

ISSN 1000-0933
CN 11-2031/Q

生态学报

Acta Ecologica Sinica



第 32 卷 第 24 期 Vol.32 No.24 **2012**

中国生态学学会
中国科学院生态环境研究中心
科学出版社

主办
出版



中国科学院科学出版基金资助出版

生态学报

(SHENGTAI XUEBAO)

第 32 卷 第 24 期

2012 年 12 月 (半月刊)

目 次

从文献计量角度分析中国生物多样性研究现状.....	刘爱原,郭玉清,李世颖,等 (7635)
CO ₂ 浓度升高和模拟氮沉降对青川箭竹叶营养质量的影响.....	周先容,汪建华,张 红,等 (7644)
陕西中部黄土高原地区空气花粉组成及其与气候因子的关系——以洛川县下黑木沟村为例.....	吕素青,李月从,许清海,等 (7654)
长三角地区 1995—2007 年生态资产时空变化.....	徐昔保,陈 爽,杨桂山 (7667)
基于智能体模型的青岛市林地生态格局评价与优化.....	傅 强,毛 锋,王天青,等 (7676)
青藏高原高寒草地生态系统服务功能的互作机制.....	刘兴元,龙瑞军,尚占环 (7688)
北京城市绿地的蒸腾降温功能及其经济价值评估.....	张 彪,高吉喜,谢高地,等 (7698)
武汉市造纸行业资源代谢分析.....	施晓清,李笑诺,赵吝加,等 (7706)
丽江市家庭能耗碳排放特征及影响因素.....	王丹寅,唐明方,任 引,等 (7716)
基于分布式水文模型和福利成本法的生态补偿空间选择研究.....	宋晓谕,刘玉卿,邓晓红,等 (7722)
设施塑料大棚风洞试验及风压分布规律.....	杨再强,张 波,薛晓萍,等 (7730)
湖南珍稀濒危植物——珙桐种群数量动态.....	刘海洋,金晓玲,沈守云,等 (7738)
云南岩陀及其近缘种质资源群体表型多样性.....	李萍萍,孟衡玲,陈军文,等 (7747)
沙埋和种子大小对柠条锦鸡儿种子萌发、出苗和幼苗生长的影响.....	杨慧玲,梁振雷,朱选伟,等 (7757)
栗山天牛天敌花绒寄甲在栎林中的种群保持机制.....	杨忠岐,唐艳龙,姜 静,等 (7764)
基于相邻木排列关系的混交度研究.....	娄明华,汤孟平,仇建习,等 (7774)
三种回归分析方法在 Hyperion 影像 LAI 反演中的比较.....	孙 华,鞠洪波,张怀清,等 (7781)
红松和蒙古栎种子萌发及幼苗生长对升温与降水综合作用的响应.....	赵 娟,宋 媛,孙 涛,等 (7791)
新疆杨边材贮存水分对单株液流通量的影响.....	党宏忠,李 卫,张友焱,等 (7801)
火干扰对小兴安岭毛赤杨沼泽温室气体排放动态影响及其影响因素.....	顾 韩,牟长城,张博文 (7808)
不同潮汐和盐度下红树植物幼苗秋茄的化学计量特征.....	刘滨尔,廖宝文,方展强 (7818)
腾格里沙漠东南缘沙质草地灌丛化对地表径流及氮流失的影响.....	李小军,高永平 (7828)
西双版纳人工雨林群落结构及其林下降雨侵蚀力特征.....	邓 云,唐炎林,曹 敏,等 (7836)
西南高山地区净生态系统生产力时空动态.....	庞 瑞,顾峰雪,张远东,等 (7844)
南北样带温带区栎属树种种子化学组成与气候因子的关系.....	李东胜,史作民,刘世荣,等 (7857)
模拟酸雨对龙眼叶片 PS II 反应中心和自由基代谢的影响.....	李永裕,潘腾飞,余 东,等 (7866)
沈阳市城郊表层土壤有机污染评价.....	崔 健,都基众,马宏伟,等 (7874)
降雨对旱作春玉米农田土壤呼吸动态的影响.....	高 翔,郝卫平,顾峰雪,等 (7883)
冬季作物种植对双季稻根系酶活性及形态指标的影响.....	于天一,逢焕成,任天志,等 (7894)
施氮量对小麦/玉米带田土壤水分及硝态氮的影响.....	杨蕊菊,柴守玺,马忠明 (7905)
微山湖鸟类多样性特征及其影响因素.....	吕昭智,潘卫林,张 鑫,等 (7925)
新疆北部棉区作物景观多样性对棉铃虫种群的影响.....	刘静静,董春颖,宋英琦,等 (7932)
杭州西湖北里湖沉积物氮磷内源静态释放的季节变化及通量估算.....	郭 静,陈求稳,张晓晴,等 (7940)
基于实码遗传算法的湖泊水质模型参数优化.....	王跃中,孙典荣,陈作志,等 (7948)
气候环境因子和捕捞压力对南海北部带鱼渔获量变动的影响.....	颜婷茹,焦海峰,毛玉泽,等 (7958)
象山港南沙岛不同养殖类型沉积物酸可挥发性硫化物的时空分布.....	
专论与综述	
提高植物抗寒性的机理研究进展.....	徐呈祥 (7966)
植被对多年冻土的影响研究进展.....	常晓丽,金会军,王永平,等 (7981)
凋落物分解主场效应及其土壤生物驱动.....	查同刚,张志强,孙 阁,等 (7991)
街尘与城市降雨径流污染的关系综述.....	赵洪涛,李叙勇,尹澄清 (8001)



封面图说: 永兴岛海滩植被——永兴岛是中国西沙群岛的主岛,也是西沙群岛及南海诸岛中最大的岛屿。国务院 2012 年 6 月批准设立的地级三沙市,管辖西沙群岛、中沙群岛、南沙群岛的岛礁及其海域,三沙市人民政府就驻西沙永兴岛。永兴岛岛上自然植被密布,野生植物有 148 种,占西沙野生植物总数的 89%,主要树种有草海桐(羊角树)、麻枫桐、野枇杷、海棠树和椰树等。其中草海桐也称为羊角树,是多年生常绿亚灌木植物,它们总是喜欢倚在珊瑚礁岸或是与其他滨海植物聚生于海岸沙滩,为典型的滨海植物。

彩图提供: 陈建伟教授 北京林业大学 E-mail: cites.chenjw@163.com

DOI: 10.5846/stxb201204010458

李小军, 高永平. 腾格里沙漠东南缘沙质草地灌丛化对地表径流及氮流失的影响. 生态学报, 2012, 32(24): 7828-7835.

