

ISSN 1000-0933
CN 11-2031/Q

生态学报

Acta Ecologica Sinica



第32卷 第18期 Vol.32 No.18 **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 18 期

2012 年 9 月 (半月刊)

目 次

亚热带典型树种对模拟酸雨胁迫的高光谱响应.....	时启龙, 江 洪, 陈 健, 等 (5621)
珠江三角洲地面风场的特征及其城市群风道的构建.....	孙 武, 王义明, 王越雷, 等 (5630)
粤北山地常绿阔叶林自然干扰后冠层结构与林下光照动态.....	区余端, 苏志尧 (5637)
四种猎物对南方小花蝽生长发育和繁殖的影响.....	张昌容, 鄧军锐, 莫利锋 (5646)
普洱季风常绿阔叶林次生演替中木本植物幼苗更新特征.....	李帅锋, 刘万德, 苏建荣, 等 (5653)
喀斯特常绿落叶阔叶混交林物种多度与丰富度空间分布的尺度效应.....	张忠华, 胡 刚, 祝介东, 等 (5663)
格氏栲天然林土壤养分空间异质性.....	苏松锦, 刘金福, 何中声, 等 (5673)
种植香根草对铜尾矿废弃地基质化学和生物学性质的影响.....	徐德聪, 詹 婧, 陈 政, 等 (5683)
灌溉对三种荒漠植物蒸腾耗水特性的影响.....	单立山, 李 毅, 张希明, 等 (5692)
真盐生植物盐角草对不同氮形态的响应.....	聂玲玲, 冯娟娟, 吕素莲, 等 (5703)
鹿泉沟自然保护区寒温性针叶林演替优势种格局动态分析.....	张钦弟, 毕润成, 张金屯, 等 (5713)
不同水肥条件下 AM 真菌对丹参幼苗生长和营养成分的影响.....	贺学礼, 马 丽, 孟静静, 等 (5721)
垄沟覆膜栽培冬小麦田的土壤呼吸.....	上官宇先, 师日鹏, 韩 坤, 等 (5729)
不同方式处理牛粪对大豆生长和品质的影响.....	郭立月, 刘雪梅, 战丽杰, 等 (5738)
基于大气沉降与径流的乌鲁木齐河源区氮素收支模拟.....	王圣杰, 张明军, 王飞腾, 等 (5747)
基于能值理论的循环复合农业生态系统发展评价——以福建省福清星源循环农业产业示范基地为例.....	钟珍梅, 翁伯琦, 黄勤楼, 等 (5755)
低温暴露和恢复对棘胸蛙雌性亚成体生存力及能量物质消耗的影响.....	凌 云, 邵 晨, 颜志刚, 等 (5763)
暗期干扰对棉铃虫两个不同地理种群滞育抑制作用的比较.....	陈元生, 涂小云, 陈 超, 等 (5770)
水土流失治理措施对小流域土壤有机碳和全氮的影响.....	张彦军, 郭胜利, 南雅芳, 等 (5777)
不同管理主体对泸沽湖流域生态系统影响的比较分析.....	董仁才, 苟亚青, 李思远, 等 (5786)
连江鱼类群落多样性及其与环境因子的关系.....	李 捷, 李新辉, 贾晓平, 等 (5795)
溶氧水平对鲫鱼代谢模式的影响.....	张 伟, 曹振东, 付世建 (5806)
象山港人工鱼礁区的网采浮游植物群落组成及其与环境因子的关系.....	江志兵, 陈全震, 寿 鹿, 等 (5813)
填海造地导致海湾生态系统服务损失的能值评估——以套子湾为例.....	李睿倩, 孟范平 (5825)
城市滨水景观的视觉环境质量评价——以合肥市为例.....	姚玉敏, 朱晓东, 徐迎碧, 等 (5836)
专论与综述	
生态基因组学研究进展.....	施永彬, 李钧敏, 金则新 (5846)
海洋酸化生态学研究进展.....	汪思茹, 殷克东, 蔡卫君, 等 (5859)
纺锤水蚤摄食生态学研究进展.....	胡思敏, 刘 胜, 李 涛, 等 (5870)
河口生态系统氨氧化菌生态学研究进展.....	张秋芳, 徐继荣, 苏建强, 等 (5878)
嗜中性微好氧铁氧化菌研究进展.....	林超峰, 龚 骏 (5889)
典型低纬度海区(南海、孟加拉湾)初级生产力比较.....	刘华雪, 宋星宇, 黄洪辉, 等 (5900)
植物叶片最大羧化速率及其对环境因子响应的研究进展.....	张彦敏, 周广胜 (5907)
中国大陆鸟类栖息地选择研究十年.....	蒋爱伍, 周 放, 覃 玥, 等 (5918)
研究简报	
孵化温度对赤链蛇胚胎代谢和幼体行为的影响.....	孙文佳, 俞 霄, 曹梦洁, 等 (5924)
不同培肥茶园土壤微生物量碳氮及相关参数的变化与敏感性分析.....	王利民, 邱珊莲, 林新坚, 等 (5930)
施肥对两种莧菜吸收积累镉的影响.....	李凝玉, 李志安, 庄 萍, 等 (5937)

期刊基本参数: CN 11-2031/Q * 1981 * m * 16 * 322 * zh * P * ¥70.00 * 1510 * 36 * 2012-09



封面图说: 冬天低空飞翔的丹顶鹤——丹顶鹤是鹤类中的一种, 因头顶有“红肉冠”而得名。是东亚地区特有的鸟种, 因体态优雅、颜色分明, 在这一地区的文化中具有吉祥、忠贞、长寿的象征, 是传说中的仙鹤, 国家一级保护动物。丹顶鹤具备鹤类的特征, 即三长——嘴长、颈长、腿长。成鸟除颈部和飞羽后端为黑色外, 全身洁白, 头顶皮肤裸露, 呈鲜红色。丹顶鹤每年要在繁殖地和越冬地之间进行迁徙, 只有在日本北海道等地是留鸟, 不进行迁徙, 这可能与冬季当地人有组织地投喂食物, 食物来源充足有关。

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

DOI: 10.5846/stxb201108181212

凌云,邵晨,颀志刚,王娜. 低温暴露和恢复对棘胸蛙雌性亚成体生存力及能量物质消耗的影响. 生态学报, 2012, 32(18): 5763-5769.

