

ISSN 1000-0933
CN 11-2031/Q

生态学报

Acta Ecologica Sinica



第 32 卷 第 14 期 Vol.32 No.14 **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 14 期

2012 年 7 月 (半月刊)

目 次

海滨沙地砂引草对沙埋的生长和生理适应对策.....	王 进,周瑞莲,赵哈林,等 (4291)
外源 K ⁺ 和水杨酸在缓解融雪剂对油松幼苗生长抑制中的效应与机理 ...	张 莹,李法云,严 霞,等 (4300)
钱塘江中游流域不同空间尺度环境因子对底栖动物群落的影响.....	张 勇,刘朔孺,于海燕,等 (4309)
贡嘎山东坡非飞行小型兽类物种多样性的垂直分布格局.....	吴永杰,杨奇森,夏 霖,等 (4318)
基于斑块的红树林空间演变机理分析方法.....	李春干,刘素青,范航清,等 (4329)
亚热带六种天然林树种细根养分异质性.....	熊德成,黄锦学,杨智杰,等 (4343)
浙江省植被 NDVI 动态及其对气候的响应	何 月,樊高峰,张小伟,等 (4352)
亚热带 6 种天然林树种细根呼吸异质性.....	郑金兴,熊德成,黄锦学,等 (4363)
亚高山/高山森林土壤有机层氨氧化细菌和氨氧化古菌丰度特征	王 奥,吴福忠,何振华,等 (4371)
耕作方式对紫色水稻土轻组有机碳的影响.....	张军科,江长胜,郝庆菊,等 (4379)
火烧对长期封育草地土壤碳固持效应的影响.....	何念鹏,韩兴国,于贵瑞,等 (4388)
闽江河口潮汐湿地二氧化碳和甲烷排放化学计量比.....	王维奇,曾从盛,仝 川,等 (4396)
2010 年夏季珠江口海域颗粒有机碳的分布特征及其来源	刘庆霞,黄小平,张 霞,等 (4403)
新疆冷泉沉积物葡萄糖利用细菌群落多样性的稳定同位素标记分析.....	楚 敏,王 芸,曾 军,等 (4413)
土壤微生物群落多样性解析法:从培养到非培养.....	刘国华,叶正芳,吴为中 (4421)
伊洛河河岸带生态系统草本植物功能群划分	郭屹立,卢训令,丁圣彦 (4434)
濒危植物蒙古扁桃不同地理种群遗传多样性的 ISSR 分析	张 杰,王 佳,李浩宇,等 (4443)
强潮区较高纬度移植红树植物秋茄的生理生态特性.....	郑春芳,仇建标,刘伟成,等 (4453)
冬季高温对白三叶越冬和适应春季“倒春寒”的影响	周瑞莲,赵 梅,王 进,等 (4462)
中亚热带细柄阿丁枫和米槠群落细根的生产和死亡动态.....	黄锦学,凌 华,杨智杰,等 (4472)
欧美杨水分利用效率相关基因 <i>PdEPF1</i> 的克隆及表达	郭 鹏,金 华,尹伟伦,等 (4481)
再力花地下部水浸提液对几种水生植物幼苗的化感作用.....	缪丽华,王 媛,高 岩,等 (4488)
无致病力青枯雷尔氏菌对烟草根系土壤微生物脂肪酸生态学特性的影响.....	郑雪芳,刘 波,蓝江林,等 (4496)
基于更新和同化策略相结合的遥感信息与水稻生长模型耦合技术的研究.....	王 航,朱 艳,马孟莉,等 (4505)
温度和体重对克氏双锯鱼仔鱼代谢率的影响.....	叶 乐,杨圣云,刘 敏,等 (4516)
夏季西南印度洋叶绿素 a 分布特征.....	洪丽莎,王春生,周亚东,等 (4525)
大沽排污河生态修复河道水质综合评价及生物毒性影响.....	王 敏,唐景春,朱文英,等 (4535)
李肖叶甲成虫数量及三维空间格局动态.....	汪文俊,林雪飞,邹运鼎,等 (4544)
专论与综述	
基于景观格局的城市热岛研究进展	陈爱莲,孙然好,陈利顶 (4553)
沉积物质量评价“三元法”及其在近海中的应用	吴 斌,宋金明,李学刚,等 (4566)
问题讨论	
中国餐厨垃圾处理的现状、问题和对策	胡新军,张 敏,余俊锋,等 (4575)
研究简报	
稻秸蓝藻混合厌氧发酵沼液及其化学物质对尖孢镰刀菌西瓜专化型生长的影响.....	刘爱民,徐双锁,蔡 欣,等 (4585)
佛山市农田生态系统的生态损益.....	叶延琼,章家恩,秦 钟,等 (4593)

期刊基本参数:CN 11-2031/Q * 1981 * m * 16 * 314 * zh * P * ¥70.00 * 1510 * 33 * 2012-07



封面图说: 噶龙山南坡的高山湖泊——喜马拉雅山南坡的噶龙山光照强烈、雨量充沛,尽管是海拔 4500 多米的高寒地区,山上的草甸依然泛着诱人的翠绿色,冰川和雪山的融水汇集在山梁的低洼处形成了一个又一个的高山湖泊,由于基底的差别和水深的不同,使得纯净清澈的冰雪融水在湖里呈现出不同的颜色,湖面或兰或绿,颜色或深或浅,犹如一块块通透透明的翡翠镶嵌在绿色的绒布之中。兰天下面,白云落在山间,通往墨脱的公路像丝带一样随随便便地缠绕着,一幅美丽的自然生态画卷就这样呈现在你的面前。

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

DOI: 10.5846/stxb201107061010

王奥, 吴福忠, 何振华, 徐振锋, 刘洋, 谭波, 杨万勤. 亚高山/高山森林土壤有机层氨氧化细菌和氨氧化古菌丰度特征. 生态学报, 2012, 32(14): 4371-4378.

Wang A, Wu F Z, He Z H, Xu Z F, Liu Y, Tan B, Yang W Q. Characteristics of ammonia-oxidizing bacteria and ammonia-oxidizing archaea abundance in soil organic layer under the subalpine/alpine forest. Acta Ecologica Sinica, 2012, 32(14): 4371-4378.