Li X J, Gao Y P. Effects of shrub encroachment in desert grassland on runoff and the induced nitrogen loss in southeast fringe of Tengger Desert. Acta Ecologica Sinica, 2012, 32(24): 7828-7835.

腾格里沙漠东南缘沙质草地灌丛化对地表径流 及氮流失的影响

李小军*, 高永平

(中国科学院寒区旱区环境与工程研究所 沙坡头沙漠研究试验站, 兰州 730000)

摘要:以腾格里沙漠东南缘沙质草地和灌丛生境为研究对象,采用人工模拟降雨实验对草地样方、灌丛间裸地样方及含灌丛斑块样方的产流及氮流失过程进行观测,揭示了地表径流及其引起的氮流失对沙质草地灌丛化的响应。结果表明:(1)草地样方出现表面积水和地表径流的时间及开始产流需要的降雨量均大于含灌丛斑块样方和灌丛间裸地样方,裸地样方最小;灌丛生境径流系数为 34.46%,显著小于裸地样方,大于含灌丛样方,产流量是沙质草地生境的 2.26 倍;表明灌木入侵造成的植被盖度下降引起了土壤水分入渗率的减小和地表产流的增加。(2)含灌丛样方单位体积径流含氮量瞬时值大于裸地样方,小于草地样方,三类样方瞬时值与单位时间径流量均呈线性负相关;草地样方单位时间氮流失量略小于含灌丛样方,两者均显著小于灌丛间裸地样方;灌丛生境氮流失总量为 0.23 g/m²,是草地生境的 2.09 倍,灌丛和草地生境单位体积径流含氮量总体平均值分别为 0.011 g/L、0.012 g/L;表明沙质草地灌丛化引起了养分流失的显著增加。

关键词:腾格里沙漠;植被变化;荒漠化;地表径流;氮

Effects of shrub encroachment in desert grassland on runoff and the induced nitrogen loss in southeast fringe of Tengger Desert

LI Xiaojun*, GAO Yongping

Shapotou Desert Research and Experiment Station, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China

Abstract: Grassland degradation typically characterized by the invasion of shrubs and semi-shrubs is a critical issue in arid and semi-arid desert regions throughout the world, which was broadly believed to eventually result in vegetation cover loss and the induced severe change of ecohydrological processes. The aim of this paper was to understand the response of runoff generation and the induced nutrient loss to shrub encroachment in desert grassland in arid regions since they are much closely related in drylands.

We took the grasslands and shrublands in the southeast fringe of Tengger Desert, north China, for the in situ case study. Simulated rainfall experiments were conducted on grassland plots (Grassland treatment, GT), intershrub bare soil plots (Bare soil treatment, BT) as well as the plots consisting of both bare soil patch and shrub patch (Shrub treatment, ST) in shrubland. The time to pond and to generate runoff, and the volume of rainfall to start runoff, the time series of runoff and nitrogen concentration, runoff coefficients, total nitrogen loss, and average concentration of total nitrogen were investigated simultaneously. By using these data, we compared soil water infiltration, runoff generation and nitrogen production from different habitats and elucidated the influences of the replacement of grassland by shrubland on the

基金项目:中国科学院“西部之光”人才培养计划“西部博士资助项目”;国家自然科学基金(40701002, 41171078)

收稿日期:2012-04-01; **修订日期:**2012-09-25

* 通讯作者 Corresponding author. E-mail: xiaojunli@lzb.ac.cn

hydrological processes and the induced biogeochemistry cycling.

Results showed that: the time to pond and to generated runoff and the amount of rainfall to start runoff for GT were slightly greater than those from ST, but significantly greater than those from intershrub bare soil plots, indicating the higher soil water infiltration rates in grassland than in shrubland. Weighted runoff coefficient in shrubland habitats was 34.46%, which was significantly less than that in intershrub plots, slightly larger than that in ST, and it was 2.26 times greater than that in GT. Time series concentration of nitrogen in ST was greater than that in intershrub plots but less than that in GT. For all the samples collected from each treatment, negative linear correlations were found between the nitrogen concentration and the amount of runoff discharge. Total nitrogen loss from shrubland habitat was 0.23 g/m², which was slightly smaller than that from intershrub plots but remarkably greater than that from shrub plots, and it was 2.09 times greater than the nitrogen loss from grassland; the volume-weighted mean concentration of nitrogen in the runoff from shrub plots, intershrub plots and shrubland habitat were 0.009, 0.007 and 0.011 g/L, respectively, they were less than the corresponding value in grassland (i.e., 0.012 g/L), all which confirmed the increased nitrogen loss induced by the vegetation replacement. The results indicate that vegetation cover decline/loss derived from the encroachment of woody plants in original grassland inevitably leads to the increase of runoff water and nutrients losses. If the general trend continued without interference, rainwater, soil material and nutrients would no longer be efficiently captured and stored within the ecosystem, then the landscape would become a degraded non-conservable system that can be termed dysfunction, these processes would expectably lead to continuous desertification.

Key Words: Tengger Desert; vegetation change; desertification; runoff; nitrogen

近年来,以灌木为优势的群落入侵干旱半干旱区草地原生植被,即草地灌丛化或草地荒漠化已经成为全球普遍发生的现象,也是生态学研究的核心问题^[1-5]。已有研究表明,导致植被发生这种变化的原因包括气候波动、大气二氧化碳浓度增加、过度放牧、火烧、周期性的干旱等^[6-8],尽管很难在实际发生的草地荒漠化过程与这些因素之间建立起明确的因果关系^[9-11],但是植被的这种替代所引发的生态系统结构和功能的变化已经成为不争的事实^[7, 12-14]。

沙质草地灌丛化往往伴随着风蚀和水蚀的发生,并可能导致生态系统生态水文过程的显著改变^[15]。许多研究表明,草地植被盖度的下降必然引起土壤水分入渗率的减小和地表径流的增加^[16-17]。与灌丛生境相比,沙质草地生境的抗水蚀能力较强,且地表径流流速往往较慢,而草地一旦被呈斑块分布的灌丛所替代,土壤水分入渗率会随着灌丛间大面积裸露地表的出现而显著下降,因而产生大量流速较快且侵蚀性更强的地表径流^[18],携带大量土壤物质和养分的流出系统外,导致系统功能失调及荒漠化的进一步发展^[19]。