Ling Y, Shao C, Xie Z G, Wang N. Effects of cold exposure and recovery on viability and energy consumption in the sub-adult female giant spiny frogs (*Paa spinosa*). Acta Ecologica Sinica, 2012, 32(18): 5763-5769.

低温暴露和恢复对棘胸蛙雌性亚成体生存力 及能量物质消耗的影响

凌 云,邵 晨,颀志刚*,王 娜

(浙江师范大学化学与生命科学学院,金华 321004)

摘要:棘胸蛙(*Paa spinosa*)亚成体在人工驯养过程中容易出现越冬困难,非正常的冬眠可能会影响次年的繁育。以雌性棘胸蛙亚成体(1—2 龄)为对象,研究该蛙在人工低温暴露(4 ℃保持 90 d)条件下的生存力、机体能量物质消耗、肥满度、脏器系数的变化特征,以及这些参数在温度恢复至正常(由 4 ℃缓慢升至 22 ℃后保持 7 d)后的变化情况。结果表明,该蛙在低温暴露过程中存活率逐渐降低,恢复期无死亡。肥满度(K)和体重/体长(Kwl)在低温暴露期间有逐渐升高的趋势,但两者在经历恢复期(22 ℃, 7 d)后均恢复至初始水平($P > 0.05$)。胃系数和脾系数在低温暴露期呈明显的上升趋势($P < 0.05$),且两者在第 90 天均显著大于初始水平($P < 0.05$)。恢复期肝系数显著减小($P < 0.05$)。在低温暴露期各阶段肝脏和肌肉脂肪含量与初始无统计差异($P > 0.05$);肝脏水分在低温暴露期间呈明显下降趋势($P < 0.05$),而肌肉水分则与之相反;肝脏非脂肪干物质含量呈显著上升趋势($P < 0.05$),而肌肉非脂肪干物质则呈相反趋势。肝糖原含量随暴露时间的延长呈现显著上升趋势($P < 0.05$),低温暴露第 60 天和第 90 天肝糖原含量与初始相比分别增加 59.4% 和 60.1%,而恢复期肝糖原含量则降至初始水平($P > 0.05$)。根据结果可以看出,在低温暴露过程中肝脏和肌肉脂肪含量变化不显著,同时肥满度、肝系数、肝脏非脂肪干物质和肝糖原含量均有不同程度的升高,而肌肉非脂肪干物质则显著减少($P < 0.05$),说明该蛙雌性亚成体在低温期主要消耗的能量物质不是脂肪而是肌肉非脂肪干物质,或者肌肉非脂肪干物质在组织间发生了大量转运。

关键词:棘胸蛙;低温暴露;生存力;能量消耗

Effects of cold exposure and recovery on viability and energy consumption in the sub-adult female giant spiny frogs (*Paa spinosa*)

LING Yun, SHAO Chen, XIE Zhigang*, WANG Na

College of Chemistry and Life Sciences, Zhejiang Normal University, Jinhua 321004, China

Abstract: The giant spiny frog (*Paa spinosa*), a typical amphibian, can exhibit abnormal hibernation caused by disturbances in energy and substrate metabolism, and can suffer decreases in egg quality during the following breeding season, especially for individuals spawning for the first time. Hibernation which is formed in the long evolutionary process of poikilothermal animals can be considered as a survival strategy and self-protective method to avoid starvation, cold, diseases and other adverse environmental factors for amphibians. Overwintering difficulty of amphibians is a widespread consequence of global climate change and habitat modification that result from human activities, and the following breeding can be influenced by abnormal hibernation with regard to the sub-adult female giant spiny frogs, which is common under the circumstance of artificial domestication. The aim of our study was to investigate the changes in viability and substrate utilization under the condition of artificial cold exposure (4 ℃, 90 d) and during recovery (22 ℃, 7 d) in the sub-adult

基金项目:国家自然科学基金(30800129)

收稿日期:2011-08-18; 修订日期:2012-02-01

* 通讯作者 Corresponding author. E-mail: xiezhiang@zjnu.cn

female spiny frogs (1—2 year old) which were chosen as the objectives in the study. The results indicated that the survival rate of sub-adult female giant spiny frogs appeared to be a decreasing trend during the period of cold exposure and the mortality rate turned to be zero in the stage of recovery; the relative fatness (K) and the ratio of body weight to body length (Kwl), which presented to be ascendant during cold exposure, both returned to the initial levels ($P > 0.05$) in the recovery stage; ascendant trend was found in both stomach and spleen coefficient during cold exposure ($P < 0.05$), particularly the both appeared to be higher in the 90th day in relation to the initial levels ($P < 0.05$), and the liver coefficient decreased dramatically in the recovery stage ($P < 0.05$). During cold exposure period, no statistical differences were observed in the lipid content in liver and muscle compared with the initial content levels ($P > 0.05$); the moisture content in liver ($P < 0.05$) and the non-lipid dry matter content in muscle both decreased during cold exposure; the moisture content in muscle and the non-lipid dry matter content in liver ($P < 0.05$) increased during cold exposure; hepatic glycogen content increased by the 60th and 90th day of cold exposure compared to the initial level ($P < 0.05$), with the growth rates of 59.4% and 60.1% respectively, and returned to the initial level during recovery ($P > 0.05$). We might draw a conclusion that the sub-adult female spiny frogs made use of the non-lipid dry matters in muscle rather than lipid, or the non-lipid dry matters in muscle were transported in the tissues in order to adapt to cold exposure, which was concluded from the facts that the body condition indexes (K and Kwl), liver coefficient, non-lipid dry matter content in liver and hepatic glycogen content emerged to be ascendant to some extent, however, non-lipid dry matter content in muscle proved to be remarkably decreasing ($P < 0.05$) and no significant changes were detected in the lipid content in liver and muscle during cold exposure.

