241, respectively; the corresponding range and average values of percentage direct biodiversity loss were 0—42.86 and 26.76, 0—42.85 and 26.76, 0—86.35 and 37.63, and -52.00—0 and -18.53, respectively. The range and average values of direct diversity loss in the herbaceous layer indicated by these indices were 2—6 and 3.8000, 1.8205—5.4614 and 3.4589, 0.2593—0.8313 and 0.5300, and 0.1728—0.7619 and -0.4863; the percentage direct loss was 100.00% for all of the indices. The average burn height of the arboreal layer was negatively correlated to DBH, positively correlated to density and percentage damage to branches, the crown and entire plants, and uncorrelated with percentage damage to bark. The arboreal layer showed higher burn heights than those of the arbuscular layer, and their correlation was negative, and was negatively correlated to potential or direct loss of biomass and positively correlated to percentage direct loss of biomass. Burn height was positively correlated to direct loss or percentage direct loss of biomass, and negatively correlated to potential loss of biomass in the arbuscular layer. Direct loss or percentage direct loss of biomass with the Patrick and Gleason indices was not obviously correlated to burn height in the arboreal layer and was positively correlated to burn height in the arbuscular layer. Burn height was positively correlated to direct loss, and negatively correlated to percentage direct loss, of biomass with the Simpson index in the arboreal layer, and positively correlated to direct loss and percentage direct loss of biomass with the Simpson index in the arbuscular layer. No obvious correlation between burn height of the arboreal or arbuscular layer and direct loss or percentage direct loss of biomass with the Hurlbert index was detected.

Key Words: karst mountain area; fire; *Pinus massoniana* forest; biomass; plant diversity

火是森林生态系统最活跃的因素之一,全球每年约有 1% 的森林遭受火的干扰^[1]。林火通过改变区域森林生态系统的格局与过程,进而影响其生态服务功能。国内外有关林火的分布格局同森林类型和立地关系^[2-4]、碳^[5-6]及其它有害气体^[7]排放,对森林净生产力^[8-10]、土壤生物与理化性质^[11-14]、森林动物^[15-16]的影响,林地可燃物^[17-18]与林火关系^[19]等方面有过一些报道。但缺少林火对森林结构、植物多样性的影响以及森林组成物种对林火响应等方面的研究。2009—2010 年,我国西南地区发生了近百年未遇的旱灾,林火是主要的次生灾害之一,火警频率与森林过火面积为历年之冠,这为研究林火对不同径级马尾松(*Pinus massoniana*)林的影响提供了模板,其结果可用于林火损失评价,也可为喀斯特山地的造林物种配置、林分结构调控提供理论依据与技术支持。

1 研究区概述

研究区位于黔中喀斯特山地的贵阳市, E106°07'—107°17'、N26°11'—27°27', 海拔变幅 506.5—1749.0 m,

其间丘陵、山地、盆地和河谷相间分布。地质构造为黔中隆起和黔南凹陷的过渡带,震旦系至第四纪的地层均有出露,以碳酸岩组分布最广。喀斯特地貌占全市总面积的 88.49%,其中石漠化面积为 25.40%,轻度石漠化 16.12%、中度石漠化 7.94%、强度石漠化 1.32%。地带性森林为常绿阔叶林、喀斯特森林为常绿落叶阔叶混交林,森林覆盖率 41.78%、林木绿化率 44.71%。属中亚热带湿润季风气候区,年均温 12.8—15.3℃、年降雨量 1168.3—1258.5 mm,日照 1084.7—1411.9 h/a、25%—32%/a。全年主导风向北偏东、夏季主导风向南偏东,平均风速 2.2 m/s·a。

试验区位于贵阳市南郊的省林科院试验林场,其碳酸岩组形成地貌上覆第四纪粘土,黄壤厚度 0.0—3.0 m 不等、依坡度、坡向、坡位而变。马尾松林为 20 世纪 60 年代人工造林后,经陆续块状采伐、天然更新后形成的次生林,林分平均胸径 5.5958—19.3900 cm、平均密度 500—2400 株/hm²。