目前,沙质草地灌丛化及其引起生态水文过程的变化已经受到了国内外学者的广泛关注,研究主要集中在植被变化的驱动因素^[6-9,11]、植被格局与过程^[2-3,7,10]、土壤水分格局及土壤资源异质性特征^[4-6,8]等方面,而关于地表径流的研究主要集中在北美,研究内容也主要侧重于细沟流^[20]及其导致的溶解养分流失^[21],国内的相关研究尚较缺乏。自19世纪初以来,由于过度放牧和沙漠向草地的扩张,腾格里沙漠南缘以旱生灌木入侵为主要特征的沙质草地退化普遍发生^[3,22]。本研究以腾格里沙漠东南缘的灌丛生境和沙质草地生境为研究对象,通过模拟降雨实验对地表产流及其引起的氮素流失进行分析,揭示生态水文过程和生物地球化学循环对植被变化的响应,为退化生态系统管理及土地荒漠化防治提供依据。

1 研究区概况与研究方法

1.1 研究区概况

实验区位于腾格里沙漠东南缘,中国科学院沙坡头沙漠研究试验站(37°25' E, 104°35' N)的长期观测样地。该区是草原化荒漠和荒漠化草原的过渡带,也是沙漠与绿洲的过渡带^[3]。平均海拔1 339 m,年平均气温10.0℃,极端最高气温38.1℃,极端最低气温为-25.1℃,冬夏昼夜温差大;年平均降水量为186.2 mm,年内

的降水分布很不均匀,80%左右的降水集中在7—9月份;年蒸发量为2 300—2 500 mm,空气平均相对湿度为40%。年平均风速为2.8 m/s,大于5 m/s的起沙风每年有200 d左右。

草地生境样地位于沙坡头站以西26 km处的阳坡,坡度约13°。主要植物种有沙生针茅(*Stipa glareosa* P. Smirn.)、短花针茅(*Stipa breviflora* Griseb.)、糙隐子草(*Cleistogenes squarrosa*)、沙葱(*Allium mongolicum*)等,伴生狗尾草(*Setaria viridis*)、小画眉草(*Eragrostis minor*)、刺沙蓬(*Salsola ruthenica*)、茵陈蒿(*Artemisia capillaris*)、虎尾草(*Chloris virgata*)、籽蒿(*Artemisia sphaerocephala*)等,植被盖度69%。灌丛生境样地位于沙坡头站以西40 km处的阳坡,坡度约10°。主要灌木种有珍珠猪毛菜(*Salsola passerina*)、伴生红砂(*Reaumuria Soongorica*)、华北驼绒藜(*Ceratoides arborescens*)、狭叶锦鸡儿(*Caragana stenophylla*)、荒漠锦鸡儿(*Caragana roborovskyi*)等,灌木盖度11%。两类生境表层土壤理化性质见表1。

表1 研究区表层土壤(0—10 cm)理化性质

Table 1 Physiochemical properties of soils (0—10 cm) in the study area

	裸地斑块 Bare soil patch	灌丛斑块 Shrub patch	沙质草地 Sandy grassland
容重 Bulk density/(g/cm ³)	1.43±0.21	1.18±0.11	1.17±0.14
粘粒含量 Clay content/%	5.68±1.13	11.81±2.06	12.26±1.87
粉粒含量 Silt content/%	15.17±2.49	22.61±3.74	23.69±2.88
有机碳 Organic carbon/(g/kg)	3.78±1.03	8.14±1.12	8.97±0.94
全氮 Total nitrogen/(g/kg)	0.23±0.08	0.58±0.14	0.62±0.12

1.2 研究方法

草地生境样地设置样方10个(1 m×1 m)(Grassland treatment, GT),灌丛生境样地设置样方20个(1 m×1 m),其中10个样方设置在由生物土壤结皮(藻类、地衣、苔藓等隐花植物)覆盖的灌丛间裸地斑块(Bare soil treatment, BT),另外10个样方均包含灌丛斑块(20%)和裸地斑块(80%)(Shrub treatment, ST),灌丛斑块位于样方的下端。样方四周将15 cm宽的铁皮轻轻砸入土壤中(10 cm在土壤表面下,5 cm在土壤表面上)。在样方下端连接一个水槽,水槽出口位置放置一个量筒收集径流和侵蚀产物。

采用自制人工降雨模拟器以80 mm/h的降雨强度实施模拟实验,降雨模拟器距离地面约2 m左右。降雨持续45 min(入渗和地表径流达到稳定),模拟降雨的同时,在每个样方四角布设4个烧杯,测定实际降雨强度和降雨量。模拟降雨事件结束时将不同样方收集的径流和侵蚀产物分别装入聚乙烯瓶中,样品采集完后立即冷藏带回实验室,随后对径流、侵蚀产物混合样进行过滤。侵蚀产物在60℃条件下烘干,分析过滤后径流中溶解氮含量及侵蚀产物的含氮量。

在每个模拟降雨事件中同时测定的参数包括:出现表面积水的时间(*TP*,样方60%以上的表面出现积水所需要的时间)、径流开始时间(*TR*)、径流开始需要的降雨量(*V*)。

2 结果与分析

2.1 不同样方水文特征

灌丛间裸地样方(BT)分别在降水开始3.32 min和4.58 min时出现表面积水和地表径流,用时显著少于含灌丛斑块的样方(ST)和草地样方(GT)(表2, $P<0.05$),而草地样方和含灌丛斑块样方之间差异不显著($P>0.05$)。裸地样方产生径流所需的降雨量为6.11 mm,而含灌丛斑块的样方和草地样方产流所需降雨量分别为裸地样方的4.4倍和4.9倍,差异显著,后两者之间差异不显著。表明灌丛斑块和草地能推迟或者减少地表径流的形成。

2.2 不同样方/生境产流特征

灌丛间裸地样方单位时间径流量在降水开始后15 min左右达到最大值,而含灌丛斑块样方和草地样方则在降水开始后30—35 min之间达到最大值(图1)。在大部分样方中,单位时间径流量均在这最大值附近波动直至降水结束,裸地样方波动范围明显大于其他两类样方。草地样方、裸地样方和含灌丛斑块样方的径

流系数分别为 15.22%、53.33% 和 19.01%。假设裸地样方和含灌丛斑块样方中单位面积裸地产流量相同,根据含灌丛样方中灌丛斑块与裸地斑块的比例及灌丛生境两者的实际比例进行加权计算,可得灌丛生境的径流系数为 34.46%,显著大于草地生境样方和含灌丛斑块样方,小于灌丛间裸地样方(图 2),产流量是草地生境的 2.26 倍。

表 2 不同样方水文参数

Table 2 Mean values ($\pm$ S. D.) of selected hydrological parameters for different types of plots

	裸地样方 Bare soil treatment (BT)	灌丛样方 Shrub treatment (ST)	草地样方 Grassland treatment (GT)
初始土壤含水量 Initial soil water content/%	2.94 (0.18) a	2.82 (0.37) a	2.97 (0.31) a
表面积水时间 Time to ponding (TP)/min	3.32 (0.72) a	6.12 (0.61) b	6.60 (0.48) b
径流开始时间 Time to runoff (TR)/min	4.58 (1.88) a	20.14 (0.64) b	22.92 (1.96) b
径流开始需要的降雨量 Rainfall for runoff commencement (V)/mm	6.11 (2.51) a	26.86 (3.04) b	30.03 (3.74) b