亚高山/高山森林土壤有机层氨氧化细菌 和氨氧化古菌丰度特征

王 奥¹, 吴福忠¹, 何振华², 徐振锋¹, 刘 洋¹, 谭 波¹, 杨万勤^{1,*}

(1. 四川农业大学生态林业研究所, 林业生态工程重点实验室, 成都 611130;

2. 四川省阿坝藏族羌族自治州川西林业局, 理县 623102)

摘要: 为了解季节性冻融对川西亚高山/高山地区土壤氨氧化微生物群落的影响, 采用 qPCR 技术, 以氨单加氧酶基因的 α 亚基 (*amoA*) 为标记, 在生长阶段、冻结阶段、融化阶段中的 9 个关键时期调查了该地区不同森林群落: 岷江冷杉 (*Abies faxoniana*) 原始林 (PF)、岷江冷杉 (*A. faxoniana*) 和红桦 (*Betula albosinensis*) 混交林 (MF)、岷江冷杉次生林 (SF) 土壤有机层的氨氧化细菌 (ammonia-oxidizing bacteria, AOB) 和氨氧化古菌 (ammonia-oxidizing archaea, AOA) 丰度的特征。结果表明, 3 个森林群落土壤有机层中都具有相当数量的氨氧化细菌和古菌, 均表现出从生长阶段至冻结阶段显著降低, 在冻结阶段最低, 但冻结阶段后显著增加, 在融化阶段为全年最高的趋势。土壤氨氧化微生物类群结构 (AOA/AOB) 受负积温影响明显。冻结后期 3 个森林群落土壤负积温最大时, AOA 数量明显高于 AOB, 但其他关键时期土壤氨氧化微生物类群结构与群落类型密切相关。高海拔的岷江冷杉林群落土壤有机层表现为 AOA>AOB (冻结初期除外), 低海拔的岷江冷杉次生林群落中表现为 AOB>AOA (冻结后期除外), 而岷江冷杉和红桦混交林群落则仅在融冻期和生长季节末期表现为 AOB>AOA。这些结果为认识亚高山/高山森林及其相似区域的生态过程提供了一定的科学依据。

关键词: 亚高山/高山森林; 土壤有机层; 氨氧化细菌; 氨氧化古菌; 积温

Characteristics of ammonia-oxidizing bacteria and ammonia-oxidizing archaea abundance in soil organic layer under the subalpine/alpine forest

WANG Ao¹, WU Fuzhong¹, HE Zhenhua², XU Zhenfeng¹, LIU Yang¹, TAN Bo¹, YANG Wanqin^{1,*}

¹ Key Laboratory of Ecological Forestry Engineering, Institute of Ecological Forestry, Sichuan Agricultural University, Cheng'du 611130, China

² Forestry Bureau of Western Sichuan, A'ba 623102, China

Abstract: Soil ammonia oxidizers play essential roles in nitrogen cycling in many forest ecosystems. Since the compositions and functions of soil ammonia oxidizer could be suffered from obviously seasonal snow cover and freeze-thaw cycles in high latitude/altitude region, there might be significant differences of soil ammonia oxidizer in different periods caused by seasonal freeze-thaw cycles. However, little attention has been paid to the variations of soil ammonia oxidizer in different key periods in subalpine/alpine regions. To determine the abundance and distribution of bacterial and archaeal ammonia oxidizers in subalpine and alpine forest, three representative forests (primitive *Abies faxoniana* forest, PF; mixed *A. faxoniana* and *Betula albosinensis* forest, MF, and secondary *A. faxoniana* forest, SF) were selected in the alpine/subalpine region of Western China. Soils were sampled in soil organic layer (OL) due to the sensitive responses to seasonal

基金项目: 国家自然科学基金项目 (31170423, 31000213); 教育部新世纪优秀人才支持计划项目 (NCET-07-0592); 教育部博士点基金项目 (20105103110002); 国家“十二五”科技支撑计划 (2011BAC09B05); 四川省青年基金项目 (2012JQ0008)

收稿日期: 2011-07-06; **修订日期:** 2011-11-28

* 通讯作者 Corresponding author. E-mail: scyangwq@163.com

climate changes. Richness of ammonia oxidizers (ammonia-oxidizing bacteria, AOB; and ammonia-oxidizing archaea, AOA) in soil organic layer were characterized by a real-time quantitative PCR method from targeting on *amoA* genes, which putatively encode ammonia monooxygenase subunit A. Based on previous investigations, we focused on nine key stages go through three periods as soil temperature varied (1) Growing period: including early growing stage, growing stage, and later growing stage. (2) Freeze period: including early freezing stage, freezing stage, and later frozen stage. (3) Thawing period: including early thawing stage, thawing stage and later thawing stage. Amounts of bacterial and archaeal *amoA* gene were detected in soil organic layer under three subalpine and alpine forests. The abundance of both bacterial and archaeal *amoA* showed similar tendency in different key stages, which significantly decreased from growing period to freeze period and then significantly increased, suggesting the strongly effects of temperature fluctuation such as seasonal freeze-thaw cycles. The abundance of bacterial and archaeal *amoA* gene were the lowest at freeze period, whereas the highest abundance of ammonia-oxidizer was observed at thawing period. Furthermore, the ratio of archaea to bacterial *amoA* abundance was significantly affected by negative accumulated temperature in all key periods except for later freeze period. Compared with bacterial *amoA*, higher abundance of archaeal *amoA* was observed at later freeze stage when soil organic layer was deeply frozen with the highest negative accumulated temperature, although the ratios were varied in different forests at other stages. Except for the early freeze stage, higher abundance of Archaeal *amoA* was observed compared with bacterial *amoA* in high altitude forests (PF) due to high negative accumulated temperature. In contrast, the abundance of bacterial *amoA* was higher than that of archaeal *amoA* in low altitude forests (SF) except for later freeze stage. The results indicated AOA might have better adaptations in cold environment condition in comparison with AOB, which provide direct evidence for understanding the ecological importance of bacterial and archaeal ammonia-oxidizer in the subalpine and alpine fir forests.