2 研究方法

2010 年 1—3 月间,试验林场近 1100 hm²以马尾松为主的林分发生呈规模的森林火场 9 个、过火面积近 93 hm²,火场面积变幅 0.89—40.13 hm²、由一至多次火警构成,以地表火为主,地表火中兼有少量林冠火。在 1:10000 地形图上标出火场位置与面积,结合 2004—2006 年森林资源二类清查小班资料,选择相近海拔高度、坡向、坡位、坡度,林分特征相似的马尾松过火和对照成对小班 5 对,不成对、但林分特征差异明显的马尾松过火小班 2 个,分布于其中的 7 个火场中。

2.1 样地设置与调查

在 12 个调查林分内有代表性的地段建立样地。样地面积 20 m × 20 m,其内灌木层、草本层和枯物层样方 3 个,代表调查样地内发育较差、一般和较好的灌木层、草本层和枯物层类型,面积分别为 5 m × 5 m、1 m × 1 m、1 m × 1 m。乔木与灌木层每木记录种名,测定胸(地)径、树高、枝下高、冠幅,过火高度,树皮、树枝与树冠受害及死亡情况;草本层记录种名、高度、株数,叶片与植株受害及死亡情况。

2.2 受害指标及判定

植物不同部位受害程度间判断无相关性,以调查期间植株表象为依据。①叶片受害:植物叶片全部或部分灼烧碳化或黄化;②树皮受害:树皮有明显灼伤痕迹,表皮碳化;③树枝受害:非树冠构成枝的叶碳化或黄化、枝皮有明显灼伤痕迹;④树冠受害:树冠构成枝的叶碳化或黄化、或树冠整体碳化与黄化;⑤植株死亡:过火后至生长初期(5 月上一中旬)植株地表根基及以上无新芽萌发。

2.3 指标计算

2.3.1 生物量

乔木层^[20-21]、灌木层^[22]生物量按已有模型推算,草本层和枯物层生物量用实测法测定。

2.3.2 多样性

Patrick 指数、Gleason 指数、Simpson 指数和 Hurlbert 指数依据已有公式^[23]计算。

3 结果分析

3.1 对林分结构的影响

过火马尾松林样地海拔 1155—1250 m、平均 1202 m,坡度 0—32°、平均 16°,岩石裸露率 0—25%、平均 4%,分布于山脊、坡上部或中部,呈东、东南或南向;植被层总盖度 55%—98%、平均 70%,乔木层 30%—65%、平均 54%,灌木层 2%—46%、平均 16%,草本层 4%—50%、平均 16%;林分其它特征指标也存在明显差异(表 1)。样地内不同径级株数分布不遵从正态分布($\alpha=0.05$)^[24],样地间径级-株数分布差异明显(图 1),映证了马尾松林分的次生性。

过火马尾松林的受害状况有相似性、也有相异性(表 2)。草本层植物叶片和植株受害率、地上部分死亡率达 100%,仅在地表根基有部分萌芽;灌木层植物树枝和树冠受害率达 100%,平均死亡率 30.43%;乔木层植物平均受害率中,树皮 95.51%、树枝 71.49%、树冠 62.95%,死亡率 29.09%。马尾松小径级林的死亡率较高,大径级林的死亡率较低。不同层片植物地上部分死亡率的变化趋势为草本层>灌木层>乔木层,乔木层

植物不同部位受害率的变化趋势为树皮>树枝>树冠。

表 1 过火马尾松林分样地基本特征表
Table 1 Basic characteristics description of fired stands of *Pinus massoniana*

样地 Site	乔木层 Arboreous layer			灌木层 Arbuscular layer			草本层 Herbaceous layer
	平均胸径 DBH/cm	平均高度 ATH/m	密度 Density /(株/hm ²)	平均地径 DGH/cm	平均高度 ATH/cm	密度 Density /(株/hm ²)	种均高度 ATHS/cm
No. 1	13.0400	9.14	1000	0.3138	31.21	38667	50.00
No. 2	14.4425	10.43	1050	0.3854	12.25	32000	22.00
No. 7	5.5958	4.11	2400	0.4325	43.38	133333	29.80
No. 11	16.7280	12.14	625	0.9424	123.33	44000	64.00
No. 13	19.3900	12.66	500	1.3400	114.80	70000	52.00
No. 17	19.0655	18.60	725	1.1152	30.65	30667	23.75
No. 18	18.4258	12.86	850	1.1714	132.38	37333	14.86