小写字母表示不同处理之间的比较,不同字母表示显著差异

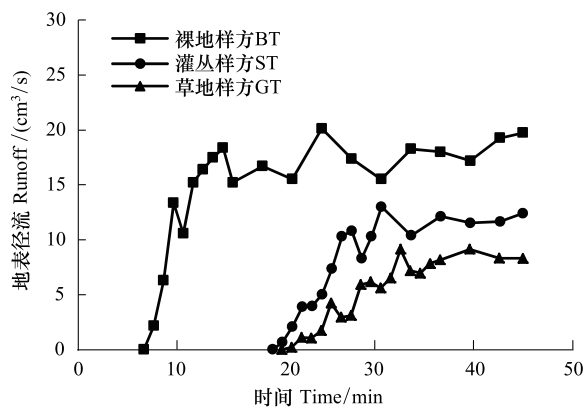


图 1 单位时间径流量随时间变化

Fig. 1 Change of runoff discharge with time

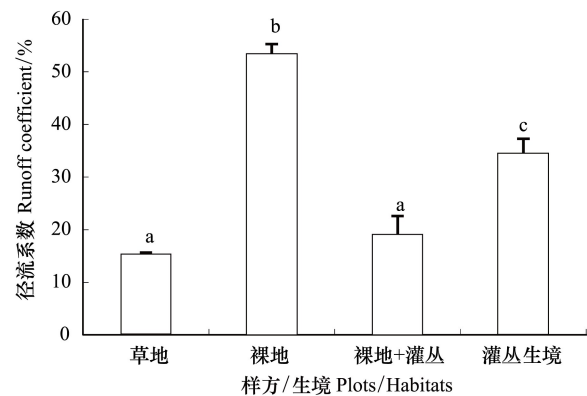


图 2 不同样方径流系数

Fig. 2 Runoff coefficients of different type of plots

2.3 不同样方/生境氮流失

在降雨开始时,草地生境样方和含灌丛斑块样方单位体积径流含氮量瞬时值出现短时间的增大,但随后即随时间迅速减小,在降雨开始约 40 min 后逐渐稳定,最大值约为稳定阶段平均值的 2.5 倍;草地生境样方在模拟实验过程中表现出明显的波动。裸地样方在降雨开始时单位体积径流含氮量瞬时值最大,随后即随时间逐渐减小,在降雨开始约 27 min 后逐渐稳定,其最大值约为稳定阶段平均值的 3 倍多(图 3)。在整个模拟降雨过程中,草地生境样方单位体积径流含氮量最大,含灌丛斑块样方较小,而裸地斑块样方显著小于其他两类样方。

裸地样方单位时间氮流失量在降雨开始约 15 min 后达到最大值,但在随后的实验过程中随时间变化呈减小趋势。其他两类样方则在约 20 min 后达到最大值,且保持最大值至实验结束(图 4)。在整个模拟降雨过程中,草地生境样方单位时间氮流失量与含灌丛斑块样方相近,而显著小于裸地斑块样方,说明草地生境与灌丛斑块能明显减少养分流失。

裸地样方和含灌丛斑块样方单位体积径流含氮量瞬时值与单位时间径流量呈显著的线性负相关关系(图 5, $P < 0.001$),表明随着单位时间径流量增大其单位体积径流含氮量显著减小,这主要因为草地被灌丛替代后出现大面积裸露地面,从而导致土壤养分含量显著下降。草地生境样方中两者也成线性负相关,但相关性不显著($P = 0.003$)。