Key Words: *Paa spinosa*; cold exposure; viability; energy consumption

冬眠是部分动物保存体能、避开寒冷、饥饿、疾病等不利环境的自我保护方式和在漫长适应进化过程中获得的重要生存策略之一。冬眠状态下的动物主要依靠体内贮存的营养物质(如脂肪和肝糖等)来维持基本生命特征^[1],体内相关激素如胰岛素、甲状腺素、糖皮质激素分泌大量减少,以及各种酶类如肝磷酸酶、肝和肌肉酯酶的活性显著降低,从而降低机体的代谢水平,使机体能量得以保存^[2]。两栖类动物作为典型的变温脊椎动物,多数温带或高海拔物种在越冬过程中以冬眠方式抵御极端气候。然而,全球气候变化和生境破坏等因素可能引起两栖类的非正常冬眠,从而导致机体能量物质的代谢紊乱和过耗以及繁殖期怀卵量或产卵量的下降,尤其对于初次产卵雌体的影响更为显著^[3]。

棘胸蛙(*Paa spinosa*)属两栖纲、无尾目、蛙科、棘蛙属,主要分布在江西、浙江、福建、云南、贵州等省份,具有较高的食用和药用价值^[4-6],市场需求量较大。由于过度捕捉和生境破坏等因素导致该蛙野生资源急剧减少,现已被列为 IUCN 红色名录的易危物种([Http:// www. iucnredlist. org/](http://www.iucnredlist.org/)),因此,亟待深入开展棘胸蛙的人工驯化和繁育研究。但由于该蛙对生态环境的要求较为苛刻,养殖过程中存在较多技术瓶颈,如野生个体在驯养过程中容易死亡,尤其在人工越冬环境下刚变态的幼蛙和亚成体死亡率较高,严重制约该产业的发展^[7],养殖者通常采用营养限制手段来延迟变态,以蝌蚪来度过越冬难关。此外,养殖条件下不适宜的越冬环境温度可能会对该蛙雌性个体次年的繁殖表现产生不利影响,但相关基础研究尚不多见。本研究以野生棘胸蛙雌性亚成体为对象,通过人为模拟冬眠环境进行低温暴露实验,研究该蛙在低温暴露期间和低温暴露结束初期的生存力及能量物质消耗等形态和生理指标的变化特征。研究结果可以为棘胸蛙越冬生理生态学提供基础知识,还可为该蛙在人工条件下冬眠提供技术指导。

1 材料与方法

1.1 材料

野生棘胸蛙雌性(胸部无棘刺为雌性)亚成体采自浙江开化县钱江源山区(118°01'—118°37'N, 28°54'—29°30'E),采集时间为野生棘胸蛙自然越冬前(2010年10月底),采集地环境温度为12—24℃。将蛙放置

在装有少量冰块的保温箱内运回实验室。

1.2 方法

1.2.1 实验动物驯化

将蛙置于水族箱(90 cm × 40 cm × 40 cm, 10 只/缸)内进行驯化,提供水陆环境和遮蔽物,控制水温(22 ± 1) °C,光周期为 12 L:12 D,每日以黄粉虫(*Tenebrio molitor*)活体作为饵料投食 1 次,投喂量为体重的 4%,隔日用经曝气脱氯的自来水换水 1/3。驯化时间为 1 周,驯化结束后,选择 36 只体重相近、体表无伤的健康棘胸蛙((55.27 ± 1.56) g, Mean ± SE)随机分配至 4 个玻璃槽(30 cm × 15 cm × 20 cm)内,然后置入低温恒温培养箱(MIR-253, SANYO, Japan)。低温恒温培养箱内温度预先降至(4 ± 0.5) °C,蛙在该低温条件下保持 90 天,并于第 30 天、60 天、90 天分别取 6 只蛙用于相关分析,在低温暴露结束后,将温度在 1d 内缓慢恢复至 22 °C(2 °C/1 h)后,移入水族箱内,在驯化条件下(不投喂饵料)保持第 7 天后取样。在实验开始前另取 6 只蛙用于初始测定。实验期间记录死亡情况。

1.2.2 身体状况指数和器官系数

对各阶段取样棘胸蛙精确称重(0.01 g),用数显游标卡尺测量动物体长(SUL)(1 mm)。经毁髓后立刻解剖,摘取肝脏、胃、脾脏、肾脏等器官后进行精确称重,计算相关参数:肥满度($K = 100 \times W/L^3$);体重/体长($Kwl = W/L$);脏器系数(Organ Coefficient, OC) = $100 \times (\text{器官重}/\text{体重})$,其中 W 为体重(g), L 为体长(cm)。

1.2.3 组织生化测定

取蛙的肌肉和肝脏,70 °C 下烘干后,称取粉碎的干样品,采用氯仿-甲醇抽提法测定组织中脂肪含量^[8]。

1.2.4 肝糖原含量测定

肝糖原测定方法详见试剂说明书(南京建成生物科技研究所)。

1.3 数据分析

实验数据均以平均值 ± 标准误(Mean ± SE)表示,用统计软件包 SPSS17.0 对数据进行统计分析,数据经 Kolmogorov-Smirnov test 后,均符合正态分布,采用 One-Way ANOVA 进行组间差异比较,当 ANOVA 检测各组间有显著性差异后,并进行 LSD 多重比较,当显著性水平 $P < 0.05$ 时表示差异显著。比较组间器官重量时,采用协方差分析去除体重的影响。

2 结果

2.1 成活率

野生雌性棘胸蛙在低温暴露期间各阶段累积成活率呈下降趋势,在恢复期(22 °C, 7 d)无死亡(图 1)。

2.2 肥满度(K)和体重/体长(Kwl)

肥满度 K 和 Kwl 在低温暴露期间有逐渐升高的趋势,且 K 在低温暴露第 90 天显著增大($P < 0.05$), Kwl 在第 60 天和 90 天显著大于第 30 天($P < 0.05$),而两者在恢复期均降至初始水平($P > 0.05$)(图 2,图 3)。

2.3 脏器系数变化

实验期间发现棘胸蛙亚成体性腺尚未发育,且仅 2 个存在极小脂肪体,因此未对这两个脂肪体进行称重。肝系数在低温暴露期间与初始无统计差异($P > 0.05$),但在数值上均高于初始值;胃系数和脾系数在低温暴露期间呈明显的上升趋势($P < 0.05$),且两者在第 90 天均显著大于初始水平($P < 0.05$)。恢复期肝系数显著减小,但与初始无统计差异($P > 0.05$);胃系数和脾系数无显著变化。肾系数在实验各阶段均无显著变化($P >$