DBH 指平均胸径,ATH 指平均高度,DGH 指地径,ATHS 指种间平均高度

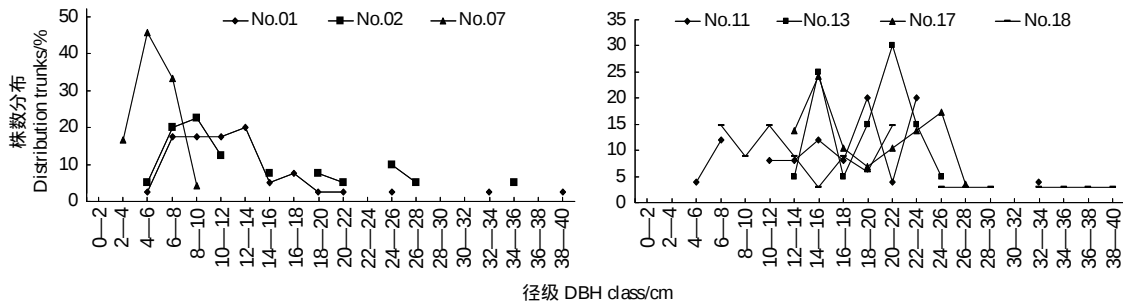


图 1 马尾松林过火样地的径级-株数分布
Fig. 1 Distribution of DBH classes-trunks in fired stands of *Pinus massoniana*

过火高度为乔木层植物高于灌木层植物,二者呈负相关。乔木层植物过火高度同乔木层植物平均胸径呈负相关、密度呈正相关,同树枝和树冠受害率及植株死亡率呈正相关、对树皮受害率影响的趋势性不明显;死亡率同乔木层植物平均胸径呈负相关,密度呈正相关;树枝受害率和树冠受害率同乔木层植物平均胸径呈负相关、密度呈正相关,树皮受害率受乔木层植物平均胸径和密度影响的趋势性不明显。灌木层植物过火高度和死亡率随灌木层植物平均地径的增加而增大、密度的增加而降低,灌木层植物死亡率随乔木层植物死亡率的升高而降低。

表 2 过火马尾松林分样地结构受损统计表
Table 2 Damaged structure indices statistics of fired stands of *Pinus massoniana*

样地 Site	乔木层 Arboreous layer					灌木层 Arbuscular layer			
	过火高度 FHS/m	树皮 Bark/%	树枝 Branch/%	树冠 Crown/%	死亡 Dead/%	过火高度 FHS/m	树枝 Branch/%	树冠 Crown/%	死亡 Dead/%
No. 1	8.67	97.50	85.00	82.50	72.50	1.56	100.00	100.00	1.72
No. 2	6.13	80.95	66.67	37.14	11.90	1.44	100.00	100.00	12.50
No. 7	6.62	100.00	100.00	100.00	100.00	1.35	100.00	100.00	0.00
No. 11	10.00	96.00	96.00	96.00	4.00	1.45	100.00	100.00	45.45
No. 13	3.39	100.00	100.00	100.00	0.00	2.05	100.00	100.00	52.38
No. 17	5.89	100.00	16.90	5.00	3.45	4.70	100.00	100.00	65.22
No. 18	2.84	94.12	35.88	20.00	11.76	1.69	100.00	100.00	35.71

FHS 指样地单株植物过火高度的均值

3.2 对生物量的影响

过火马尾松林(表3)生物量直接损失量平均值中,乔木层 6.9382 t/hm²,灌木层 2.4964 t/hm²,草本层 0.8861 t/hm²,枯物层 3.3441 t/hm²,植被层地上部分 12.1818 t/hm²;生物量潜在损失量平均值中,乔木层 61.4525 t/hm²,灌木层 3.3785 t/hm²,植被层地上部分 68.7755 t/hm²。过火马尾松林生物量的潜在损失量>直接损失量,生物量直接损失量中乔木层>枯物层>灌木层>草本层,生物量潜在损失量中乔木层>灌木层>枯物层>草本层。

生物量直接损失率平均值中,乔木层 23.59%,灌木层 33.36%,草本层和枯物层达 100.00%,植被层地上部分 22.41%。生物量直接损失率变化趋势为草本层或枯物层>灌木层>乔木层。