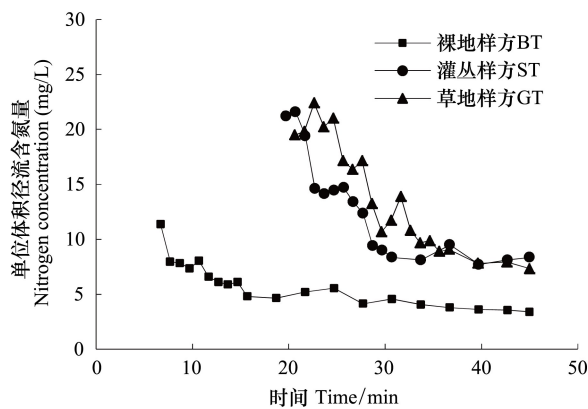


图3 单位体积径流含氮量随时间变化

Fig. 3 Change of nitrogen concentration with time

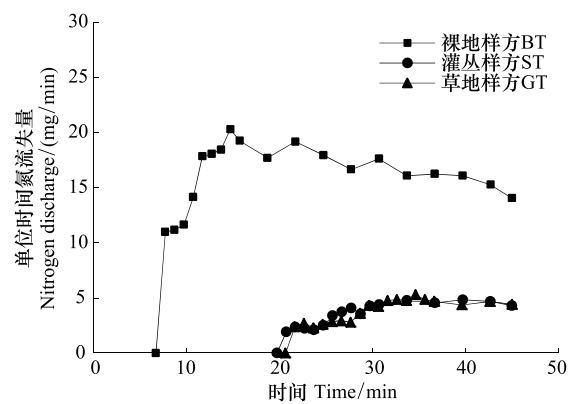


图4 单位时间氮流失量随时间变化

Fig. 4 Change of nitrogen discharge with time

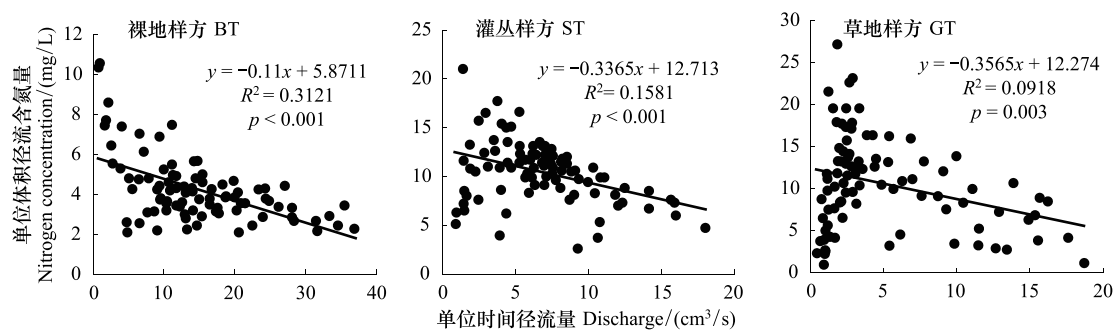


图5 单位体积径流含氮量与单位时间径流量之间的关系

Fig. 5 Relationship between the nitrogen concentration and the runoff discharge

草地样方、裸地样方和含灌丛样方氮流失总量分别为 0.11、0.29、0.09 g/m², 根据含灌丛样方中灌丛斑块与裸地斑块的比例及灌丛生境两者的实际比例进行加权计算, 可得灌丛生境氮流失总量为 0.23 g/m², 灌丛生境氮流失量显著大于草地和含灌丛样方 (图 6, $P < 0.05$), 小于裸地样方, 但差异不显著 ($P > 0.05$), 灌丛生境氮流失总量为沙质草地生境的 2.09 倍。草地样方、裸地样方和含灌丛斑块样方单位体积径流含氮量总体平均值 (样方氮流失总量除以样方径流量) 分别为 0.012、0.009、0.007 g/L。根据同样加权计算, 可得灌丛生境单位体积径流含氮量为 0.011 g/L, 小于草地生境, 差异不显著 ($P > 0.05$), 显著大于裸地和含灌丛斑块样方 (图 7, $P < 0.05$)。

3 讨论

3.1 沙质草地灌丛化对地表产流的影响

在腾格里沙漠东南缘, 沙质草地生境通常盖度较高且更趋于均匀分布, 在以珍珠猪毛菜 (*S. passerina*) 为优势的灌丛生境中, 植被盖度显著下降, 且呈现明显的异质性特征或空间斑块化分布, 即表现为灌丛斑块与生物土壤结皮覆盖的裸地斑块镶嵌分布的格局特征^[14], 这种特征与 Schlesinger 等^[7]提出的关于 Chihuahuan 沙漠中荒漠化导致植被空间异质性增加的假设一致。许多研究者认为, 干旱区草地覆盖的下降及旱生灌木的入侵将导致土壤入渗率下降和生态系统径流的增加^[15,17]。在模拟降雨试验中, 沙质草地样方出现表面积水和地表径流的时间及产流所需降雨量大于含灌丛斑块样方, 差异不显著, 两类样方 3 个参数均显著大于裸地样方 (表 2)。由于含灌丛斑块样方中灌丛斑块盖度为 20%, 而灌丛生境中灌丛斑块的盖度为 11%, 因此, 灌丛生境实际出现表面积水和地表径流的时间和产流所需降雨量应更小于草地生境, 表明沙质草地灌丛化引起了土壤水分入渗率的减小。草地样方产流量与含灌丛斑块样方相近, 显著小于裸地样方和经加权计算的灌

从生境产流量(图2),证明了以灌丛入侵为主要特征的植被变化引起的水文过程变化。已有的许多研究报道了相似的研究结果^[17,20-24]。与草原原生植被相比,灌丛入侵导致大面积贫瘠的裸露地表出现,使许多生物过程显著减少甚至丧失,植物根系生长、动物掘穴等生物过程形成的许多大孔隙急剧减少或消失,不利于水分传输^[18],植被的这种变化必然会引起土壤水分入渗的下降和地表径流的增加^[17]。另一方面,灌丛间裸地表面覆盖着发育良好的生物土壤结皮,其中的蓝藻分泌的多糖对土壤颗粒的黏合作用使土壤表面结构紧实,同时结皮表面的大气降尘及有机物在遇到降水后膨胀,堵塞土壤孔隙,使裸地斑块土壤导水率显著减小^[25],减少土壤水分入渗,进而促进地表径流的发生^[14,26]。

3.2 草地灌丛化对养分流失的影响

图6表明裸地斑块样方和经加权计算的灌丛生境氮总流失量均显著大于草地生境,这一结果与Schlesinger等在Chihuahuan沙漠的研究结果相反。他们采用强度为140 mm/h人工模拟降雨实验研究了灌丛和沙质草地两种生境的产流及N、P养分流失过程,发现草地养分总流失量明显大于灌丛生境,并将其归因于草地灌丛化导致的土壤养分含量下降^[21,27]。由图3可知,在整个模拟降雨过程中,裸地样方和灌丛样方单位体积径流含氮量瞬时值均小于草地样方,且裸地样方、含灌丛样方和经加权计算的灌丛生境单位体积径流含氮量总体平均值均小于草地样方(图7),而草地样方径流系数均小于裸地样方和含灌丛斑块样方,也显著小于灌丛生境(图2),表明裸地样方及灌丛生境中较大的氮流失量是由于其地表产流量大引起的。另一方面,在腾格里沙漠东南缘,灌丛生境中的裸地斑块表面覆盖着发育良好的生物土壤结皮,其中的苔藓、地衣和藻类等隐花植物对氮的固定是干旱区关键的氮源,也是裸地斑块氮素的重要贡献者^[28]。这一结果同时也证明经过了由人为活动等因素引起的长期退化过程,草地生境中土壤养分含量出现了明显的下降^[3,14,22]。

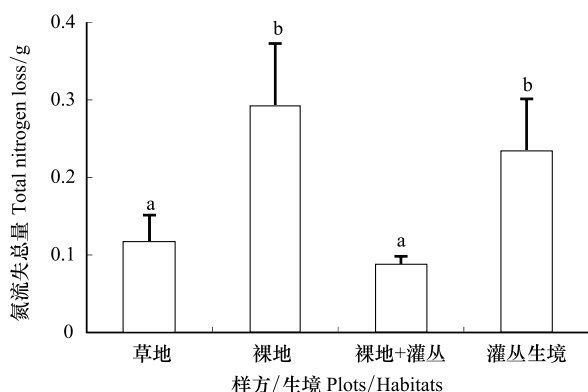


图6 不同样方/生境氮流失总量

Fig. 6 Average total nitrogen loss from different plots/habitats

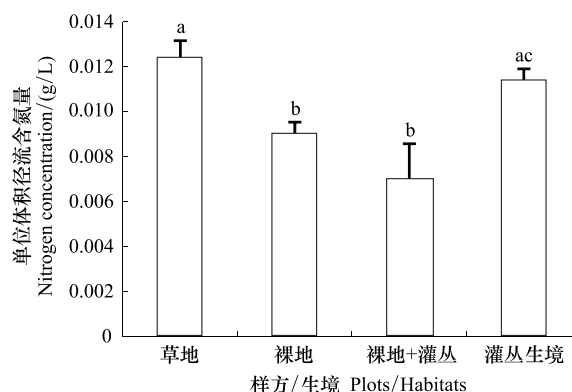


图7 不同样方/生境单位体积径流含氮量

Fig. 7 Nitrogen concentration for different plots/habitats

由表2可知,草地样方出现表面积水和地表径流的时间及出现径流所需要的降雨量略大于含灌丛斑块样方,显著大于裸地样方;经过加权计算的灌丛生境产流量、N流失量均大于草地生境(图2,图6)。坡度是影响地表产流过程的重要影响因素之一,通常情况下,地表产流产沙量随坡度的增大而增大。在本研究中,草地和灌丛生境的坡度分别13°和10°,草地生境坡度大于灌丛生境,这就缩小了两类生境在水文参数、产流过程及养分流失等指标上原本就存在的差异,如果在两者坡度相同,这种差异可能更大^[21]。