Key Words: subalpine/alpine forest; soil organic layer; ammonia-oxidizing bacteria; ammonia-oxidizing archaea; accumulated temperature

以微生物为媒介的氨氧化作用是硝化作用的初始步骤,也是生态系统氮循环中的中心环节和限速步骤^[1],并与全球变化背景下温室气体(如 N_2O)的排放有关^[2]。除已知的氨氧化细菌^[3],近年来的研究表明广泛分布在海洋、湖泊和土壤等多种生态系统中的古菌也参与了氨氧化过程^[3-5]。过去认为,冻结会导致土壤微生物活动停滞甚至大量死亡^[6-8],已有研究更加关注生长季节土壤微生物的动态特征。近年来的研究证明土壤冻结后仍存在相当数量的微生物类群^[9-10],并表现出一定的生理活性^[11-14],且受到微生物类型以及温度驱动的冻融特征的深刻影响^[13,15-16]。由温度变化所引起的土壤季节性冻结和融化是亚高山/高山地区变化最显著的环境因子之一^[17-18],可能改变氨氧化微生物群落特征,进而影响氨氧化作用甚至 N 循环过程。因此,研究氨氧化微生物对温度驱动的季节性冻融的响应,有助于深入认识受季节性冻融影响明显的高寒地区土壤生态过程。

川西亚高山/高山森林是我国西部林区的主体,在水源涵养、水土保持、生物多样性保育等方面具有十分重要的作用和地位^[19]。受低温和频繁地质灾害的影响,土层浅薄,普遍具有一层较厚的土壤有机层(Organic Layer, OL),其在生态系统的物质循环和能量转换中具有非常重要的作用^[20]。前期研究证实,亚高山/高山地区随温度变化表现出明显的季节性冻融特征,显著影响了微生物群落结构和多样性^[4,9-10,21],但极少研究关注到调控土壤 N 循环过程的氨氧化微生物特征。因此,以该区典型的岷江冷杉(*Abies faxoniana*)原始林、岷江冷杉和红桦(*Betula albosinensis*)混交林、岷江冷杉次生林为研究对象,采用实时定量 PCR 方法同步研究不同关键时期土壤有机层中氨氧化微生物 *amoA* 基因的丰度变化,探讨温度驱动的季节性冻融对土壤氨氧化微生物的影响,以期为深入了解亚高山/高山 N 循环过程提供科学依据。

1 材料与方法

1.1 研究区域与样地概况

研究区域位于四川省理县毕棚沟(E102°53'—102°57', N31°14'—31°19'),处于青藏高原东缘和长江上

游,土壤冻结时间长达5—6个月。主要植被类型为针阔混交林和针叶林。乔木层树种主要为岷江冷杉、川西云杉(*Picea likiangensis* var *balfouriana*)和红桦。林下灌木主要为箭竹(*Fargesia spathacea*)、高山杜鹃(*Rhododendron delavayi*)、三颗针(*Berberis julianae*)、红毛花楸(*Sorbus rufopilosa*)、沙棘(*Hippophae rhamnoides*)、扁刺蔷薇(*Rosa weginzowii*)等;草本主要有蟹甲草(*Cacalia* spp)、冷蕨(*Cystopteris montana*)、苔草属(*Carex* spp.)和莎草属(*Cyperus* spp.)等。

为避免其他环境因素的影响,基于前期调查和研究结果^[9-10,21],在研究区域中选取了环境条件基本一致的3个代表性森林群落:岷江冷杉原始林,岷江冷杉和红桦天然混交林,岷江冷杉次生林,作为定位研究样地。3个样地土壤有机层的基本理化性质如表1所示。

表1 不同海拔森林群落的土壤有机层理化性质
Table 1 Soil organic layer properties in the sampled forests at different altitudes

森林类型 Forest type	海拔高度 Altitude	有机层厚度 Thickness /cm	pH	有机碳 Organic carbon /(g/kg)	全氮 Nitrogen /(g/kg)	全磷 Phosphorus /(g/kg)	坡向 Aspect	坡度 Slope
岷江冷杉原始林 Primitive forest	3582 m	15±2	6.2±0.3	161.4±20.3	9.5±1.9	1.2±0.2	NE45°	34°
岷江冷杉和红桦天然混交林 Mixed forest	3298 m	12±2	6.6±0.2	174.0±55.8	9.5±2.1	1.5±0.1	NE42°	31°
岷江冷杉次生林 Secondary forest	3023 m	12±2	6.5±0.3	161.9±31.1	8.1±1.6	0.9±0.1	NE38°	24°

1.2 样品采集

在2009年8月20日至2010年5月22日期间,在生长阶段、冻结阶段和融化阶段划分9个关键时期^[22],分别于样地内随机选取5个5 m×5 m的均质样方采集土壤有机层样品(0—15 cm)^[20]。多点采集后分别混合样品,除去可见的石块、根系后,装入无菌样品袋低温保存,即时运回实验室立即分析。各研究阶段下,不同关键时期的具体采样时间如下:

生长阶段 生长季(Ⅰ 2009-08-20),生长季后期(Ⅱ 2009-10-20),生长季前期(Ⅲ 2010-05-22)。

冻结阶段 冻结前期(Ⅳ 2009-11-20),冻结期(Ⅴ 2009-12-10),冻结后期(Ⅵ 2010-01-22);

融化阶段 融化前期(Ⅶ 2010-03-05),融冻期(Ⅷ 2010-04-05),融冻后期(Ⅸ 2010-04-22)。

1.3 土壤有机层温度特征

2009年8月1日分别在各样地内5 cm处理设纽扣式温度计(iButton DS1923-F5, Maxim Com. USA),每2 h记录1次数据,3个样地在2009年8月1日至次年5月31日的温度变化特征如图1所示。

为表征不同关键时期温度整体动态,根据采样前12 d的温度数据^[23]计算了该时间段的正积温、负积温(表2)。正积温(Positive accumulated temperature, PAT)为各关键时期内高于0℃的逐日日平均气温的总和,负积温(Negative accumulated temperature, NAT)为各关键时期内低于0℃的逐日日平均气温的总和^[24]。

1.4 土壤总DNA提取

取0.5 g土壤样品,采用Griffiths的bead-beating提取方法^[25],在mini-beadbeater(Biospec, USA)振荡器上以最大速度振荡30 s,用50 μL Tris-EDTA缓冲液溶解

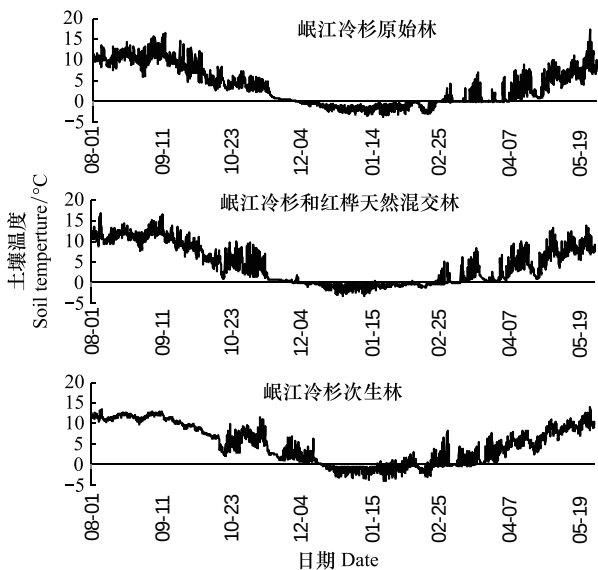


图1 3个典型川西高山/亚高山森林土壤有机层温度动态变化(2009-8-1—2010-5-31)