过火马尾松林乔木层生物量潜在损失量同乔木层植物平均胸径呈正相关、密度呈负相关,直接损失量或直接损失率的趋势性相反;灌木层生物量潜在损失量、直接损失量或直接损失率同灌木层植物平均地径呈正相关,密度呈负相关。过火高度同乔木层生物量的直接损失量或潜在损失量呈负相关、同直接损失率呈正相关,过火高度同灌木层生物量的直接损失量或直接损失率呈正相关、同潜在损失量呈负相关。

表3 过火马尾松林分样地生物量受损统计表(t/hm²)

Table 3 Damaged biomass statistics of fired stands of *Pinus massoniana*

样地 Site	指标 Index	乔木层 Arboreous layer				灌木层 Arbustular layer	草本层 Herbaceous layer	枯物层 Litter layer	生物量 Total biomass
		树皮 Bark	树干 Stem	树枝 Branch	树叶 Leaf				
No. 1	DL	1.2507	11.6540	2.5097	1.8387	0.0474			22.0880
	PL	2.9790	27.8007	8.2824	6.7953	2.0692	1.0651	3.7224	52.7141
No. 2	DL	0.0723	0.6725	0.1011	0.0660	0.2208			6.6429
	PL	4.8397	45.1986	15.1217	12.7268	1.5649	1.3471	4.1631	84.9618
No. 7	DL					0.0000			8.2421
	PL	0.4852	4.5063	0.5221	0.3159	7.6601	0.8861	1.5264	15.9022
No. 11	DL	0.0068	0.0629	0.0075	0.0046	1.3895			5.0856
	PL	3.4127	31.4098	9.4711	7.7264	3.0063	0.6263	2.9882	56.6408
No. 13	DL	0.0000	0.0000	0.0000	0.0000	2.9860			5.3912
	PL	3.1941	29.8159	8.8583	7.1330	4.7364	0.1619	2.2433	56.1429
No. 17	DL	0.0708	0.6601	0.1513	0.1123	1.3509			9.3780
	PL	6.6340	61.9621	20.6627	17.2582	2.1163	1.2937	5.7389	115.6662
No. 18	DL	1.3486	12.6072	5.0547	4.4858	1.0997			28.4448
	PL	6.2271	53.3113	17.9179	15.5991	2.4964	0.8223	3.0264	99.4005

DL: 直接损失量,指过火样地植物地上部分死亡或烧毁所形成的生物量损失,不包括受害植株的叶、树皮、树枝和树冠受损量; PL: 潜在损失量,指过火样地因全面更新造林所形成的地上部分生物量损失

3.3 对植物多样性的影响

过火马尾松林植物多样性直接损失量平均值中(表4),Patrick 指数、Gleason 指数、Simpson 指数、Hurlbert 指数在乔木层分别为 0.1429、0.0238、0.1586、-0.0166,在灌木层分别为 1.8571、0.4301、0.1115、-0.1241;潜在损失量中,乔木层分别为 1.4286、0.2384、0.8972、0.1062,灌木层分别为 6.7143、1.5551、0.4424、0.5663。过火马尾松林植物多样性的潜在损失量>直接损失量,Patrick 指数、Gleason 指数和 Hurlbert 指数的潜在损失量和直接损失量趋势为灌木层>乔木层,Simpson 指数为乔木层>灌木层。

过火马尾松林分草本层植物焚烧殆尽,通过建立相似立地和林分起源的马尾松林对照样地估测草本层植物多样性的损失(表5),成对样地林分的平均胸径 *T*-检验和径级-株数分布 *X*²-检验($\alpha=0.05$)未达显著水平,可视为同质林分。草本层植物多样性平均值中,Patrick 指数为 3.8000、Gleason 指数为 3.4589、Simpson 指数为 0.5300、Hurlbert 指数为 0.4863。同过火马尾松林分样地比较,多样性指数为草本层>乔木层,Patrick 指数和 Hurlbert 指数为灌木层>草本层、Gleason 指数和 Simpson 指数则相反。

表 4 过火马尾松林分样地植物多样性受损统计表
Table 4 Damaged biodiversity statistics of fired stands of *Pinus massoniana*