与草地生境相比,由于植被覆盖的下降甚至丧失导致灌丛生境在特定降水事件中产生大量的地表径流,携带疏松土壤物质、有机质、氮等资源流出系统外,使大量养分流失。如果这一过程继续发生,水、养分等资源就不能被有效地捕获并储存在系统内,整个景观必然会退化成非储存型系统,造成系统功能失调^[18],并进一步导致荒漠化的发展^[29]。

4 结论

腾格里沙漠东南缘以木本植物入侵为显著特征的沙质草地退化普遍发生,通过人工模拟降雨实验观测了

地表产流及养分流失过程对沙质草地灌丛化的响应,结果表明:

(1) 沙质草地生境出现表面积水和地表径流的时间及开始产流需要的降雨量均大于灌丛生境,其产流量显著小于灌丛生境,预示着草地灌丛化引起了以这些指标为指征的土壤水分入渗率的显著下降。

(2) 灌丛生境单位体积径流含氮量瞬时值和总体平均值均小于草地生境,氮流失量则显著大于草地生境,表明草地灌丛化引起了土壤养分的下降和受地表径流驱动的营养流失的增加。沙质草地退化引起的资源流失的增加必然可能导致生态系统功能失调和荒漠化的进一步发展。

References:

- [1] Li X R. Influence of variation of soil spatial heterogeneity on vegetation restoration. *Science in China Series D: Earth Sciences*, 2005, 48(11): 2020-2031.
- [2] Biedenbender S H, McClaran M P, Quade J, Weltz M A. Landscape patterns of vegetation change indicated by soil carbon isotope composition. *Geoderma*, 2004, 119(1/2): 69-83.
- [3] Li X R, Jia X H. Association between vegetation patterns and soil properties on the southeastern edge of the Tengger Desert. *Acta Agrestia Sinica*, 2005, 13(Suppl): 37-43.
- [4] Xiong X G, Han X G. Spatial heterogeneity in soil carbon and nitrogen resource, caused by *Caragana microphylla*, in the thickening of semiarid grassland, Inner Mongolia. *Acta Ecologica Sinica*, 2005, 25(7): 1678-1683.
- [5] Xiong X G, Han X G. Resource islands and its roles in the thickening of grasslands and thickening-grasslands. *Acta Prataculturae Sinica*, 2006, 15(1): 9-14.
- [6] Tongway D J, Ludwig J A. Small-scale resource heterogeneity in semi-arid landscapes. *Pacific Conservation Biology*, 1994, 1(3): 201-208.
- [7] Schlesinger W H, Reynolds J F, Cunningham G L, Huenneke L F, Jarrell W M, Virginia R A, Whiteford W G. Biological feedbacks in global desertification. *Science*, 1990, 247(4946): 1043-1048.
- [8] Cheng X L, An S Q, Qin P, Liu S R. The heterogeneity in spatial distribution of the above-ground biomass in the degraded grasslands in Ordos. *Acta Ecologica Sinica*, 2003, 23(8): 1526-1532.
- [9] Humphrey R R. The desert grassland: a history of vegetational change and an analysis of causes. *The Botanical Review*, 1958, 24: 193-252.
- [10] Archer S. Woody plant encroachment into southwestern grasslands and savannas: rates, patterns, and proximate causes // Vavra M, Laycock W, Pieper R, eds. *Ecological Implications of Livestock Herbivory in the West*. Denver (CO): Society for Range Management, 1994: 13-68.
- [11] Polley H W, Mayeux H S, Johnson H B, Tischler C R. Viewpoint: atmospheric CO₂, soil water, and shrub/grass ratios on rangelands. *Journal of Range Management*, 1997, 50(3): 278-284.
- [12] Hibbard K A, Archer S, Schimel D S, Valentine D W. Biogeochemical changes accompanying woody plant encroachment in a subtropical Savanna. *Ecology*, 2001, 82(7): 1999-2011.
- [13] Jin Z, Qi Y C, Dong Y S. Shrub encroachment and accompanied changes of biogeochemistry cycles in semiarid and arid grasslands. *Progress in Geography*, 2007, 26(4): 23-32.
- [14] Li X J, Li X R, Song W M, Gao Y P, Zheng J G, Jia R L. Effects of crust and shrub patches on runoff, sedimentation, and related nutrient (C, N) redistribution in the desertified steppe zone of the Tengger desert, Northern China. *Geomorphology*, 2008, 96(1/2): 221-232.
- [15] Cross A F, Schlesinger W H. Plant regulation of soil nutrient distribution in the northern Chihuahuan Desert. *Plant Ecology*, 1999, 145(1): 11-25.
- [16] Gutierrez J, Hernandez I I. Runoff and interrill erosion as affected by grass cover in a semi-arid rangeland of northern Mexico. *Journal of Arid Environments*, 1996, 34(3): 287-295.
- [17] Castillo V M, Martinez-Mena M, Albaladejo J. Runoff and soil loss response to vegetation removal in a semiarid environment. *Soil Science Society of America Journal*, 1997, 61(4): 1116-1121.
- [18] Ludwig J A, Wilcox B P, Breshears D D, Tongway D J, Imeson A C. Vegetation patches and runoff-erosion as interacting ecohydrological processes in semiarid landscapes. *Ecology*, 2005, 86(2): 289-297.
- [19] Wilcox B P, Breshears D D, Allen C D. Ecohydrology of a resource-conserving semiarid woodland: effects of scale and disturbance. *Ecological Monographs*, 2003, 73(2): 223-239.
- [20] Abrahams A D, Parsons A J, Wainwright J. Effects of vegetation change on interrill runoff and erosion, Walnut Gulch, southern Arizona. *Geomorphology*, 1995, 13(1/4): 37-48.
- [21] Schlesinger W H, Abrahams A D, Parsons A J, Wainwright J. Nutrient losses in runoff from grassland and shrubland habitats in Southern New