Fig. 1 Soil temperature dynamic in OL of three alpine/subalpine forests from Aug. 1 2009 to May. 31 2010 PF: Primitive forest; MF: Mixed forest; SF: Secondary forest

沉淀的 DNA 粗提物,并用 1% 的琼脂糖凝胶进行电泳检测。

表 2 3 个典型川西高山/亚高山森林土壤有机层正负积温特征/℃
Table 2 Soil temperature characteristic in OL of three typical alpine/subalpine forests

		I	II	III	IV	V	VI	VII	VIII	IX
正积温	岷江冷杉原始林 Primitive forest	135.61	62.66	32.54	0.74	0	1.79	5.89	42.72	87.16
Positive accumulated temperature	岷江冷杉和红桦天然混交林 Mixed forest	143.71	65.43	35.23	2.38	0	5.13	16.14	67.82	101.26
	岷江冷杉次生林 Secondary forest	148.89	82.55	67.22	30.36	0	7.96	28.59	76.16	114.64
负积温	岷江冷杉原始林 Primitive forest	0	0	0	3.22	21.96	2.57	0.26	0	0
Negative accumulated temperature	岷江冷杉和红桦天然混交林 Mixed forest	0	0	0	0.75	11.09	1.13	0	0	0
	岷江冷杉次生林 Secondary forest	0	0	0	0	15.84	1.92	0	0	0

I :生长季 Growing stage; II :生长季后期 Later growing stage; III :生长季前期 Early growing stage; IV :冻结前期 Early freezing stage; V :冻结期 Freezing stage; VI :冻结后期 later frozen stage; VII :融化前期 Early thawing stage; VIII :融化期 Thawing stage; IX :融化后期 Later thawing stage

1.5 amoA 基因丰度测定

氨氧化细菌(AOB)和氨氧化古菌(AOA)的引物对分别为 *amoA*-1F/*amoA*r-2R^[26] 和 Arch-*amoA*F/Arch-*amoA*R^[27]。经过琼脂糖凝胶电泳回收纯化后的总 DNA 作为模板,在 Bio-Rad CFX 96 thermocycler 中进行 qPCR 扩增。反应体系为:12.5 mL SYBR® Premix Ex Taq™ (TaKaRa),0.4 mg/mL BSA (TaKaRa),上下游引物各 400 nmol/L (AOB)/200 nmol/L (AOA),1 μL 未稀释的总 DNA 作为模板,以灭菌的去离子水补足 25 μL;每样品各 3 个重复。经优化的反应条件为:预变性 95 °C 30s,40 个循环的 95 °C 变性 10s,AOB 57 °C/AOA 63 °C 退火 25 s,72 °C 延伸 45 s,每循环结束后读取荧光值。反应结束进行 melting curve analysis (65—95 °C, 0.5 °C per read, 5s hold),并以 2% 的琼脂糖凝胶进行电泳检测。

qPCR 扩增产物经琼脂糖凝胶电泳回收后,与 pMD19-T 载体连接 (Takara) 并转入 *Escherichia coli* DH5α 感受态细胞。用 M13-47 和 RV-M 引物对 (Takara) 进行菌落 PCR 扩增后,选取阳性克隆并提取质粒供 qPCR 反应的标准曲线使用。质粒的浓度经 Biophotometer (Eppendorf) 检测,*amoA* 的基因拷贝数通过质粒的浓度进行计算^[28]。用 10 倍梯度稀释的已知浓度的质粒 DNA 作为 qPCR 反应的模板来制作外标标准曲线。细菌和古菌 *amoA* 基因的 qPCR 反应效率和相关性分别为 91.1%, $r^2 = 0.999$ 和 93.4%, $r^2 = 0.998$ 。

1.6 土壤有机层铵态氮、硝态氮的测定

土壤中的铵态氮(NH₄⁺-N, ammonia nitrogen)和硝态氮(NO₃⁻-N, nitrate nitrogen)经 2 mol/L KCL 提取后,分别以靛酚蓝比色法和酚二磺酸比色方法进行测定^[29]。

1.7 统计分析

用 SPSS 19.0 进行单因素方差分析(One-way ANOVA),以 LSD 法检验同一森林群落中 AOB、AOA 丰度在不同时期的差异显著性($P < 0.05$)。并对细菌、古菌 *amoA* 丰度及其比值与正积温、负积温、平均温度、铵态氮、硝态氮进行了相关分析。

2 结果与分析

2.1 amoA 基因丰度

3 个森林群落土壤有机层细菌和古菌 *amoA* 基因的丰度都表现出相似的变化规律(图 2)。从生长季至冻结期,PF 和 MF 群落的岷江冷杉原始林及岷江冷杉和红桦天然混交林细菌和古菌 *amoA* 基因丰度均明显降低。从生长季至冻结后期,岷江冷杉次生林、古菌 *amoA* 基因丰度也明显降低。3 个森林群落土壤有机层细菌和古菌 *amoA* 基因丰度均在冻结阶段达全年最低,但岷江冷杉原始林及岷江冷杉和红桦天然混交林在冻结期最低,而岷江冷杉次生林在冻结后期最低。之后 3 个森林群落土壤有机层细菌和古菌 *amoA* 丰度均显著增加,在融化阶段(ETS 或 LTS)达到全年最高,但融化期(TS)较 ETS 和 LTS 有显著降低($P < 0.05$)。