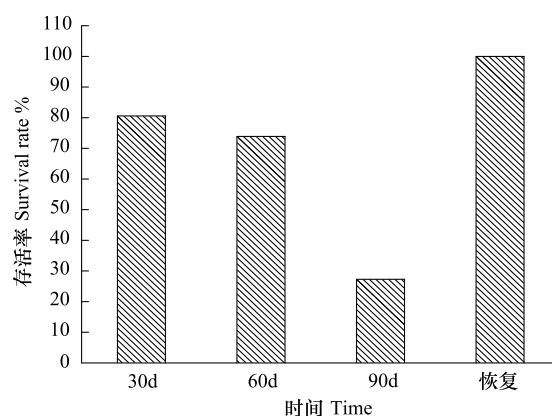


图 1 棘胸蛙雌性亚成体在低温暴露和恢复各阶段成活率的变化
Fig.1 Changes of survival rate of sub-adult female giant spiny frogs (*Paa spinosa*) in different stages during the period of cold exposure and recovery

0.05)(表1)。

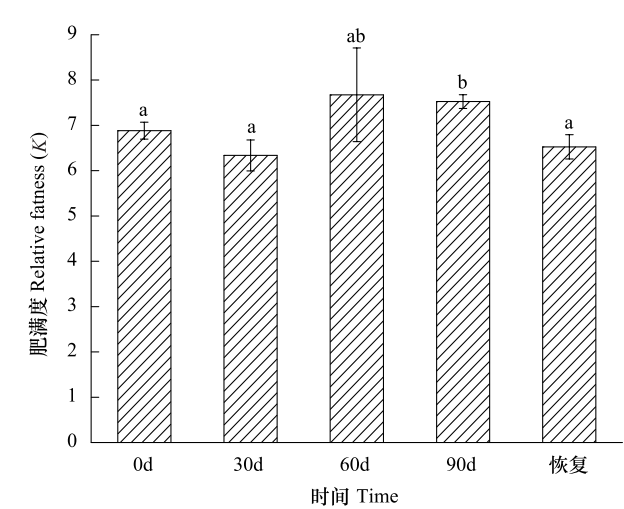


图2 棘胸蛙(*Paa spinosa*)雌性亚成体在低温暴露和恢复各阶段肥满度(*K*)的变化

Fig.2 Changes of relative fatness (*K*) in sub-adult female giant spiny frogs (*Paa spinosa*) in different stages during the period of cold exposure and recovery

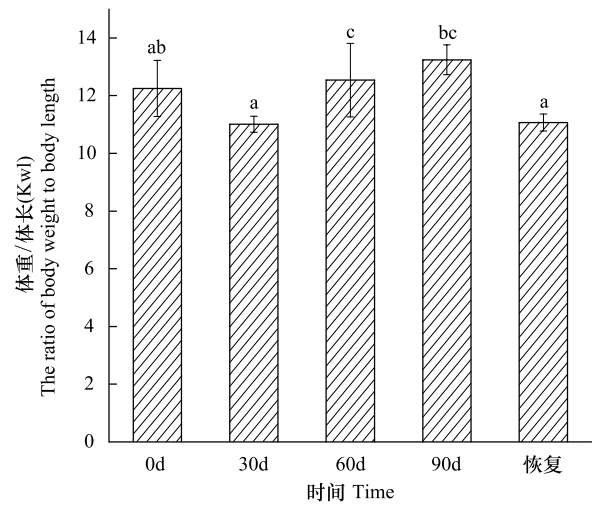


图3 棘胸蛙(*Paa spinosa*)雌性亚成体在低温暴露和恢复各阶段体重/体长(*Kwl*)的变化

Fig.3 Changes of the ratio of body weight to body length (*Kwl*) in sub-adult female giant spiny frogs (*Paa spinosa*) in different stages during the period of cold exposure and recovery

表1 棘胸蛙(*Paa spinosa*)雌性亚成体在低温暴露和恢复各阶段脏器系数的变化

Table 1 Changes of different organ coefficients in sub-adult female giant spiny frogs (*Paa spinosa*) in different stages during the period of cold exposure and recovery

取样条件 Sampling condition	肝系数 Liver coefficient	胃系数 Stomach coefficient	脾系数 Spleen coefficient	肾系数 Kidney coefficient
0d	0.0144±0.0011ab	0.0157±0.0011a	0.0005±0.0001a	0.0034±0.0003
4℃,30d	0.0166±0.0011b	0.0161±0.0013a	0.0005±0.0001ab	0.0040±0.0005
4℃,60d	0.0164±0.0008b	0.0166±0.0005a	0.0006±0.0001ab	0.0037±0.0003
4℃,90d	0.0148±0.0010b	0.0212±0.0009b	0.0009±0.0001b	0.0038±0.0003
22℃,7d	0.0116±0.0011a	0.0186±0.0004ab	0.0006±0.0001ab	0.0033±0.0002

平均值以 Mean ± SE 表示;组间无相同字母表示差异显著($P < 0.05$); $n = 6$

2.4 组织生化测定

在低温暴露期间,肝脏和肌肉脂肪含量各阶段均与初始无统计差异($P > 0.05$);肝脏水分在低温暴露期间呈明显下降趋势,低温第90天显著低于初始水平($P < 0.05$),而肌肉水分则与之相反,在第60天和90天显著高于初始($P < 0.05$);肝脏非脂肪干物质含量呈上升趋势,在第90天显著高于初始($P < 0.05$),而肌肉非脂肪干物质则呈相反趋势,在第60天和90天显著低于初始($P < 0.05$)。在恢复期间,肝脏脂肪含量无显著变化,但肌肉脂肪含量与低温第60天和90天相比显著降低($P < 0.05$),但与初始无统计差异;肝脏水分降至最低,显著低于初始和低温第30天和60天,而肌肉水分则无显著变化;肝脏非脂肪干物质仍保持较高水平,显著大于初始和低温第30天和60天,而肌肉非脂肪干物质仅与低温第30天存在显著差异(表2)。

2.5 肝糖原变化

在低温暴露期间,肝糖原含量随暴露时间的延长呈现上升趋势,且在低温第60天和第90天肝糖原含量显著高于初始水平($P < 0.05$),低温第60天和第90天肝糖原含量与初始相比分别增加59.4%和60.1%,而恢复期肝糖原含量则降至初始水平($P > 0.05$)(图4)。