- Mexico; I. rainfall simulation experiments. *Biogeochemistry*, 1999, 45(1): 21-34.
- [22] Shapotou Desert Research and Experiment Station. Study on Shifting Sand Control in Shapotou Region of Tengger Desert (1). Yinchuan: Ningxia People's Publishing House, 1980: 1-15.
- [23] Gimeno-García E, Andreu V, Rubio J L. Influence of vegetation recovery on water erosion at short and medium-term after experimental fires in a Mediterranean shrubland. *Catena*, 2007, 69(2): 150-160.
- [24] Wu Y S, Hasi E, Wugetemole, Wu X. Characteristics of surface runoff in a sandy area in southern Mu Us sandy land. *Chinese Science Bulletin*, 2011, 57: 270-275.
- [25] George D B, Roundy B A, St Clair L L, Johansen J R, Schaalje G B, Webb B L. The effects of microbiotic soil crusts on soil water loss. *Arid Land Research and Management*, 2003, 17(2): 113-125.
- [26] Barger N N, Herrick J E, van Zee J, Belnap J. Impacts of biological soil crust disturbance and composition on C and N loss from water erosion. *Biogeochemistry*, 2006, 77(2): 247-263.
- [27] Schlesinger W H, Raikes J A, Hartley A E, Cross A F. On the spatial pattern of soil nutrients in desert ecosystem. *Ecology*, 1996, 77(2): 364-374.
- [28] Su Y G, Zhao X, Li A X, Li X R, Huang G. Nitrogen fixation in biological soil crusts from the Tengger desert, northern China. *European Journal of Soil Biology*, 2011, 47(3): 182-187.
- [29] Avni Y, Porat N, Plakht J, Avni G. Geomorphic changes leading to natural desertification versus anthropogenic land conservation in an arid environment, the Negev Highlands, Israel. *Geomorphology*, 2006, 82(3/4): 177-200.

参考文献:

- [3] 李新荣, 贾晓红. 腾格里沙漠东南缘荒漠植被格局与土壤资源的关系. *草地学报*, 2005, 13(增刊): 37-43.
- [4] 熊小刚, 韩兴国. 内蒙古半干旱草原灌丛化过程中小叶锦鸡儿引起的土壤碳、氮资源空间异质性分布. *生态学报*, 2005, 25(7): 1678-1683.
- [5] 熊小刚, 韩兴国. 资源岛在草原灌丛化和灌丛化草原中的作用. *草业学报*, 2009, 15(1): 9-14.
- [8] 程晓莉, 安树青, 钦佩, 刘世荣. 鄂尔多斯草地退化过程中植被地上生物量空间分布的异质性. *生态学报*, 2003, 23(8): 1526-1532.
- [13] 金钊, 齐玉春, 董云社. 干旱半干旱地区草原灌丛荒漠化及其生物地球化学循环. *地理科学进展*, 2007, 26(4): 23-32.
- [24] 吴永胜, 哈斯, 乌格特莱勒. 毛乌素沙地南缘沙丘表面径流特征. *科学通报*, 2011, 56(34): 2917-2922.

ACTA ECOLOGICA SINICA Vol. 32, No. 24 December, 2012 (Semimonthly)

CONTENTS

A bibliometric study of biodiversity research in China	LIU Aiyuan, GUO Yuqing, LI Shiyong, et al (7635)
Effects of elevated CO ₂ and nitrogen deposition on leaf nutrient quality of <i>Fargesia rufa</i> Yi	 ZHOU Xianrong, WANG Jianhua, ZHANG Hong, et al (7644)
Airborne pollen assemblages and their relationships with climate factors in the central Shaanxi Province of the Loess Plateau: a case in Xiaheimugou, Luochuan County	LÜ Suqing, LI Yuecong, XU Qinghai, et al (7654)
Spatial and temporal change in ecological assets in the Yangtze River Delta of China 1995—2007	 XU Xibao, CHEN Shuang, YANG Guishan (7667)
Evaluation and optimization of woodland ecological patterns for Qingdao based on the agent-based model	 FU Qiang, MAO Feng, WANG Tianqing, et al (7676)
Interactive mechanism of service function of alpine rangeland ecosystems in Qinghai-Tibetan Plateau	 LIU Xingyuan, LONG Ruijun, SHANG Zhanhuan (7688)
Preliminary evaluation of air temperature reduction of urban green spaces in Beijing	 ZHANG Biao, GAO Jixi, XIE Gaodi, et al (7698)
Resources metabolism analysis for the pulp and paper industry in Wuhan, China	 SHI Xiaoqing, LI Xiaonuo, ZHAO Linjia, et al (7706)
The characteristics and influential factors of direct carbon emissions from residential energy consumption: a case study of Lijiang City, China	WANG Danyin, TANG Mingfang, REN Yin, et al (7716)
Spatial targeting of payments for ecosystem services Based on SWAT Model and cost-benefit analysis	 SONG Xiaoyu, LIU Yuqing, DENG Xiaohong, et al (7722)
The wind tunnel test of plastic greenhouse and its surface wind pressure patterns	 YANG Zaiqiang, ZHANG Bo, XUE Xiaoping, et al (7730)
Population quantitative characteristics and dynamics of rare and endangered plant <i>Davidia involucrata</i> in Hunan Province	 LIU Haiyang, JIN Xiaoling, SHEN Shouyun, et al (7738)
Phenotypic diversity in populations of germplasm resources of <i>Rodgersia sambucifolia</i> and related species	 LI Pingping, MENG Hengling, CHEN Junwen, et al (7747)
Effects of sand burial and seed size on seed germination, seedling emergence and growth of <i>Caragana korshinskii</i> Kom. (Fabaceae) ...	 YANG Huiling, LIANG Zhenlei, ZHU Xuanwei, et al (7757)
Population-keeping mechanism of the parasitoid <i>Dastarcus helophoroides</i> (Coleoptera: Bothrideridae) of <i>Massicus raddei</i> (Coleoptera: Cerambycidae) in oak forest	YANG Zhongqi, TANG Yanlong, JIANG Jing, et al (7764)
Study of mingling based on neighborhood spatial permutation	LOU Minghua, TANG Mengping, QIU Jianxi, et al (7774)
Comparison of three regression analysis methods for application to LAI inversion using Hyperion data	 SUN Hua, JU Hongbo, ZHANG Huaiqing, et al (7781)
Response of seed germination and seedling growth of <i>Pinus koraiensis</i> and <i>Quercus mongolica</i> to comprehensive action of warming and precipitation	ZHAO Juan, SONG Yuan, SUN Tao, et al (7791)
Impacts of water stored in sapwood <i>Populus bolleana</i> on its sap flux	DANG Hongzhong, LI Wei, ZHANG Youyan, et al (7801)
Dynamics of greenhouse gases emission and its impact factors by fire disturbance from <i>Alnus sibirica</i> forested wetland in Xiaoxing'an Mountains, Northeast China	GU Han, MU Changcheng, ZHANG Bowen (7808)
Different tide status and salinity alter stoichiometry characteristics of mangrove <i>Kandelia candel</i> seedlings	 LIU Biner, LIAO Baowen, FANG Zhanqiang (7818)
Effects of shrub encroachment in desert grassland on runoff and the induced nitrogen loss in southeast fringe of Tengger Desert	 LI Xiaojun, GAO Yongping (7828)
Community structure and throughfall erosivity characters of artificial rainforest in Xishuangbanna	 DENG Yun, [TANG Yanlin], CAO Min, et al (7836)
Temporal-spatial variations of net ecosystem productivity in alpine area of southwestern China	 PANG Rui, GU Fengxue, ZHANG Yuandong, et al (7844)