3 个森林群落土壤有机层古菌和细菌 *amoA* 丰度比例在整个研究期间均先升高后降低,在 LTS 最高(表

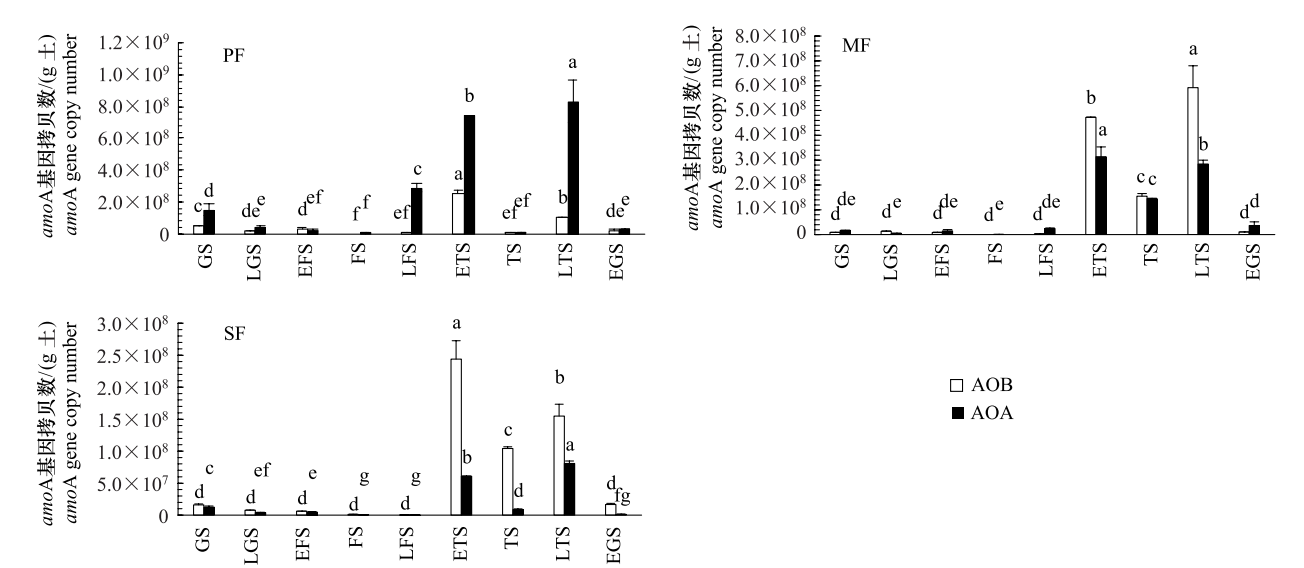


图2 不同森林群落中细菌和古菌 *amoA* 的丰度

Fig. 2 Abundance of bacterial and archaeal *amoA* gene in three forest community (mean±SD, n=5)

图2中不同的小写字母表示同一群落的 AOB 或 AOA 在不同时期的差异性达到 $P<0.05$ 水平; 古菌和细菌 *amoA* 基因丰度比例; GS: 生长季 Growing stage; LGS: 生长季后期 Later growing stage; EGS: 生长季前期 Early growing stage; EFS: 冻结前期 Early freezing stage; FS: 冻结期 Freezing stage; LFS: 冻结后期 later frozen stage; ETS: 融化前期 Early thawing stage; TS: 融化期 Thawing stage; LTS: 融化后期 Later thawing stage

3)。除冻结前期外,岷江冷杉原始林土壤有机层均具有相对较高的古菌 *amoA* 丰度($AOA/AOB>1$)。除冻结后期外,岷江冷杉次生林有机层均具有相对较高的细菌 *amoA* 丰度($AOA/AOB<1$),但岷江冷杉和红桦天然混交林在融化阶段、生长季后期具有高的细菌 *amoA* 丰度($AOA/AOB<1$)。

表3 不同森林群落中古菌和细菌 <i>amoA</i> 丰度比例									
Table 3 Ratio of archaeal to bacterial <i>amoA</i> abundance in three forest soil									
	I	II	III	IV	V	VI	VII	VIII	IX
岷江冷杉原始林 Primitive forest	3.03±1.03c	1.60±0.73d	0.71±0.23d	7.43±0.01b	33.15±0.56a	3.01±.035c	1.04±0.09d	8.04±1.83b	1.61±0.46d
岷江冷杉和红桦天然混交林 Mixed forest	1.97±0.02c	0.37±0.05e	1.74±0.43cd	3.20±0.58b	7.59±0.33a	0.67±0.11de	0.94±0.08cde	0.49±0.07e	3.38±1.88b
岷江冷杉次生林 Secondary forest	0.76±0.07b	0.48±0.09c	0.79±0.01b	0.51±0.07c	2.35±0.03a	0.25±0.04d	0.08±0.01e	0.52±0.05c	0.08±0.01e

2.2 AOB、AOA 丰度与环境因子的关系

相关性分析结果表明(表4),古菌、细菌 *amoA* 丰度比值与土壤有机层负积温呈极显著正相关($P<0.01$),相关系数分别为0.777。而古菌、细菌 *amoA* 丰度与积温特征、铵态氮、硝态氮、平均温度间无显著相关关系。

3 讨论与结论

土壤有机层氨氧化微生物丰度在不同关键时期的变化,有助于深入了解雪被和冻融影响明显的亚高山/高山地区的土壤生态过程。以 qPCR 技术对亚高山/高山森林土壤有机层氨氧化微生物丰度的研究表明,不同森林群落土壤有机层中都具有相当的 AOB 和 AOA,但其数量明显受土壤季节性冻融作用影响,在不同关键时期存在明显差异。而氨氧化微生物类群组成(AOA/AOB)与不同海拔上的温度动态差异密切联系。这些结果证明了川西亚高山/高山森林土壤有机层具有相当的氨氧化潜力,能在一定程度上调控季节性冻融地区的氮素循环等过程;还暗示了温度及其导致的环境变化会显著改变氨氧化微生物类群组成。

表 4 古菌、细菌 *amoA* 丰度与正负积温、平均温度、铵态氮及硝态氮的相关关系Table 4 Correlation analyses among the abundance of AOA/AOB, PAT, NAT, Average temperature, $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$

	AOB	AOA	AOA/AOB	PAT	NAT	$\text{NH}_4^+\text{-N}$	$\text{NO}_3^-\text{-N}$	时期均温
AOA	0.463 *							
AOA/AOB	-0.174	0.275						
PAT	-0.162	-0.205	-0.290					
NAT	-0.152	0.072	0.777 **	-0.438 *				
$\text{NH}_4^+\text{-N}$	-0.005	0.012	-0.008	-0.057	0.154			
$\text{NO}_3^-\text{-N}$	-0.036	0.121	0.034	-0.080	-0.006	0.220		
时期均温	-0.138	-0.203	-0.358	0.995 **	-0.522 **	-0.070	-0.075	
日均温	-0.084	-0.174	-0.339	0.928 **	-0.461 *	0.022	-0.102	0.929 **

“*”表示相关达到显著水平($P<0.05$);“**”表示相关达到极显著水平($P<0.01$);时期均温:用于计算积温的各时期的平均温度;日均温:采样当天的平均温度;AOB:Ammonia oxidizing bacteria 氨氧化细菌;AOA:Ammonia oxidizing archaea 氨氧化古菌;PAT:Positive accumulated temperature 正积温;NAT:Negative accumulated temperature 负积温; $\text{NH}_4^+\text{-N}$:Ammonia nitrogen 铵态氮; $\text{NO}_3^-\text{-N}$:Nitrate nitrogen 硝态氮