样地 Site	指标 Index	乔木层 Arboreous layer				灌木层 Arbuscular layer			
		Patrick 指数	Gleason 指数	Simpson 指数	Hurlbert 指数	Patrick 指数	Gleason 指数	Simpson 指数	Hurlbert 指数
No. 1	DL	0	0	0	0	1	0.2316	0.0003	-0.0003
	PL	1	0.1669	1	0	3	0.6948	0.9007	0.1010
No. 2	DL	0	0	0	0	1	0.2316	0.0373	-0.0394
	PL	1	0.1669	1	0	3	0.6948	0.6155	0.3927
No. 7	DL	1	0.1669	1	0	0	0	0	0
	PL	1	0.1669	1	0	3	0.6948	0.5238	0.4786
No. 11	DL	0	0	0.0056	-0.0061	3	0.6948	0.1152	-0.1286
	PL	2	0.3338	0.8528	0.1533	7	1.6213	0.2392	0.7725
No. 13	DL	0	0	0	0	1	0.2316	0.2744	-0.2871
	PL	1	0.1669	1	0	9	2.0845	0.3439	0.6625
No. 17	DL	0	0	0	0	5	1.1581	0.2987	-0.3477
	PL	1	0.1669	1	0	10	2.3162	0.3459	0.6686
No. 18	DL	0	0	0.1038	-0.1098	2	0.4632	0.0548	-0.0655
	PL	3	0.5007	0.4273	0.5900	12	2.7794	0.1276	0.8883

DL: 直接损失量, 指过火样地植物地上部分死亡所形成的植物多样性损失; PL: 潜在损失量, 指过火样地因全面更新造林所形成的植物多样性损失

过火马尾松林分植物多样性直接损失率平均值中, Patrick 指数、Gleason 指数、Simpson 指数、Hurlbert 指数在乔木层分别为 14.29%、14.29%、17.85%、11.29%, 在灌木层分别为 26.76%、26.76%、37.63%、18.53%。植物多样性直接损失率为草本层>灌木层>乔木层。

表 5 过火马尾松林分成对样地草本层植物多样性统计表
Table 5 Biodiversity statistics of herbaceous layer from non-fired stands in similar stands of *Pinus massoniana*

指标 Index	样地 Paired No.				
	No. 1—No. 10	No. 2—No. 9	No. 7—No. 8	No. 11—No. 12	No. 13—No. 14
Patrick 指数	2	3	4	4	6
Gleason 指数	1.8205	2.7307	3.6410	3.6410	5.4614
Simpson 指数	0.8313	0.7899	0.3242	0.4453	0.2593
Hurlbert 指数	0.1728	0.2142	0.6908	0.5917	0.7619

进一步分析发现 Patrick 指数、Gleason 指数的直接损失量和直接损失率在乔木层的趋势性不明显, 同灌木层植物的平均地径呈正相关、密度呈负相关, 与过火高度呈正相关。Simpson 指数的直接损失量和直接损失率同乔木层植物的平均胸径呈负相关、密度呈正相关, 在灌木层变化的趋势性相反; 乔木层过火高度同 Simpson 指数的直接损失量呈正相关、直接损失率呈负相关, 灌木层过火高度同 Simpson 指数直接损失量和直接损失率呈正相关。Hurlbert 指数的直接损失量和直接损失率同乔木层、灌木层植物相关特征指标和过火高度变化的趋势性不明显。

3.4 植物对林火的响应

过火样地乔木层以马尾松为主, 间有杉木 (*Cunninghamia lanceolata*) 和泡桐 (*Paulownia tomentosa*)、但株数极少。分析表明(表 6)不同径级马尾松的平均高度均大于过火高度, 受害率的变化趋势为树皮>树枝>树冠>植株, 树皮受害率随径级增加的变化较小, 树枝、树冠受害率, 植株死亡率、生物量直接损失率随径级的增加而降低。小于 5 cm 径级马尾松的树皮、树枝和树冠受害率, 以及死亡率、生物量直接损失率达 100.00%; 大于 25 cm 径级马尾松的死亡率和生物量直接损失率分别为 0。