表 2 棘胸蛙(*Paa spinosa*)雌性亚成体在低温暴露和恢复各阶段肝脏和肌肉组织粗脂肪、水分、非脂肪干物质含量变化Table 2 Changes of crude fat, moisture and non-lipid dry matter levels of liver and muscle in sub-adult female giant spiny frogs (*Paa spinosa*) in different stages during the period of cold exposure and recovery

取样条件 Sampling condition	粗脂肪 Crude fat/%		水分 Moisture/%		非脂肪干物质 Non-lipid dry matter/%	
	肝脏 Liver	肌肉 Muscle	肝脏 Liver	肌肉 Muscle	肝脏 Liver	肌肉 Muscle
0d	13.45±0.67	3.31±0.15ab	79.08±0.59b	81.07±0.50ab	20.92±0.59a	18.93±0.50bc
4℃,30d	15.07±1.8	3.02±0.13ab	78.81±0.80bc	80.96±0.43a	21.19±0.80ab	19.04±0.43c
4℃,60d	12.70±0.5	3.45±0.08b	78.35±0.28bc	82.83±0.23c	21.65±0.28ab	17.30±0.36a
4℃,90d	15.86±3.6	3.51±0.78b	77.07±0.72ac	82.70±0.36c	22.93±0.72bc	17.17±0.23a
22℃,7d	12.08±1.1	2.33±0.16a	75.71±0.27a	82.29±0.50bc	22.01±0.27c	17.71±0.50ab

平均值以 Mean ± SE 表示;组间无相同字母表示差异显著($P < 0.05$); $n = 6$

3 讨论

冬眠期间两栖动物通过消耗体内营养物质来维持生命活动,体内各组织器官(尤其是肝脏和脂肪体)储存的能量物质能够为机体提供必要的能量。由此推测:具有冬眠习性的蛙类在冬眠期和出眠期肥满度、肝系数和脂肪体会有所下降。如黑斑蛙(*Rana nigromaculata*)^[9]、东方铃蟾(*Bombina orientalis*)^[10]、花背蟾蜍(*Bufo raddei*)^[11]等蛙类在自然冬眠后肥满度 K 显著下降。但在对金线蛙(*Rana plancyi*)^[12]、花背蟾蜍^[13]的研究中发现,冬眠前后 K 无显著变化,甚至存在相反的报道,如邹寿昌^[14]研究表明大蟾蜍(*Bufo bufo gargarizans*)冬眠后 K 显著增加,花背蟾蜍 K 和躯体肥满度(去除内脏的躯壳重量与体重比)的平均值均有所增加,且躯体肥满度增加显著^[15]。本研究中,低温暴露期间雌性棘胸蛙亚成体(1—2 龄) K 和 K_{ul} 均有增大的趋势,恢复期与初始间也无显著差异。导致这一现象的原因

可能是这些冬眠蛙类皮肤从环境中吸入水分所致^[14]。又如林蛙在冬季其肝和肌肉中水含量显著增加,从而导致体重增加^[16],而研究者认为这可能是因为肾代谢功能下降,而不能将水从机体排除的缘故^[17]。此外,冬眠前后肥满度变化也存在性别差异,如东方铃蟾经过自然冬眠后雄体躯体肥满度变化不大,而雌体躯体肥满度显著降低,这可能与其在冬眠期生殖腺的增大相关,致使躯体显著消瘦^[10]。然而,雌性棘胸蛙亚成体(50 g 左右)在近三个月的低温期内性腺无明显发育,这是因为棘胸蛙生育年龄一般在 2—3 龄左右(体重 100 g 以上),且繁殖期主要在夏季,而蟾蜍、黑斑蛙等物种其性腺在冬季已经开始发育,因此,这是导致不同蛙类冬眠前后肥满度变化差异的重要原因之一。肝脏和脂肪体是蛙类越冬期最重要的两个储能和供能器官,如东方铃蟾^[10]、花背蟾蜍^[11]、黑斑蛙^[9]等在冬眠后肝系数和脂肪体系数均明显降低,说明越冬期能量和营养的大量消耗,而本研究发现棘胸蛙雌性亚成体在低温暴露期第 30 天和 60 天肝系数平均值却普遍高于初始,且在整个实验期间仅个别蛙体内存在极小的脂肪体。这可能与繁殖年龄有关,如 1 龄泽蛙(*Rana limnocharis*)入眠前肥满度虽然最小,但是肝系数却最大,而且脂肪体系数很小或几乎没有脂肪体;而 3 龄泽蛙脂肪体系数则最大^[18]。因此,这些差异可能与被研究物种所处的年龄阶段和其首次繁育年龄有关。此外,本研究发现胃系数和脾系数在低温暴露期显著增加,推测可能出现如胃壁增厚、组织养分变化等适应性变化,而脾肥大可能是胁迫特征之一,这与低温暴露期存活率下降相一致,具体原因有待进一步研究。

蛙类机体代谢是随季节变化而变化^[19-20],通常夏季脂肪代谢旺盛,冬季糖代谢旺盛^[21-23]。肝糖原是蛙类

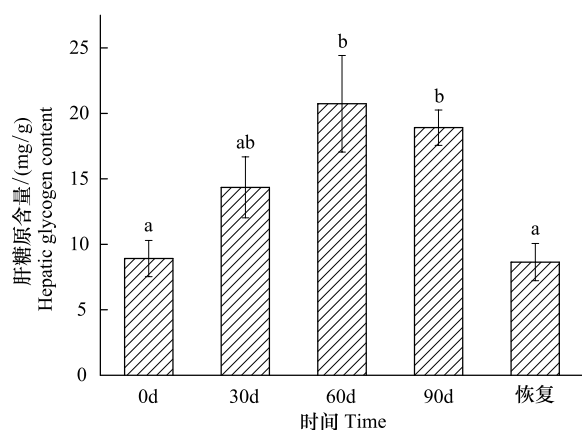


图 4 棘胸蛙(*Paa spinosa*)雌性亚成体在低温暴露和恢复各阶段肝糖原的变化

Fig. 4 Changes of hepatic glycogen content in sub-adult female giant spiny frogs (*Paa spinosa*) in different stages during the period of cold exposure and recovery

