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生物多样性与生态系统功能的实验研究

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Studies on biodiversity and ecosystem function via manipulation experiments

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人类活动加剧导致物种丧失。在物种绝灭之前, 负面影响就已经产生, 主要体现在对生态系统功能的影响。如何量化物种丧失对生态系统功能产生的影响, 最有效的途径就是控制实验。相关的研究进展本刊曾经作过比较详细的报道(黄建辉等, 2001; 张全国和张大勇, 2002, 2003)。生物多样性的生态系统功能(biodiversity and ecosystem function, BEF)是生物多样性科学领域的热点问题之一。

早在20世纪80年代, 人们研究物种丧失速率时就发现, 物种丧失可能影响生境的变化(Lawton, 1994)、生物地球化学循环(Sterner & Elser, 2002)和生态系统生产力(Power *et al.*, 1996)等生态系统的结构和功能。环境问题委员会(SCOPE)和联合国环境规划署(UNEP)分别组织编写的*Biodiversity and Ecosystem Function*(Schulze & Mooney, 1993)和*Global Biodiversity Assessment*(Heywood, 1995)两本书在BEF的知识总结和理论思考方面起到了重要作用。而国际生物多样性项目(DIVERSITAS)也一直致力于推动这方面的研究, 其不断更新完善的研究计划发挥了重要的指导作用(http://www.diversitas-international.org)。最早关于生物多样性和生态系统功能的研究始于20世纪90年代初的英国生态箱(ecotron)实验(Naeem *et al.*, 1994), 之后美国和欧洲开展了一系列的草地生物多样性与生态系统功能的实验(Tilman *et al.*, 1996; Leadley & Körner, 1996)。实验结果显示生物多样性与生态系统功能密切相关, 但如何解释这些结果背后的机制却出现了完全不同的观点, 包括对其实验设计和分析方法都提出过质疑(Grime, 1997; Huston, 1997; Schmid *et al.*, 2002; Loreau *et al.*, 2002), 争论非常激烈, 甚至有人将2002年称为多样性与生态系统功能关系争论之年(Cameron, 2002)。截至2009年, 国内外已有数百篇文章报道了来自不同生态系统类型的600多个实验的结果(Cardinale *et al.*, 2011; Loreau *et al.*, 2002), 有力地推动了生态学的发展。

而今生物多样性与生态系统功能研究开始向大尺度发展, 并且逐渐与人类社会的发展密切联系起来, 形成了新的研究重点, 即生物多样性与生态系统服务的关系(biodiversity and ecosystem service, BES)(Cardinale *et al.*, 2012)。在全球变化的背景下, 生物多样性的生态系统功能和服务会如何作出响应, 也是当前人们关注的热点问题。

以往的生物多样性与生态系统功能实验多以草地为主, 对陆地生态系统中生产力最高、组成最复杂的森林生态系统的研究却为之不多。森林生物多样性的生态系统功能实验较之草地系统有其突出的优势: (1)可以在个体水平上开展实验研究; (2)树木生长时间长, 可更加充分地观察到物种间及其与环境间的相互作用随时间的变化; (3)森林实验更方便控制密度和均匀度。第一个森林生物多样性的生态系统功能实验样地于1999年在芬兰建立, 到目前为止世界上已有12个森林实验样地(http://www.treedivnet.ugent.be/index.html)。由中国国家自然科学基金委员会和德国科学基金会联合资助的项目"中国亚热带森林生物多样性与生态系统功能实验研究(Biodiversity-Ecosystem Functioning Experiment China, 简称BEF-China)"于2008–2010年在江西德兴市新岗山镇建立的大型森林控制实验样地是其中包含树种最多、涉及多样性水平最高, 且建于地形复杂林区的实验平台。

BEF-China实验样地包括三个部分：古田山国家级自然保护区天然林的比较实验样地、与古田山毗邻的新岗山预实验样地和新岗山主实验样地。

天然林比较样地：样地的建立旨在探讨: (1)随着森林的演替, 木本植物丰富度的变化规律; (2)影响这些变化规律的随机扩散、种间竞争、个体死亡等重要过程所起的作用。样地于2008年建立, 共设27个30 m × 30 m的小样地(附图1)。样地覆盖5个演替阶段, 群落年龄分别约为35年、43年、66年、79年和95年。根据第一次普查, 株高大于1 m的木本植物有148种, 隶属于46科(Bruelhaide *et al.*, 2011)。每个小样地中的工作均涉及植物、昆虫、微生物等不同营养级水平(附图2)。