Relationships between chemical compositions of <i>Quercus</i> species seeds and climatic factors in temperate zone of NSTEC	LI Dongsheng, SHI Zuomin, LIU Shirong, et al (7857)
Effects of simulated acid rain stress on the PS II reaction center and free radical metabolism in leaves of longan	LI Yongyu, PAN Tengfei, YU Dong, et al (7866)
Assessment of organic pollution for surface soil in Shenyang suburbs	CUI Jian, DU Jizhong, MA Hongwei, et al (7874)
The impact of rainfall on soil respiration in a rain-fed maize cropland	GAO Xiang, HAO Weiping, GU Fengxue, et al (7883)
Effects of winter crops on enzyme activity and morphological characteristics of root in subsequent rice crops	YU Tianyi, PANG Huancheng, REN Tianzhi, et al (7894)
Dynamic changes of soil moisture and nitrate nitrogen in wheat and maize intercropping field under different nitrogen supply	YANG Ruiju, CHAI Shouxi, MA Zhongming (7905)
Characteristics of the bird diversity and the impact factors in Weishan Lake	YANG Yuewei, LI Jiuen (7913)
The effect of cropping landscapes on the population dynamics of the cotton bollworm <i>Helicoverpa armigera</i> (Lepidoptera, Noctuidae) in the northern Xinjiang	LU Zhaozhi, PAN Weilin, ZHANG Xin, et al (7925)
The seasonal variations of nitrogen and phosphorus release and its fluxes from the sediments of the Beili Lake in the Hangzhou West Lake	LIU Jingjing, DONG Chunying, SONG Yingqi, et al (7932)
Optimization of lake model salmo based on real-coded genetic algorithm	GUO Jing, CHEN Qiuwen, ZHANG Xiaoqing, et al (7940)
The influence of climatic environmental factors and fishing pressure on changes of hairtail catches in the northern South China Sea	WANG Yuezhong, SUN Dianrong, CHEN Zuozhi, et al (7948)
Seasonal and spatial distribution of acid volatile sulfide in sediment under different mariculture types in Nansha Bay, China	YAN Tingru, JIAO Haifeng, MAO Yuze, et al (7958)
Review and Monograph	
Research progress on the mechanism of improving plant cold hardiness	XU Chengxiang (7966)
Influences of vegetation on permafrost: a review	CHANG Xiaoli, JIN Huijun, WANG Yongping, et al (7981)
Home-field advantage of litter decomposition and its soil biological driving mechanism: a review	ZHA Tonggang, ZHANG Zhiqiang, SUN Ge, et al (7991)
Research progress on the relationship of pollutants between road-deposited sediments and its washoff	ZHAO Hongtao, LI Xuyong, YIN Chengqing (8001)

《生态学报》2013 年征订启事

《生态学报》是中国生态学学会主办的生态学专业性高级学术期刊,创刊于 1981 年。主要报道生态学研究原始创新性科研成果,特别欢迎能反映现代生态学发展方向的优秀综述性文章;研究简报;生态学新理论、新方法、新技术介绍;新书评介和学术、科研动态及开放实验室介绍等。

《生态学报》为半月刊,大 16 开本,300 页,国内定价 90 元/册,全年定价 2160 元。

国内邮发代号:82-7,国外邮发代号:M670

标准刊号:ISSN 1000-0933 CN 11-2031/Q

全国各地邮局均可订阅,也可直接与编辑部联系购买。欢迎广大科技工作者、科研单位、高等院校、图书馆等订阅。

通讯地址:100085 北京海淀区双清路 18 号 电 话:(010)62941099; 62843362

E-mail: shengtaixuebao@rcees.ac.cn 网 址: www.ecologica.cn

编辑部主任 孔红梅

执行编辑 刘天星 段 靖

生 态 学 报

(SHENGTAI XUEBAO)

(半月刊 1981 年 3 月创刊)

第 32 卷 第 24 期 (2012 年 12 月)

ACTA ECOLOGICA SINICA

(Semimonthly, Started in 1981)

Vol. 32 No. 24 (December, 2012)

编 辑	《生态学报》编辑部 地址:北京海淀区双清路 18 号 邮政编码:100085 电话:(010)62941099 www.ecologica.cn shengtaixuebao@rcees.ac.cn	Edited by	Editorial board of ACTA ECOLOGICA SINICA Add:18, Shuangqing Street, Haidian, Beijing 100085, China Tel:(010)62941099 www.ecologica.cn Shengtaixuebao@rcees.ac.cn
主 编	冯宗炜	Editor-in-chief	FENG Zong-Wei
主 管	中国科学技术协会	Supervised by	China Association for Science and Technology
主 办	中国生态学学会 中国科学院生态环境研究中心 地址:北京海淀区双清路 18 号 邮政编码:100085	Sponsored by	Ecological Society of China Research Center for Eco-environmental Sciences, CAS Add:18, Shuangqing Street, Haidian, Beijing 100085, China
出 版	科 学 出 版 社 地址:北京东黄城根北街 16 号 邮政编码:100717	Published by	Science Press Add:16 Donghuangchenggen North Street, Beijing 100717, China
印 刷	北京北林印刷厂	Printed by	Beijing Bei Lin Printing House, Beijing 100083, China
发 行	科 学 出 版 社 地址:东黄城根北街 16 号 邮政编码:100717 电话:(010)64034563 E-mail:journal@cspg.net	Distributed by	Science Press Add:16 Donghuangchenggen North Street, Beijing 100717, China Tel:(010)64034563 E-mail:journal@cspg.net
订 购	全国各地邮局	Domestic	All Local Post Offices in China
国外发行	中国国际图书贸易总公司 地址:北京 399 信箱 邮政编码:100044	Foreign	China International Book Trading Corporation Add:P. O. Box 399 Beijing 100044, China
广告经营 许 可 证	京海工商广字第 8013 号		



ISSN 1000-0933
CN 11-2031/Q

国内外公开发行

国内邮发代号 82-7

国外发行代号 M670

定价 70.00 元