冬眠期能量的主要来源,肝糖原蓄积量通常在秋季时达到最大,进入冬季后逐渐下降,至产卵期时完全消耗尽,如芬兰北部的林蛙(*Rana temporaria* L.)肝糖原含量在秋末达到最大值,春季产卵后降到最低^[17]。这是因为肝糖原等小分子碳水化合物合成有助于增强无尾两栖类动物的耐寒性,可以降低其在冬眠期间死亡的风险。如在低温下蟾蜍可以将体内的肝糖原转化成防冻剂,而出冬眠后则将防冻剂转化成肝糖原^[24]。蛙类最主要的生物防冻剂就是葡萄糖^[25],而肝糖原能够转化为葡萄糖,表现在冬眠期葡萄糖合成途径中肝糖磷酸化酶活性的提高^[24-25],如冬眠期三锯拟蝗蛙(*Pseudacris triseriata*)肝糖原的含量降低,而肝脏和肌肉组织中的葡萄糖含量及磷酸化酶的活力均出现显著性升高,进一步证实了肝糖原与葡萄糖之间的转化关系^[26]。而本研究中,低温暴露却导致棘胸蛙肝糖原上升,恢复期肝糖原则却回落至初始水平,这可能是由于低温暴露能够诱导肝糖原酶和葡萄糖酶活性的修饰,增强糖分解和糖异生酶的活性,增加肝糖原蓄积量^[27],或者部分种类在冬眠期间磷酸化酶活性增强,肝糖原的合成能力也随之增强,导致组织中肝糖原含量显著升高^[28]。如在爬行类中,沙漠巨蜥(*Vuronus griseus*)在冬眠期间其骨骼、心肌以及肝中的糖原含量不变甚至升高^[29-30]。因此,肝糖原变化趋势在自然冬眠或人工低温暴露条件下出现差异可能与不同物种采取的低温生理适应机制有关。值得一提的是,本研究中发现在低温暴露过程中该蛙肝脏和肌肉脂肪含量变化不显著,同时肥满度、肝系数、肝脏非脂肪干物质和肝糖原含量均有不同程度的升高,而肌肉非脂肪干物质则显著减少,说明该蛙雌性亚成体在低温期主要消耗的能量物质不是脂肪而是肌肉非脂肪干物质(如肌糖原等糖类物质),或者肌肉非脂肪干物质在组织间发生了大量转运。对于大部分冬眠动物来说,在冬眠状态下其脂肪组织起到非常重要的作用^[31],而葡萄糖是最直接的供能物质^[32],可以通过肝脏的糖异生和肝糖分解来产生。本研究中肝糖原呈现上升趋势,并没有被大量消耗,在漫长的冬眠过程中糖异生可能是产生葡萄糖的重要途径^[33],那么肌肉非脂肪干物质的减少是否与糖异生有关,需要进一步研究。另外,虽然该蛙雌性亚成体在低温暴露条件下的状态并不能完全等同于其在自然生境中的正常冬眠,但本研究结果可以为棘胸蛙自然越冬生理研究提供参考。

References:

- [1] Superina M, Boily P. Hibernation and daily torpor in an armadillo, the pichi (*Zaedyus pichiy*). *Comparative Biochemistry and Physiology-Part A: Molecular and Integrative Physiology*, 2007, 148(4): 893-898.
- [2] Jenkins J L, Swanson D L. Liver glycogen, glucose mobilization and freezing survival in chorus frogs, *Pseudacris triseriata*. *Journal of Thermal Biology*, 2005, 30(6): 485-494.
- [3] Reading C J. Linking global warming to amphibian declines through its effects on female body condition and survivorship. *Oecologia*, 2007, 151(1): 125-131.
- [4] Shu M A. An analysis of the nutritive compositions in muscle of *Paa spinosa*. *Journal of Zhejiang University: Sciences Edition*, 2000, 27(4): 433-437.
- [5] Zhu B Q. An analysis of the nutritive compositions of *Paa spinosa* David. *Chinese Journal of Zoology*, 2000, 35(3): 31-32.
- [6] Wen T, Xie F, Jiang J P, Huang B. A study on mode of utilization of *Paa* resource in China. *Journal of Modern Fisheries Information*, 2006, 21(12): 14-16.
- [7] Wang A M, Liu W B, Guo W H, Gao G F, Huang N C. Primary study on the overwintering experiment of *Paa spinosa*. *Reservoir Fisheries*, 2002, 22(1): 3-4.
- [8] Cui Y B. Bioenergetics of fishes: theory and methods. *Acta Hydrobiologica Sinica*, 1989, 13(4): 369-383.
- [9] Can Y P, Bai M, Ma R, Chen H B, Zhang Z, Li Z, Ren S S. Studies on the ecology and morphological physiology of *Rana nigromaculata* before and after hibernation. *Sichuan Journal of Zoology*, 2000, 19(3): 159-162.
- [10] Xu J M, Li Y C, Gong Z Y. Changes on relative fatness and some viscera of *Bombina orientalis* during the period of hibernation and starvation. *Chinese Journal of Zoology*, 1997, 32(4): 20-22.
- [11] Yu D, Zhao W G. Breeding ecology of *Bufo raddei* in Harbin region. *Sichuan Journal of Zoology*, 2006, 26(2): 409-411.
- [12] Feng Z J, Wang Y Q, Liu H X, Chen Y, Sun M, Xia Z Y. Changes on relative fatness and some viscera of *Rana plancyi* before and after hibernation. *Sichuan Journal of Zoology*, 2003, 22(1): 29-30.
- [13] Jiang Y F. Primary study on hibernation ecology of *Bufo raddei*. *Chinese Journal of Zoology*, 1988, 23(4): 8-11.
- [14] Zou S C. Changes on relative fatness and some viscera of *Bufo bufo gargarizans* during the period of hibernation. *Acta Herpetologica Sinica*, 1985, 4(4): 320-324.
- [15] Zou S C. Changes on relative fatness and some viscera of *Bufo raddei*. *Sichuan Journal of Zoology*, 1988, 7(3): 34-35.