过火样地灌木层累计调查面积 105 m², 计 22 种、564 株, 平均过火高度大于种平均高度。除主要种(表 7)外, 偶见种(总株数<5)死亡率达 100.00% 的有火棘(*Pyracantha fortuneana*)、柃木(*Eurya brevistyla*)、小果蔷薇(*Rosa cymosa*)和鸡矢藤(*Paederia scandens*)等, 臭椿(*Ailanthus altissima*)、山楂(*Crataegus cuneata*)、漆树(*Toxicodendron vericifluum*)、木姜(*Neolitsea aurata*)和野葡萄(*Vitis amurensis*)等在林火过后的生长初期从地表根基萌生新苗。常见种内的马尾松、西南桦和油茶死亡率达 100.00%, 杉木、茅栗和槲木部分死亡, 其它种在生长初期的地表根基均有部分萌生苗。

表 6 不同径级马尾松过火受损统计表
Table 6 Damaged statistics of DBH-classes in fired stands of *Pinus massoniana*

径级/cm DBH classes	径级特征 DBH class index			株数 Trunks				生物量 Biomass	
	株数 Trunks	均高 ATH/m	过火高度 FHS/m	树皮 Bark/%	树枝 Branch/%	树冠 Crown/%	死亡 Dead/%	总量 Sum/T	损失率 Loss/%
0—5	8	3.90	1.87	100.00	100.00	100.00	100.00	0.0012	100.00
5—10	54	6.58	2.01	95.19	81.48	71.11	61.11	0.0656	54.51
10—15	37	11.06	2.66	92.16	75.14	68.92	40.54	0.2607	33.61
15—20	38	13.13	4.23	86.84	60.53	57.37	15.79	0.6257	16.03
20—25	32	16.08	4.89	96.88	53.13	50.00	3.13	1.1163	3.45
25—30	15	18.00	4.30	100.00	40.00	33.33	0.00	2.7926	0.00
30—35	5	18.30	6.00	100.00	35.00	20.00	0.00	1.8774	0.00
35—40	4	19.00	5.50	85.00	25.00	15.00	0.00	1.6340	0.00

表 7 过火马尾松林灌木受损统计表
Table 7 Damaged statistics of brushes in fired stands of *Pinus massoniana*

物种 Species	地径变幅 DGH range/cm	平均地径 DGH/cm	平均高度 ATH/m	过火高度 FHS/m	死亡率 Dead rate/%
马尾松 <i>Pinus massoniana</i>	0.8—3.1	1.6653	1.47	2.91	100.00
杉木 <i>Cunninghamia lanceolata</i>	0.6—4.2	1.3000	1.25	2.19	87.50
西南桦 <i>Betula alnoides</i>	0.5—2.0	1.3000	2.10	2.00	100.00
茅栗 <i>Castanea sequinii</i>	0.2—2.1	0.4662	0.48	1.60	4.83
白栎 <i>Quercus fabri</i>	0.2—0.5	0.4570	0.49	1.53	0.00
油茶 <i>Camellia oleifera</i>	1.1—3.5	3.0833	3.26	1.92	100.00
小果南烛 <i>Lyonia ovalifolia</i> var. <i>elliptica</i>	0.3—0.6	0.3889	0.15	1.31	0.00
琴叶悬钩子 <i>Rubus panduratus</i>	0.2—0.4	0.2467	0.33	1.23	0.00
铁仔 <i>Myrsine africana</i>	0.1—0.3	0.2000	0.30	1.64	0.00
拔莫 <i>Smilax scobinicaulis</i>	0.3—0.7	0.3727	0.60	1.35	0.00
薄叶鼠李 <i>Rhamnus leptophylla</i>	0.6—3.2	1.2500	1.50	2.92	0.00
槲木 <i>Aralia chinensis</i>	0.2—1.2	0.7444	0.50	1.26	55.56
樱 <i>Prunus serrulata</i>	0.3—0.6	0.500	0.50	1.25	0.00

过火样地草本层植物主要有五节芒(*Miscanthus floridulus*)、珍珠菜(*Lysimachia clethroides*)、铁芒萁(*Dicranopteris linearis*)、滇白珠(*Gaultheria leucocarpa* var. *crenulata*)、松毛火绒草(*Leontopodium andersonii*)等, 均在过火中烧毁、但大部分物种在生长初期又从地表根基发芽。