新岗山预实验样地：建于2009年4月, 旨在小规模短时间内考察树种在幼苗期间的相互作用及其对光、土壤养分、菌根真菌等的响应, 同时也为稍后开展的大规模主实验设计和理解主实验树种的早期表现提供基础资料。样地建在邻近主实验样地的1 ha农田中, 分为4个基本实验小区, 每个小区含333个1 m × 1 m的样方, 共计1,332个; 每个样方种植16株树苗, 物种数为1, 2, 4三个水平, 株行距一般为25 cm (附图3)。根据天然林比较样地中物种多度、与生长相关的功能性状和种子可获性等因素选择21个树种构成预实验物种库。从物种库中随机抽取4个物种为一组, 对应种植于每个实验小区。有8个子项目参与预实验, 控制处理包括遮光、菌根菌杀除、家系水平的变异等。实验于2011年7月结束。

新岗山主实验样地：建立在两大自然坡地上, 分别为样地A和样地B(附图4), 样地A于2009年建成, 海拔105–275 m; 样地B于2010年建成, 海拔105–190 m。两个样地均以1亩(25.82 m × 25.82 m)为基本单元样方进行幼苗种植, 共计566个, 其中样地A有271个, 样地B有295个, 净占地38.4 ha, 总占地53 ha。幼苗物种库由42种乔木(包括杉木(*Cuuninghamia lanceolata*)和马尾松(*Pinus massoniana*)两个当地的主要造林树种)和18种灌木构成。1亩的基本样方中, 乔木物种水平分别为1, 2, 4, 8, 16和24种。样方中物种的分配按照随机断棍设计和物种直接丧失两种方案进行。此外, 样地设置64个超级样方, 由4个1亩样方组成, 配置有灌木, 物种水平分别为2, 4, 8种。据此, 物种水平最高的样方会有16种乔木和8种灌木或者全部为乔木, 即24种木本植物。根据比较样地中乔木冠层的研究结果, 主实验样地中每个样方的株行距均为1.29 m, 相当于每亩400株幼苗的密度。两个样地栽植木本植物总数超过30万株。样地植物配置与功能划分格局见附图5。根据2009年11月和2010年6月对样地A的两次调查统计, 栽植14个月后的树苗成活率为87%, 其中常绿树种成活率84%, 落叶树种成活率93%(Yang *et al.*, 2013)。

BEF-China实验项目还同时建立了数据库(http://159.226.89.107), 成为各子项目提供数据和信息管理与共享的平台。

BEF-China实验最初于2006年2月在德国哈雷开始讨论和筹备, 2008年正式开展野外工作。项目从确定实验设计、比较样地建立与数据分析、预实验样地建立与数据分析, 一直到主实验样地建立与数据采集, 各个环节都为研究亚热带森林生物多样性和生态系统功能积累了丰富的数据, 中德双方分别在*Ecology Letters, Ecological Monographs*等生态学主流刊物联合发表近30篇论文(附录I), 特别是在森林演替过程中物种丰富度和稀有种丰富度变化、植物多样性与昆虫多样性的关系、植物功能性状与环境的关系以及邻体植物间的相互作用等方面取得了明显的进展, 在国际同行中产生了较大的影响。

开展森林生物多样性和生态系统功能实验研究, 除了关注物种丧失对生态系统功能影响的机制外, 扩大造林树种的选择也是其重要目标。目前, 造林树种很单一, 以中国南方为例, 主要是杉木、马尾松和桉树(*Eucalyptus* spp.)等少数物种, 大量的本土树种还有待开发利用。森林BEF实验不仅可以用来筛选速生优质用材树种, 还可以来筛选不同树种的组合方式, 为林业发展提供更多的适宜的造林树种资源。木材是森林生态系统提供的重要“产品”之一, 而保持水土和固碳则是森林生态系统重要的“服务”功能。因此, 研究生物多样性与生态系统服务也是这种大型控制实验的重要目标。