- [16] Zamachowski W. Changes in the weight of the body of the common frog, *Rana temporaria* L. during the period of hibernation. *Acta Biologica Cracoviensia Series Zoologia*, 1966, 11: 199-206.
- [17] Pasanen S, Koskela P. Seasonal and age variation in the metabolism of the common frog, *Rana temporaria* L. in northern Finland. *Comparative Biochemistry and Physiology Part A: Physiology*, 1974, 47(2): 635-654.
- [18] Wang X L, Wang J L, Jiang H R, Xue W J, Xu H F. Primary survey on relative fatness and population of *Rana limnocharis* lived in Shanghai suburb farm. *Sichuan Journal of Zoology*, 2007, 26(2): 424-427.
- [19] Smith C L. Seasonal changes in blood sugar, fat body, liver glycogen, and gonads in the common frog, *Rana temporaria*. *Journal of Experimental Biology*, 1950, 26(4): 412-429.
- [20] Smith C L. Environmental temperature and the glycogen content of the frog's liver (*Rana temporaria*) *Nature*, 1952, 170(4315): 74-75.
- [21] Mizell S. Seasonal changes in energy reserves in the common frog, *Rana pipiens*. *Journal of Cellular and Comparative Physiology*, 1965, 66(2): 251-258.
- [22] Jungreis A M. The effects of long-term starvation and acclimation temperature on glucose regulation and nitrogen anabolism in the frog, *Rana pipiens*-II. Summer animals. *Comparative Biochemistry and Physiology*, 1970, 32(3): 433-444.
- [23] Jungreis A M, Hooper A B. The effects of long-term starvation and acclimation temperature on glucose regulation and nitrogen anabolism in the frog, *Rana pipiens*-I. Winter animals. *Comparative Biochemistry and Physiology*, 1970, 32(3): 417-432.
- [24] Storey K B. Glycolysis and the regulation of cryoprotectant synthesis in liver of the freeze tolerant wood frog. *Journal of Comparative Physiology B: Biochemical, Systemic, and Environmental Physiology*, 1987, 157(3): 373-380.
- [25] Storey K B. Life in a frozen state: adaptive strategies for natural freeze tolerance in amphibians and reptiles. *American Journal of Physiology*, 1990, 258(3): R559-R568.
- [26] Jenkins J L, Swanson D L. Liver glycogen, glucose mobilization and freezing survival in chorus frogs, *Pseudacris triseriata*. *Journal of Thermal Biology*, 2005, 30(6): 485-494.
- [27] Blier P, Guderley H. The enzymatic and metabolic effects of extended food deprivation in *Rana pipiens*. *Physiological Zoology*, 1986, 59(2): 230-239.
- [28] Abdel-Kader A K M, El-Daly E, Okasha S, Mansour A H. Carbohydrate metabolism in *Malpolon monspessulanus* and *Uromastix aegyptius* during the entry, deep and arousal phases of hibernation. *Journal of Thermal Biology*, 1995, 20(5): 367-372.
- [29] Haggag G, Raheem K A, Khalil F. Hibernation in reptiles-II. Changes in blood cell glucose, haemoglobin, red blood cell count, protein and non-protein nitrogen. *Comparative Biochemistry and Physiology*, 1966, 17(1): 335-339.
- [30] Haggag G, Raheem K A, Khalil F. Hibernation in reptiles-III. Tissue analysis for glycogen and high energy phosphate compounds. *Comparative Biochemistry and Physiology*, 1966, 17(1): 341-347.
- [31] Chanda D, Abhilasha, Krishna A. Seasonal adiposity and delayed ovulation in a vespertilionid bat, *Scotophilus heathi*: role of tumor necrosis factor- α . *Physiological and Biochemical Zoology*, 2003, 76(2): 271-280.
- [32] Boswell T, Woods S C, Kenagy G J. Seasonal changes in body mass, insulin, and glucocorticoids of free-living golden-mantled ground squirrels. *General and Comparative Endocrinology*, 1994, 96(3): 339-346.
- [33] Mustonen A M, Nieminen P, Hyvärinen H. Melatonin and the wintering strategy of the tundra vole, *Microtus oeconomus*. *Zoological Science*, 2002, 19(6): 683-687.

参考文献:

- [5] 朱炳全. 棘胸蛙营养成分的分析. *动物学杂志*, 2000, 35(3): 31-32.
- [7] 王爱民, 刘文斌, 郭文汉, 高国富, 黄宁昌. 棘胸蛙越冬试验初步研究. *水利渔业*, 2002, 22(1): 3-4.
- [8] 崔奕波. 鱼类生物能量学的理论与方法. *水生生物学报*, 1989, 13(4): 369-383.
- [9] 曹玉萍, 白明, 马荣, 陈红波, 张昭, 李志, 任珊珊. 黑斑蛙蛰眠前后形态生理生态变化初探. *四川动物*, 2000, 19(3): 159-162.
- [10] 徐敬明, 李永臣, 龚兆铎. 东方铃蟾冬眠时与禁食致死时肥满度及某些内脏器官的变化. *动物学杂志*, 1997, 32(4): 20-22.
- [11] 于东, 赵文阁. 黑龙江哈尔滨地区花背蟾蜍繁殖生态的观察. *四川动物*, 2006, 26(2): 409-411.
- [12] 冯照军, 王永强, 刘海侠, 陈云, 孙敏, 夏正艳. 金线蛙冬眠前后肥满度及部分内脏器官的变化. *四川动物*, 2003, 22(1): 29-30.
- [13] 姜雅凤. 花背蟾蜍冬眠生态学的初步研究. *动物学杂志*, 1988, 23(4): 8-11.
- [14] 邹寿昌. 大蟾蜍冬眠期的肥满度及部分内脏器官的变化. *两栖爬行动物学报*, 1985, 4(4): 320-324.
- [15] 邹寿昌. 花背蟾蜍冬眠期肥满度及部分内脏器官的变化. *四川动物*, 1988, 7(3): 34-35.
- [18] 王晓黎, 王晶琳, 姜海瑞, 薛文杰, 徐宏发. 上海郊区农田泽蛙种群动态和肥满度状况初探. *四川动物*, 2007, 26(2): 424-427.