4 讨论

4.1 林火对森林影响的复杂性

由于调查区域主要立地因子的相似性^[3], 此项研究更多地反应了林火对马尾松人工次生林结构的影响。林火过后, 灰分与火烧残体在地表堆积, 可能影响到土壤理化性质^[13]、微生物与土壤呼吸^[12]、以及土壤的其它方面^[11], 大量尘埃和热量散布林区、也会影响区域性气候变化^[5-7], 有关林火过后阔叶林净生产力变

化^[8-10]、昆虫和病原菌同林火的关系^[16]在国外已有报道,但针叶林、特别是马尾松林的相关报道较少,有必要进行长期定位研究。

4.2 森林植物对林火响应的差异性

林火过后,草本层物种或死亡、或萌生,灌木层物种或全部死亡、或部分死亡、或全部存活,反应了物种对林火的不同生态对策;乔木层马尾松树皮受害率不因径级增大而变化、树枝和树冠受害率及植株死亡率随径级的增加而降低,反应了不同年龄种群对林火响应的差异性。森林经营上,在灌木层移入或保留具有萌生性、或部分抗火的物种,乔木层由单树种变为多树种,有利于林火过后的森林恢复;幼龄林的林火受损率较高,宜加强林地火源管理。

4.3 过火植物受损评估的准确性

本文以植物地表死亡个体为对象分析林火对马尾松林分的影响,对部位的影响仅限于定性,一定程度上干扰了研究结论的精度。如过火样地乔木层与灌木层物种树皮、非树冠构成枝、树冠构成枝的受损数量未列入林分结构变化与生物量损失,灌木层与草本层部分物种因碳化丧失辩识标准而忽略、部分物种因萌生而低估了受损林分的植物多样性。建议细化植物受损评判标准,进行模拟试验,提高研究结论的准确性。

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ACTA ECOLOGICA SINICA Vol. 31, No. 21 November, 2011 (Semimonthly)