3 个森林群落的 AOB 和 AOA 数量在不同的关键时期均表现出相似的变化规律,暗示它们可能受相同环境因子影响。而土壤季节性冻融是高山/亚高山地区最为明显的环境变化之一,不仅可以直接影响土壤生物群落^[9-10,21],而且还可以通过改变土壤理化性质、水分动态等,间接对土壤微生物造成影响^[17,18]。本项研究表明,从生长阶段至冻结阶段,随着温度的下降 3 个森林群落的细菌和古菌数量都明显降低^[6]。冻结过程不但对微生物有明显的致死作用,还限制了底物、养分的有效性^[4,8],使得冻结阶段具有最低的氨氧化微生物数量(岷江冷杉原始林,岷江冷杉和红桦天然混交林在冻结期最低;岷江冷杉次生林在冻结后期最低)。由于不同海拔的温度差异^[30],海拔较低的岷江冷杉次生林群落冻结时间较晚(图 1 和表 1),故其中氨氧化微生物在冻结后期也最低。一般认为,土壤完全冻结后微生物群落变化相对较小^[22]。然而,本项研究中亚高山/高山森林土壤有机层氨氧化微生物数量在冻结阶段之后均显著增加,在融化阶段达到最高,这和已有研究结果基本一致^[8,31-32]。主要原因可能是,一方面温湿度环境的改善促进了微生物生长繁衍;另一方面,生长季节后期积累的大量凋落物、细根以及土壤团聚体和微生物的受冻融作用而破碎,可释放出相当底物和养分物质,有利于土壤微生物的迅速生长^[6,8,33-34]。但是,土壤氨氧化微生物等的迅速生长必然消耗大量的底物和养分物质,同时还受到融化阶段明显的土壤冻融循环作用的致死作用^[16],使得融冻期的土壤氨氧化微生物数量显著降低。

尽管季节性冻融作用对氨氧化细菌和古菌都表现出明显的影响,但不同群落不同关键时期的氨氧化微生物类群组成(AOA/AOB)明显不同。除冻结前期外,海拔最高的岷江冷杉原始林都具有相对较高的 AOA 数量,而海拔最低的岷江冷杉次生林具有相对较高的 AOB 数量,这与不同海拔上环境温度的差异有关^[30]以及 AOA 和 AOB 对环境变化的耐受性不同^[13,35]有关。张丽梅等对珠峰地区的研究也证实,氨氧化微生物类群组成(AOA/AOB)在不同海拔明显不同,在相对较温暖的土壤中^[30],往往具有相对较高的 AOB 数量^[5]。值得注意的是,冻结后期 3 个群落的氨氧化微生物类群都以 AOA 为主,说明 AOA 能够更好的适应低温条件。此外,本项研究表明 AOA/AOB 仅和负积温呈极显著正相关关系,说明温度是影响氨氧化微生物类群的主要因素,而负积温值越大则 AOA/AOB 越高,也在一定程度上证明了 AOA 种群对土壤低温环境具有相对较强的耐受性。

综上所述,川西亚高山/高山森林群落土壤有机层具有较高的 AOB 和 AOA 丰度,但明显受温度驱动的季节性冻融特征的影响,在不同阶段和关键时期表现出显著差异。氨氧化微生物类群的构成(AOA/AOB)明显受负积温影响而在不同森林群落和不同关键时期表现出明显不同的格局,海拔较高环境条件相对恶劣的岷江冷杉原始林以 AOA 为主,而海拔较低的岷江冷杉次生林以 AOB 为主;但冻结后期均以 AOA 为主,暗示了相对于 AOB, AOA 更能适应低温恶劣环境。这些结果为深入认识亚高山/高山森林土壤生态系统氮循环过程提供了一定基础数据。

References:

- [1] He J Z, Zhang L M. Advances in ammonia-oxidizing microorganisms and global nitrogen cycle. *Acta Ecologica Sinica*, 2009, 29(1): 406-415.
- [2] Shen J P, He J Z. Responses of microbes-mediated carbon and nitrogen cycles to global climate change. *Acta Ecologica Sinica*, 2011, 31(11): 2957-2967.
- [3] Francis C A, Roberts K J, Beman J M, Santoro A E, Oakley B B. Ubiquity and diversity of ammonia-oxidizing archaea in water columns and sediments of the ocean. *Proceedings of the National Academy of Sciences of the United States of America*, 2005, 102(41): 14683-14688.
- [4] Auguet J C, Nomokonova N, Camarero L, Casamayor E O. Seasonal changes of freshwater ammonia-oxidizing archaeal assemblages and nitrogen species in oligotrophic alpine lakes. *Applied and Environmental Microbiology*, 2011, 77(6): 1937-1945.
- [5] Zhang L M, Wang M, Prosser J I, Zheng Y M, He J Z. Altitude ammonia-oxidizing bacteria and archaea in soils of Mount Everest. *FEMS Microbiology Ecology*, 2009, 70(2): 208-217.
- [6] Sulkava P, Huhta V. Effects of hard frost and freeze-thaw cycles on decomposer communities and N mineralisation in boreal forest soil. *Applied Soil Ecology*, 2003, 22(3): 225-239.
- [7] Campbell J L, Mitchell M J, Groffman P M, Christenson L M, Hardy J P. Winter in northeastern North America: a critical period for ecological processes. *Frontiers in Ecology and the Environment*, 2005, 3(6): 314-322.
- [8] Edwards K A, McCulloch J, Peter Kershaw G, Jefferies R L. Soil microbial and nutrient dynamics in a wet Arctic sedge meadow in late winter and early spring. *Soil Biology and Biochemistry*, 2006, 38(9): 2843-2851.
- [9] Liu L, Wu F Z, Yang W Q, Wang A, Tan B, Yu S. Soil bacterial diversity in the subalpine/alpine forests of western Sichuan at the early stage of freeze-thaw season. *Acta Ecologica Sinica*, 2010, 30(20): 5687-5694.
- [10] Wang A, Zhang J, Yang W Q, Wu F Z, Liu L, Tan B. Bacterial diversity in organic soil layers of subalpine and alpine forests at the end of freeze-thaw periods. *Journal of Beijing Forestry University*, 2010, 32(4): 144-150.
- [11] Feller G, Gerday C. Psychrophilic enzymes: hot topics in cold adaptation. *Nature Reviews Microbiology*, 2003, 1(3): 200-208.
- [12] Price P B, Sowers T. Temperature dependence of metabolic rates for microbial growth, maintenance, and survival. *Proceedings of the National Academy of Sciences of the United States of America*, 2004, 101(13): 4631-4636.
- [13] Cavicchioli R. Cold-adapted archaea. *Nature Reviews Microbiology*, 2006, 4(5): 331-343.
- [14] Schmidt S K, Nemergut D R, Miller A E, Freeman K R, King A J, Seimon A. Microbial activity and diversity during extreme freeze-thaw cycles in periglacial soils, 5400 m elevation, Cordillera Vilcanota, Perú. *Extremophiles*, 2009, 13(5): 807-816.
- [15] Schimel J, Balser T C, Wallenstein M. Microbial stress-response physiology and its implications for ecosystem function. *Ecology*, 2007, 88(6): 1386-1394.
- [16] Poutou E, Krinner G, Genthon C, de Noblet-Ducoudré N. Role of soil freezing in future boreal climate change. *Climate Dynamics*, 2004, 23(6): 621-639.
- [17] Zhou Y W. Permafrost in China. Beijing: Science Press, 2000.
- [18] Yang Z N. Hydrology in Cold Regions of China. Beijing: Science Press, 2000.
- [19] Yang W Q, Wang K Y, Kellomäki S, Gong H D. Litter dynamics of three subalpine forests in Western Sichuan. *Pedosphere*, 2005, 15(5): 653-659.
- [20] Feng R F, Yang W Q, Zhang J. Review on biochemical property in forest soil organic layer and its responses to climate change. *Chinese Journal of Applied and Environmental Biology*, 2006, 12(5): 734-739.
- [21] Tan B, Wu F Z, Yang W Q, Liu L, Yu S. Characteristics of soil animal community in the subalpine/alpine forests of western Sichuan during onset of freezing. *Acta Ecologica Sinica*, 2010, 30(2): 93-99.
- [22] Henry H A L. Soil freeze-thaw cycle experiments: trends, methodological weaknesses and suggested improvements. *Soil Biology and Biochemistry*, 2007, 39(5): 977-986.
- [23] Tourna M, Freitag T E, Nicol G W, Prosser J I. Growth, activity and temperature responses of ammonia-oxidizing archaea and bacteria in soil microcosms. *Environmental Microbiology*, 2008, 10(5): 1357-1364.
- [24] Wang Y R. Evolvement of the cumulative temperatures in China loess plateau. *Journal of Glaciology and Geocryology*, 2007, 29(1): 119-125.
- [25] Griffiths R I, Whiteley A S, O'Donnell A G, Bailey M J. Rapid method for coextraction of DNA and RNA from natural environments for analysis of ribosomal DNA- and rRNA-based microbial community composition. *Applied and Environmental Microbiology*, 2000, 66(12): 5488-5491.
- [26] Rotthauwe J H, Witzel K P, Liesack W. The ammonia monooxygenase structural gene amoA as a functional marker: molecular fine-scale analysis of natural ammonia-oxidizing populations. *Applied and Environmental Microbiology*, 1997, 63(12): 4704-4712.

- [27] Francis C A, Roberts K J, Beman J M, Santoro A E, Oakley B B. Ubiquity and diversity of ammonia-oxidizing archaea in water columns and sediments of the ocean. *Proceedings of the National Academy of Sciences of the United States of America*, 2005, 102(41): 14683-14688.
- [28] Okano Y, Hristova K R, Leutenegger C M, Jackson L E, Denison R F, Gebreyesus B, Lebauer D, Scow K M. Application of real-time PCR to study effects of ammonium on population size of ammonia-oxidizing bacteria in soil. *Applied and Environmental Microbiology*, 2004, 70(2): 1008-1016.
- [29] Lu R K. *Soil and Agro-Chemical Analytical Methods*. Beijing: China Agricultural Science and Technology Press, 1999: 296-338.
- [30] Giorgi F, Hurrell J W, Marinucci M R, Beniston M. Elevation dependency of the surface climate change signal: a model study. *Journal of Climate*, 1997, 10(2): 288-296.
- [31] Schimel J P, Mikan C. Changing microbial substrate use in Arctic tundra soils through a freeze-thaw cycle. *Soil Biology and Biochemistry*, 2005, 37(8): 1411-1418.
- [32] Henry H A L. Climate change and soil freezing dynamics: historical trends and projected changes. *Climatic Change*, 2008, 87(3/4): 421-434.
- [33] Oztas T, Fayetorbay F. Effect of freezing and thawing processes on soil aggregate stability. *Catena*, 2003, 52(1): 1-8.
- [34] Wu F Z, Yang W Q, Zhang J, Deng R J. Litter decomposition in two subalpine forests during the freeze-thaw season. *Acta Oecologica*, 2010, 36(1): 135-140.
- [35] Erguder T H, Boon N, Wittebolle L, Marzorati M, Verstraete W. Environmental factors shaping the ecological niches of ammonia-oxidizing archaea. *FEMS Microbiology Reviews*, 2009, 33(5): 855-869.

参考文献:

- [1] 贺纪正, 张丽梅. 氨氧化微生物生态学与氮循环研究进展. *生态学报*, 2009, 29(1): 406-415.
- [2] 沈菊培, 贺纪正. 微生物介导的碳氮循环过程对全球气候变化的响应. *生态学报*, 2011, 31(11): 2957-2967.
- [9] 刘利, 吴福忠, 杨万勤, 王奥, 谭波, 余胜. 季节性冻结初期川西亚高山/高山森林土壤细菌多样性. *生态学报*, 2010, 30(20): 5687-5694.
- [10] 王奥, 张健, 杨万勤, 吴福忠, 刘利, 谭波. 冻融末期亚高山/高山森林土壤有机层细菌多样性. *北京林业大学学报*, 2010, 32(4): 144-150.
- [17] 郭东信. *中国的冻土*. 兰州: 甘肃教育出版社, 1990.
- [18] 杨针娘. *中国寒区水文*. 北京: 科学出版社, 2000.
- [20] 冯瑞芳, 杨万勤, 张健. 森林土壤有机层生化特性及其对气候变化的响应研究进展. *应用与环境生物学报*, 2006, 12(5): 734-739.
- [24] 王毅荣. 1961—2005 年黄土高原地区积温演变. *冰川冻土*, 2007, 29(1): 119-125.
- [29] 鲁如坤. *土壤农化分析*. 北京: 中国农业科技出版社, 1999: 296-338.