文中引用的参考文献见附录II。

附录I BEF-China 项目发表论文目录(截止2013年5月30日) (http://www.biodiversity-science.net/fileup/PDF/W2013-132-1.pdf)
附录II 参考文献(http://www.biodiversity-science.net/fileup/PDF/W2013-132-2.pdf)
附图1 BEF-China实验样地中的浙江古田山天然林比较样地(http://www.biodiversity-science.net/fileup/PDF/W2013-132-3.pdf)
附图2 BEF-China实验样地中的比较样地的实验设计和相关的子项目(http://www.biodiversity-science.net/fileup/PDF/W2013-132-4.pdf)
附图3 BEF-China实验样地中的新岗山预实验样地一角(http://www.biodiversity-science.net/fileup/PDF/W2013-132-5.pdf)
附图4 BEF-China实验样地中的新岗山主样地样方空间分布(http://www.biodiversity-science.net/fileup/PDF/W2013-132-6.pdf)
附图5 BEF-China实验样地中的新岗山主样地植物配置与功能分区(http://www.biodiversity-science.net/fileup/PDF/W2013-132-7.pdf)

附录I BEF-China项目发表论文目录(截至2013年5月30日)

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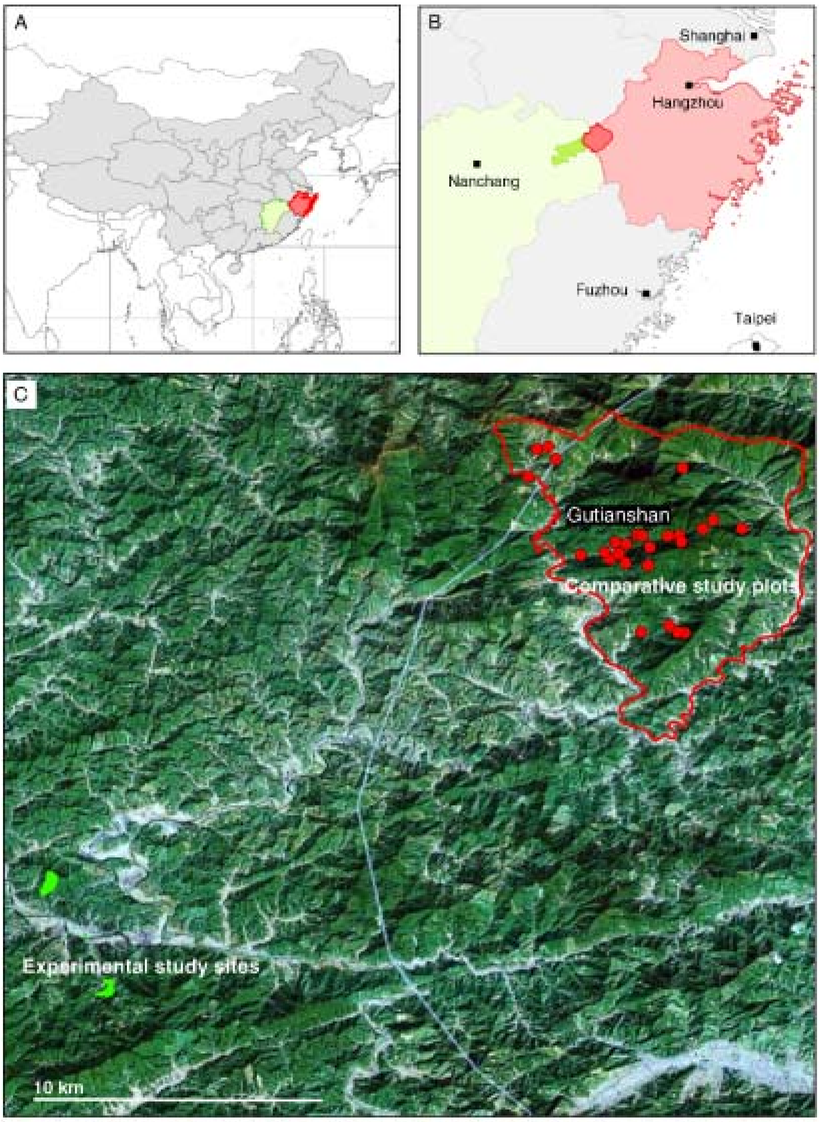
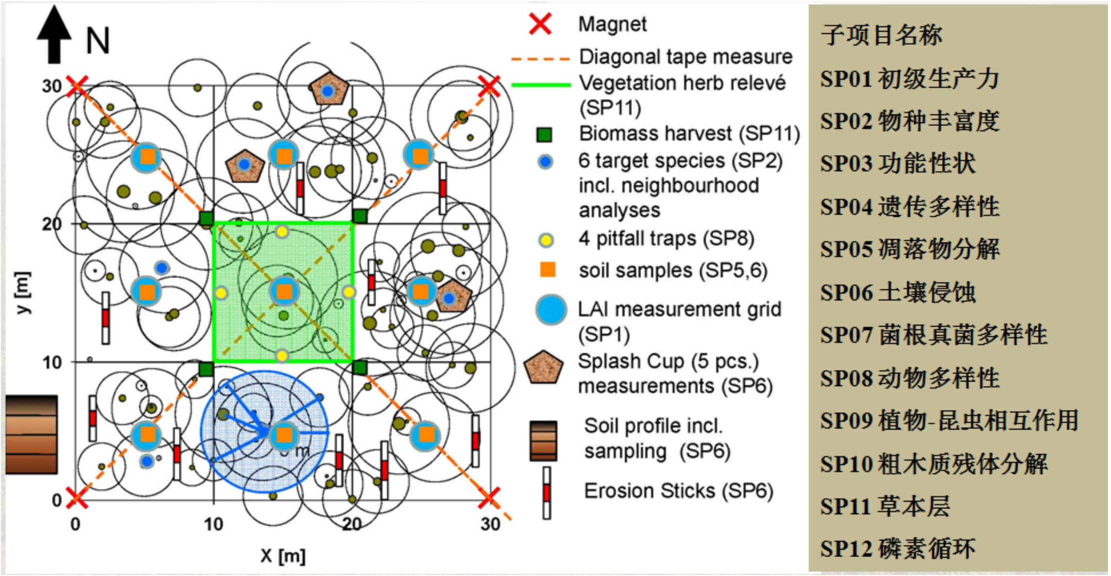
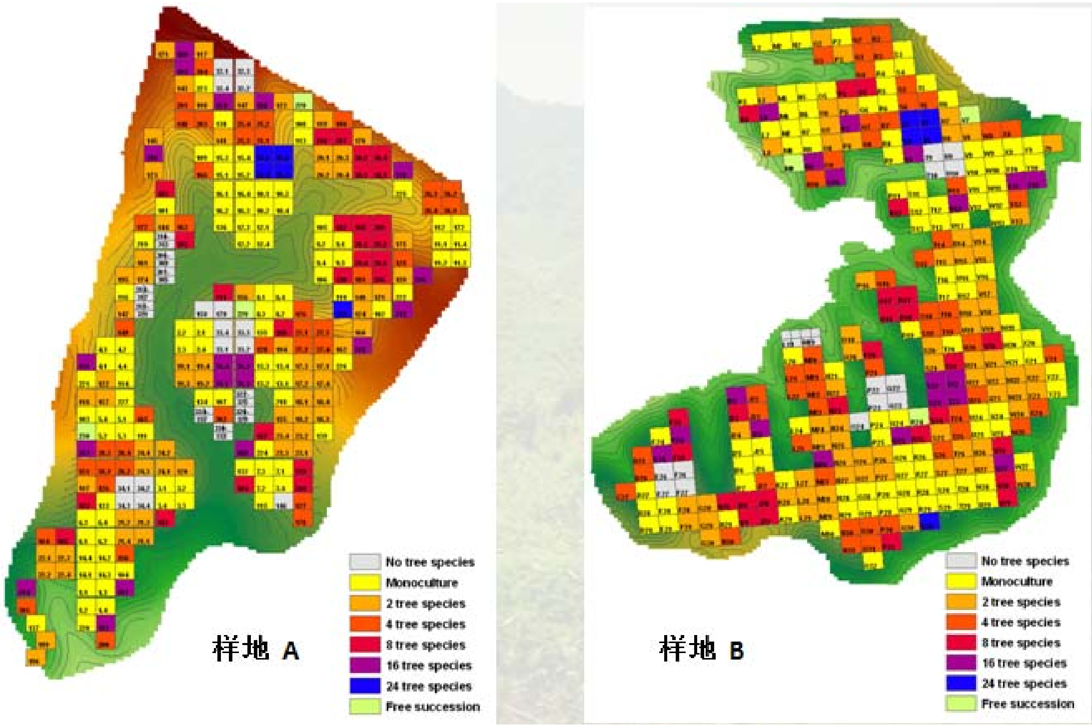