CONTENTS

Landscape spatial analysis of a traditional tibetan settlement based on landscape pattern theory and feng-shui theory; the case of Zhagana, Diebu, Gansu Province	SHI Lisha, YAN Lijiao, HUANG Lu, et al (6305)
Temporal-spatial differentiation and its change in the landscape ecological security of Wuyishan Scenery District	YOU Weibin, HE Dongjin, WU Liyun, et al (6317)
Evaluation of eco-sustainability of roads in a tourism area; a case study within Yulong County	JIANG Yiyi (6328)
Study on the compactness assessment model of urban spatial form	ZHAO Jingzhu, SONG Yu, SHI Longyu, et al (6338)
A multi-scale analysis of red-crowned crane's habitat selection at the Yellow River Delta Nature Reserve, Shandong, China	CAO Mingchang, LIU Gaohuan, XU Haigen (6344)
Assessment and spatial distribution of water and soil loss in karst regions, southwest China	FAN Feide, WANG Kelin, XIONG Ying, et al (6353)
Construction of an eco-environmental database for watershed-scale data; an example from the Tarim River Basin	GAO Fan, YAN Zhenglong, HUANG Qiang (6363)
Reproductive allocation in dioecious shrub, <i>Rhamnus davurica</i>	WANG Juan, ZHANG Chunyu, ZHAO Xiuhai, et al (6371)
Age-dependent growth responses of <i>Pinus koraiensis</i> to climate in the north slope of Changbai Mountain, North-Eastern China	WANG Xiaoming, ZHAO Xiuhai, GAO Lushuang, et al (6378)
Fine-scale spatial point patterns of <i>Stipa krylovii</i> population in different alpine degraded grasslands	ZHAO Chengzhang, REN Heng, SHENG Yaping, et al (6388)
Community structure and population regeneration in remnant <i>Ginkgo biloba</i> stands	YANG Yongchuan, MU Jianping, TANG Cindy Q., et al (6396)
Reproductive characteristics and adaptive evolution of pin and thrum flowers in endangered species, <i>Primula merrilliana</i>	SHAO Jianwen, ZHANG Wenjuan, ZHANG Xiaoping (6410)
Leaf functional traits of four typical forests along the altitudinal gradients in Mt. Shennongjia	LUO Lu, SHEN Guozhen, XIE Zongqiang, et al (6420)
Reclaimed soil properties and weathered gangue change characteristics under various vegetation types on gangue pile	WANG Liyan, HAN Youzhi, ZHANG Chengliang, et al (6429)
Influence of fire on stands of <i>Pinus massoniana</i> in a karst mountain area of central Guizhou province	ZHANG Xi, CHUI Yingchun, ZHU Jun, et al (6442)
Morphological and physiological adaptation of <i>Caragana</i> species in the Inner Mongolia Plateau	MA Chengcang, GAO Yubao, LI Qingfang, et al (6451)
A comparative study on reasons of degenerated of <i>Haloxylon ammodendron</i> population in the western part of Gurbantunggut desert	SI Langming, LIU Tong, LIU Bin, et al (6460)
Self-thinning of natural broadleaved forests in Baishilazi Nature Reserve ...	ZHOU Yongbin, YIN You, YIN Mingfang, et al (6469)
Population status and dynamic trends of Amur tiger's prey in Eastern Wandashan Mountain, Heilongjiang Province	ZHANG Changzhi, ZHANG Minghai (6481)
The relationship between the occurrence of Colorado Potato Beetle, <i>Leptinotarsa decemlineata</i> , and rivers based on GIS: a case study of Shawan Country	LI Chao, ZHANG Zhi, GUO Wenchao, et al (6488)
Occurrence dynamics and trajectory analysis of <i>Cnaphalocrocis medinalis</i> Guenée in Xing'an Guangxi Municipality in 2010	JIANG Chunxian, QI Huihui, SUN Mingyang, et al (6495)
Adaptability of B-biotype <i>Bemisia tabaci</i> (Gennadius) to Host Shift	ZHOU Fucui, LI Chuanming, GU Aixiang, et al (6505)
Structural change analysis of cecal bacterial flora in different poultry breeds using PCR-DGGE ...	LI Yongzhu, Yongquan Cui (6513)
Effect of chicken manure-amended copper mine tailings on growth of three leguminous species, soil microbial biomass and enzyme activities	ZHANG Hong, SHEN Zhangjun, YANG Guide, et al (6522)
Physiological response of <i>Microcystis</i> to solar UV radiation	WANG Yan, LI Shanshan, LI Jianhong, et al (6532)
Relationship between cell volume and cell carbon and cell nitrogen for ten common dinoflagellates	WANG Yan, LI Ruixiang, DONG Shuanglin, et al (6540)
The community structure and abundance of microcystin-producing cyanobacteria in surface sediment of Lake Taihu in winter	LI Daming, KONG Fanxiang, YU Yang, et al (6551)
Influence of green belt structure on the dispersion of particle pollutants in street canyons	LIN Yinding, WU Xiaogang, HAO Xingyu, et al (6561)
Spatio-temporal variation analysis of urbanization and land use benefit of oasis urban areas in Xinjiang	YANG Yu, LIU Yi, DONG Wen, et al (6568)
Nitrate contamination and source tracing from NO_3^- - $\delta^{15}\text{N}$ in groundwater in Weifang, Shandong Province	XU Chunying, LI Yuzhong, LI Qiaozhen, et al (6579)
The impact of rising temperature on spring wheat production in the Yellow River irrigation region of Ningxia	XIAO Guoju, ZHANG Qiang, ZHANG Fengju, et al (6588)
A new hyperspectral index for the estimation of nitrogen contents of wheat canopy	LIANG Liang, YANG Minhua, DENG Kaidong, et al (6594)
The feature of N_2O emission from a paddy field in irrigation area of the Yellow River	ZHANG Hui, YANG Zhengli, LUO Liangguo, et al (6606)
Review and Monograph	
Research perspective for the effects of nitrogen deposition on biogenic volatile organic compounds	HUANG Juan, MO Jiangming, KONG Guohui, et al (6616)
Recruitment limitation of plant population: from seed production to sapling establishment	LI Ning, BAI Bing, LU Changhu (6624)
Scientific Note	
Response of anatomical structure and photosynthetic characteristics to low light stress in leaves of different maize genotypes	DU Chengfeng, LI Chaohai, LIU Tianxue, et al (6633)

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