CONTENTS

Growth and physiological adaptation of <i>Messerschmidia sibirica</i> to sand burial on coastal sandy	WANG Jin, ZHOU Ruilian, ZHAO Halin, et al (4291)
Alleviation effect and mechanism of exogenous potassium nitrate and salicylic acid on the growth inhibition of <i>Pinus tabulaeformis</i> seedlings induced by deicing salts	ZHANG Ying, LI Fayun, YAN Xia, et al (4300)
Influence of different spatial-scale factors on stream macroinvertebrate assemblages in the middle section of Qiantang River Basin	ZHANG Yong, LIU Shuoru, YU Haiyan, et al (4309)
Species diversity and distribution pattern of non-volant small mammals along the elevational gradient on eastern slope of Gongga Mountain	WU Yongjie, YANG Qisen, XIA Lin, et al (4318)
A patch-based method for mechanism analysis on spatial dynamics of mangrove distribution	LI Chungan, LIU Suqing, FAN Huangqing, et al (4329)
Nutrient heterogeneity in fine roots of six subtropical natural tree species	XIONG Decheng, HUANG Jinxue, YANG Zhijie, et al (4343)
Variation of vegetation NDVI and its response to climate change in Zhejiang Province	HE Yue, FAN Gaofeng, ZHANG Xiaowei, et al (4352)
Heterogeneity in fine root respiration of six subtropical tree species	ZHENG Jinxing, XIONG Decheng, HUANG Jinxue, et al (4363)
Characteristics of ammonia-oxidizing bacteria and ammonia-oxidizing archaea abundance in soil organic layer under the subalpine/alpine forest	WANG Ao, WU Fuzhong, HE Zhenhua, et al (4371)
Effect of tillage systems on light fraction carbon in a purple paddy soil	ZHANG Junke, JIANG Changsheng, HAO Qingju, et al (4379)
Effects of prescribed fire on carbon sequestration of long-term grazing-excluded grasslands in Inner Mongolia	HE Nianpeng, HAN Xingguo, YU Guirui, et al (4388)
Stoichiometry of carbon dioxide and methane emissions in Minjiang River estuarine tidal wetland	WANG Weiqi, ZENG Congsheng, TONG Chuan, et al (4396)
Distribution and sources of particulate organic carbon in the Pearl River Estuary in summer 2010	LIU Qingxia, HUANG Xiaoping, ZHANG Xia, et al (4403)
The glucose-utilizing bacterial diversity in the cold spring sediment of Shawan, Xinjiang, based on stable isotope probing	CHU Min, WANG Yun, ZENG Jun, et al (4413)
Culture-dependent and culture-independent approaches to studying soil microbial diversity	LIU Guohua, YE Zhengfang, WU Weizhong (4421)
The classification of plant functional types based on the dominant herbaceous species in the riparian zone ecosystems in the Yiluo River	GUO Yili, LU Xunling, DING Shengyan (4434)
Genetic diversity of different eco-geographical populations in endangered plant <i>Prunus mongolica</i> by ISSR Markers	ZHANG Jie, WANG Jia, LI Haoyu, ZHANG Huirong, et al (4443)
Ecophysiological characteristics of higher-latitude transplanted mangrove <i>Kandelia candel</i> in strong tidal range area	ZHENG Chunfang, QIU Jianbiao, LIU Weicheng, et al (4453)
The effect of artificial warming during winter on white clover (<i>Trifolium repens</i> Linn): overwintering and adaptation to coldness in late spring	ZHOU Ruilian, ZHAO Mei, WANG Jin, et al (4462)
Estimating fine root production and mortality in subtropical <i>Altingia grilipes</i> and <i>Castanopsis carlesii</i> forests	HUANG Jinxue, LING Hua, YANG Zhijie, et al (4472)
The cloning and expression of WUE-related gene (<i>PdEPF1</i>) in <i>Populus deltoides</i> × <i>Populus nigra</i>	GUO Peng, JIN Hua, YIN Weilun, et al (4481)
The allelopathy of aquatic rhizome and root extract of <i>Thalia dealbata</i> to seedling of several aquatic plants	MIAO Lihua, WANG Yuan, GAO Yan, et al (4488)
Effect of the avirulent strain of <i>Ralstonia solanacearum</i> on the ecological characteristics of microorganism fatty acids in the rhizosphere of tobacco	ZHENG Xuefang, LIU Bo, LAN Jianglin, et al (4496)
Coupling remotely sensed information with a rice growth model by combining updating and assimilation strategies	WANG Hang, ZHU Yan, MA Mengli, et al (4505)
Effects of water temperature and body weight on metabolic rates of Yellowtail clownfish <i>Amphiprion clarkii</i> (Pisces: Perciformes) during larval development	YE Le, YANG Shengyun, LIU Min, et al (4516)
The distribution of chlorophyll a in the Southwestern Indian Ocean in summer	HONG Lisha, WANG Chunsheng, ZHOU Yadong, et al (4525)
Evaluation of the effects of ecological remediation on the water quality and biological toxicity of Dagou Drainage River in Tianjin	WANG Min, TANG Jingchun, ZHU Wenyong, et al (4535)
Quantitative dynamics of adult population and 3-D spatial pattern of <i>Ceoporus variabilis</i> (Baly)	WANG Wenjun, LIN Xuefei, ZOU Yunding, et al (4544)
Review and Monograph	
Studies on urban heat island from a landscape pattern view: a review	CHEN Ailian, SUN Ranhao, CHEN Liding (4553)
Sediment quality triad and its application in coastal ecosystems in recent years	WU Bin, SONG Jinming, LI Xuegang, et al (4566)
Discussion	
Food waste management in China: status, problems and solutions	HU Xinjun, ZHANG Min, YU Junfeng, et al (4575)
Scientific Note	
Effects of microchemical substances in anaerobic fermented liquid from rice straw and cyanobacteria on <i>Fusarium oxysporum</i> f. sp. <i>niveum</i> growth	LIU Aimin, XU Shuangsoo, CAI Xin, et al (4585)
Ecological benefit-loss analysis of agricultural ecosystem in Foshan City, China	YE Yanqiong, ZHANG Jiaen, QIN Zhong, et al (4593)

《生态学报》2012 年征订启事

《生态学报》是中国生态学学会主办的自然科学高级学术期刊,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,280 页,国内定价 70 元/册,全年定价 1680 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 14 期 (2012 年 7 月)

ACTA ECOLOGICA SINICA
(Semimonthly, Started in 1981)
Vol. 32 No. 14 (July, 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:1000717	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