附图**1**　浙江古田山天然林比较样地分布图
(A) 浙江省(红色)和江西省(绿色)位置; **(B)** 古田山国家级自然保护区(深红色)和德兴市(深绿色)位置; **(C)** 古田山天然林比较样地27个小样地分布图(红色圆点)(引自项目申请报告**Proposal for the 2nd of the DFG Research Unit 891 phase (2011–2014)**第**13**页)。

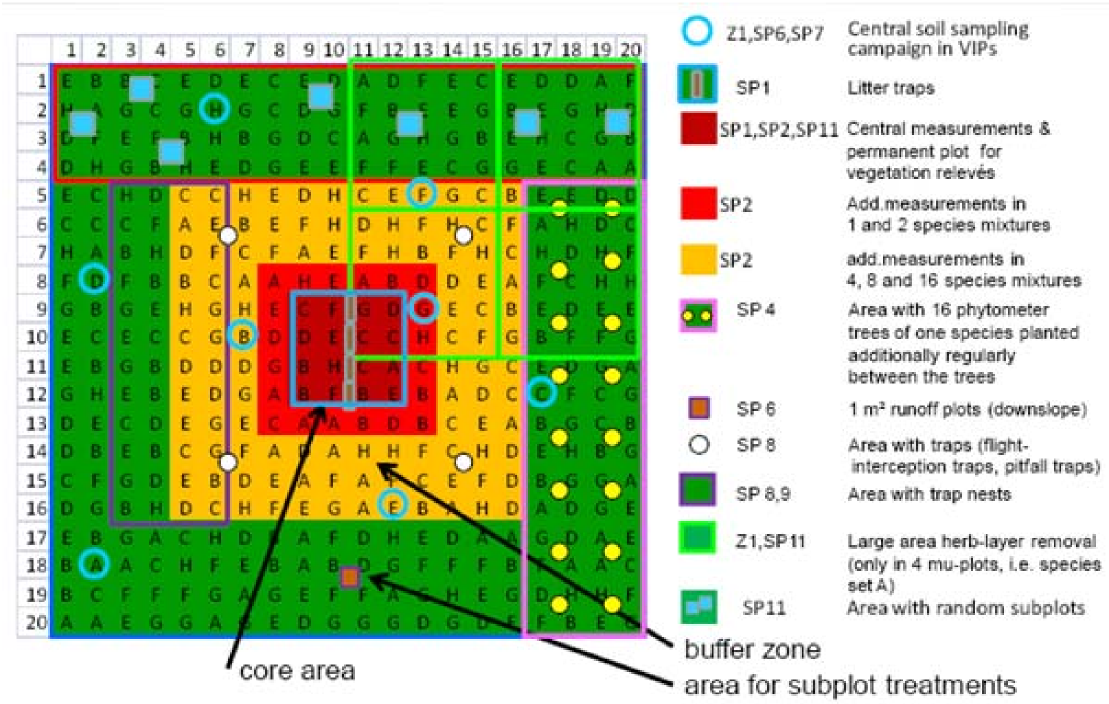


附图2　比较样地每个小样地中的实验设计和与此相关的子项目示意图(引自项目申请报告**Proposal for the 2nd of the DFG Research Unit 891 phase (2011–2014)**第23页)

附图3　新岗山预实验样地一角(马克平摄)



附图**4**　新岗山主样地样方空间分布以及物种多样性水平示意(引自项目申请报告**Proposal for the 2nd of the DFG Research Unit 891 phase (2011–2014)**第**50–51**页)



附图**5**　新岗山主样地1亩基本样方中植物配置与功能分区示意图(子项目代号的意义同图2，引自项目申请报告**Proposal for the 2nd of the DFG Research Unit 891 phase (2011–2014)**)第57页)