CONTENTS

Hyperspectral characteristics of typical subtropical trees at different levels of simulated acid rain	SHI Qilong, JIANG Hong, CHEN Jian, et al (5621)
Wind fields and the development of wind corridors in the urban metropolis of the Pearl River Delta	SUN Wu, WANG Yiming, WANG Yuelei, et al (5630)
Dynamics of canopy structure and understory light in montane evergreen broadleaved forest following a natural disturbance in North Guangdong	OU Yudian, SU Zhiyao (5637)
The influence of 4 species of preys on the development and fecundity of <i>Orius similis</i> Zheng	ZHANG Changrong, ZHI Junrui, MO Lifeng (5646)
Woody seedling regeneration in secondary succession of monsoon broad-leaved evergreen forest in Puer, Yunnan, Southwest China	LI Shuaifeng, LIU Wande, SU Jianrong, et al (5653)
Scale-dependent spatial variation of species abundance and richness in two mixed evergreen-deciduous broad-leaved karst forests, Southwest China	ZHANG Zhonghua, HU Gang, ZHU Jiedong, et al (5663)
The spatial heterogeneity of soil nutrients in a mid-subtropical <i>Castanopsis kawakamii</i> natural forest	SU Songjin, LIU Jinfu, HE Zhongsheng, et al (5673)
Effects of <i>Vetiveria zizanioides</i> L. growth on chemical and biological properties of copper mine tailing wastelands	XU Decong, ZHAN Jing, CHEN Zheng, et al (5683)
Effects of different irrigation regimes on characteristics of transpiring water-consumption of three desert species	SHAN Lishan, LI Yi, ZHANG Ximing, et al (5692)
The response of euhalophyte <i>Salicornia europaea</i> L. to different nitrogen forms	NIE Lingling, FENG Juanjuan, LÜ Sulian, et al (5703)
Dynamic analysis on spatial pattern of dominant tree species of cold-temperate coniferous forest in the succession process in the Pangquangou Nature Reserve	ZHANG Qindi, BI Runcheng, ZHANG Jintun, et al (5713)
Effects of AM fungi on the growth and nutrients of <i>Salvia miltiorrhiza</i> Bge. under different soil water and fertilizer conditions	HE Xueli, MA Li, MENG Jingjing, et al (5721)
The dynamics of soil respiration in a winter wheat field with plastic mulched-ridges and unmulched furrows	SHANGGUAN Yuxian, SHI Ripeng, HAN Kun, et al (5729)
Cattle dung composted by different methods had different effects on the growth and quality of soybean	GUO Liyue, LIU XueMei, ZHAN Lijie, et al (5738)
Nitrogen budget modelling at the headwaters of Urumqi River Based on the atmospheric deposition and runoff	WANG Shengjie, ZHANG Mingjun, WANG Feiteng, et al (5747)
Evaluating the ecosystem sustainability of circular agriculture based on the energy theory: a case study of the Xingyuan circular agriculture demonstration site in Fuqing City, Fujian	ZHONG Zhenmei, WENG Boqi, HUANG Qinlou, et al (5755)
Effects of cold exposure and recovery on viability and energy consumption in the sub-adult female giant spiny frogs (<i>Paa spinosa</i>)	LING Yun, SHAO Chen, XIE Zhigang, et al (5763)
A comparison of night-interruption on diapause-averting among two populations of the cotton bollworm, <i>Helicoverpa armigera</i>	CHEN Yuansheng, TU Xiaoyun, CHEN Chao, et al (5770)
Effects of soil erosion control measures on soil organic carbon and total nitrogen in a small watershed	ZHANG Yanjun, GUO Shengli, NAN Yafang, et al (5777)
Comparative analysis of Lugu Lake watershed ecosystem function under different management authorities	DONG Rencai, GOU Yaqing, LI Siyuan, et al (5786)
Relationship between fish community diversity and environmental factors in the Lianjiang River, Guangdong, China	LI Jie, LI Xinhui, JIA Xiaoping, et al (5795)
Effect of dissolved oxygen level on metabolic mode in juvenile crucian carp	ZHANG Wei, CAO Zhendong, FU Shijian (5806)
Community composition of net-phytoplankton and its relationship with the environmental factors at artificial reef area in Xiangshan Bay	JIANG Zhibing, CHEN Quanzhen, SHOU Lu, et al (5813)
Emergency appraisal on the loss of ecosystem service caused by marine reclamation: a case study in the Taozi Bay	LI Ruiqian, MENG Fanping (5825)
Assessing the visual quality of urban waterfront landscapes: the case of Hefei, China	YAO Yumin, ZHU Xiaodong, XU Yingbi, et al (5836)
Review and Monograph	
Advances in ecological genomics	SHI Yongbin, LI Junmin, JIN Zexin (5846)
Advances in studies of ecological effects of ocean acidification	WANG Siru, YIN Kedong, CAI Weijun, et al (5859)
Advances in feeding ecology of <i>Acartia</i>	HU Simin, LIU Sheng, LI Tao, et al (5870)
Research progress on ammonia-oxidizing microorganisms in estuarine ecosystem	ZHANG Qiufang, XU Jirong, SU Jianqiang, et al (5878)
Recent progress in research on neutrophilic, microaerophilic iron(II)-oxidizing bacteria	LIN Chaofeng, GONG Jun (5889)
A comparison study on primary production in typical low-latitude seas (South China Sea and Bay of Bengal)	LIU Huaxue, SONG Xingyu, HUANG Honghui, et al (5900)
Advances in leaf maximum carboxylation rate and its response to environmental factors	ZHANG Yanmin, ZHOU Guangsheng (5907)
10-years of bird habitat selection studies in mainland China: a review	JIANG Aiwu, ZHOU Fang, QIN Yue, et al (5918)
Scientific Note	
The effects of incubation temperature on embryonic metabolism and hatchling behavior in the Red-banded Snake, <i>Dinodon rufonotatum</i>	SUN Wenjia, YU Xiao, CAO Mengjie, et al (5924)
Sensitivity analysis and dynamics of soil microbial biomass carbon, nitrogen and related parameters in red-yellow soil of tea garden with different fertilization practices	WANG Limin, QIU Shanlian, LIN Xinjian, et al (5930)
Effect of fertilizers on Cd uptake of two edible amaranthus herbs	LI Ningyu, LI Zhian, ZHUANG Ping, et al (5937)

《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 18 期 (2012 年 9 月)

ACTA ECOLOGICA SINICA

(Semimonthly, Started in 1981)

Vol. 32 No. 18 (September, 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