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神农架自然遗产地植被垂直带谱的特点和代表性

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摘　要　充分认识并掌握我国自然遗产地山地植被垂直带谱代表性, 对正确评估自然遗产地的价值进而制定相关保护管理政策具有重要的科学意义和现实意义。该研究基于群落调查数据、全球1 km^{2}土地利用数据, 通过对比分析、空间分析等方法, 从植被垂直带谱的地带性、完整性及不同垂直带群落物种更替等角度, 分析论证了神农架自然遗产地植被垂直带谱的代表性。结果显示: 神农架自然遗产地从低海拔到高海拔依次发育有常绿阔叶林带(遗产地南坡)、常绿落叶阔叶混交林带、落叶阔叶林带、针阔混交林带、针叶林带及亚高山灌丛和草甸带, 其北坡保存的地带性常绿落叶阔叶混交林是北半球常绿落叶阔叶混交林生态系统的最典型代表。神农架自然遗产地拥有的植被垂直带谱是“全球生物地理区划”中东方落叶林生物地理省最完整的植被垂直带谱, 在东方落叶林生物地理省具有唯一性和代表性, 在较小的水平距离范围内浓缩了中亚热带、北亚热带、暖温带、温带和寒温带等生态系统特征, 成为研究全球气候变化下山地生态系统垂直分异规律及其生态学过程的杰出范例, 具有突出的世界自然遗产价值。

关键词　海拔梯度; 地带性植被; 常绿落叶阔叶混交林; 东方落叶林生物地理省; 完整性

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Characteristic and representativeness of the vertical vegetation zonation along the altitudinal gradient in Shennongjia Natural Heritage

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Abstract

Aims　Mountains contain broad environmental gradients, which are to be an outstanding universal value representing significant on-going ecological and biological processes in the evolution and development of zonal vegetation along the elevation gradients. Exploring the biological and ecological value of the vegetation zonation along the elevation gradients of Chinese mountain natural heritage site is important for biodiversity conservation and management.

Methods　Based on the community survey data of the six vegetation zonation along the elevational gradients in Shennongjia, the global land use dataset, and the literature data of the communities along the altitudinal gradients of other natural heritage sites and the nominated world natural heritage sites in Oriental Deciduous Forest Biogeographic Province by Udvardy, we explored the outstanding universal value of the zonal vegetation along the altitude gradients by the methods of spatial analysis.

Important findings　Shennongjia heritage site preserves the intact vegetation zonation of the typical Oriental Deciduous Forest Biogeographical Province in the Classification of the Biogeographical Provinces of the World by Udvardy, including evergreen broad-leaved forests (South Slope of the Heritage Site), evergreen deciduous broad-leaved mixed forests, deciduous broad-leaved forests, coniferous and broad-leaved mixed forests, coniferous forests and subalpine shrub and meadow along the elevation gradients. The altitudinal zonation of vegetation in the Shennongjia heritage site represented a variety of bio-ecological processes, such as the turnover of the dominant trees along the altitudinal gradients, and is an outstanding example of the ongoing ecological processes occurring in the development of intact subtropical mixed broadleaved evergreen and deciduous forest in the Northern Hemisphere.

Key words　elevation gradient; zonal vegetation; evergreen and deciduous broad-leaved mixed forest; Oriental

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山地是指具有一定海拔高度、相对高度和坡度的地面(王襄平等, 2004)。山地覆盖全球陆地地表近25%, 全球近1/3世界自然遗产地分布于山地(Barthlott *et al*., 1996; He *et al*., 2016)。山地因其在较小的空间范围内显著的环境梯度, 浓缩了水平自然带的自然地理和生态学特征(Korner, 2007)。山地因受第四纪冰川和现代人类活动的影响较小而保存了良好的自然生境和植被, 形成了显著的植被垂直带谱, 成为生物多样性的避难所和关键生物生态学过程的集中展示地(Beniston, 2003)。生态学家和生物地理学家很早就认识到山地植被垂直带谱的生物生态学意义和突出价值(Sundqvist *et al*., 2013)。1914年, Grinnell首次认识到山地海拔梯度对动植物分布的限制作用, 并认识到山地海拔梯度决定动植物进化和适应等生物生态学方面的重要性(Grinnell, 1924)。20世纪Whittaker开展了美国大烟山(Great Smoky Mountains)和锡斯基尤山(Siskiyou Mountains)山地植被垂直带谱的生物生态学研究(Whittaker, 1956, 1960)。近年来, 日趋增多的山地群落多样性(Rahbek, 2005)和生态系统过程等方面的研究, 进一步证实了山地植被垂直带谱在生物生态学过程方面的重要价值(Raich *et al*., 1997; Rahbek, 2005; Colwell *et al*., 2008)。

中国是一个山地大国, 国土面积的2/3为山地(中国科学院中国自然地理编委会, 1980), 15处被列入《世界自然遗产名录》(其中4处为世界自然和文化双遗产地)的自然遗产地均位于山地(马克平, 2016)。充分认识并掌握我国自然遗产地山地植被垂直带谱的代表性, 凝练其世界自然遗产地全球突出普遍价值, 对正确地评估自然遗产地的保护价值进而制定相关保护管理政策, 具有重要的科学意义和现实意义。

神农架自然遗产地地处Udvardy全球生物地理区划(Giogeographic Classification System)中的东方落叶林生物地理省, 山体海拔高差达2 700 m, 从低海拔到高海拔依次呈现出亚热带、暖温带、温带、寒温带等气候特点, 海拔垂直分异显著。本研究围绕植被垂直带谱的代表性, 从植被垂直带谱的地带性、完整性以及不同垂直带群落物种更替等角度, 分析论证了神农架自然遗产地植被垂直带谱的突出遗产价值, 以期为神农架自然遗产地的科学保护和管理提供依据。

1 材料和方法

1.1 研究区概况

神农架自然遗产地主体位于湖北神农架国家级自然保护区, 包括部分巴东沿渡河自然保护区, 总面积73 318 hm^2, 缓冲区总面积41 536 hm^2。遗产地位于中国地势第二阶梯的东部边缘, 为大巴山脉东段组成的中山地貌, 呈近东西方向延伸, 地势西南高东北低, 最高海拔神农顶3 106.2 m, 为华中第一峰, 最低海拔400 m (遗产地南坡)。神农架自然遗产地地跨中亚热带和北亚热带, 年平均气温12.1 ℃, 最冷月(1月)平均气温–8 ℃, 最热月(7月)平均气温26.5 ℃。年降水量800–2 500 mm, 有明显的季节性。

1.2 研究方法

1.2.1 群落调查

在神农架自然遗产地沿海拔梯度设置14条调查样线, 每条样线按海拔每升高100 m设置1个样地, 或选取特殊的群落类型设置样地。森林样地大小为20 m × 20 m (部分样地为20 m × 30 m或30 m × 30 m), 灌丛样地大小为10 m × 10 m, 草丛样地大小为5 m × 5 m。共调查森林样地166个, 灌丛样地21个, 草丛样地4个。另外, 在常绿阔叶林带、常绿落叶阔叶混交林带、落叶阔叶林带、针叶林带还调查了4个100 m × 100 m的固定样地。群落环境因子记录地名、经纬度、海拔、坡向、坡度、土壤类型、干扰因子等; 森林样地乔木层进行每木调查, 记录种名、高度、胸径和冠幅; 灌木层设置5个2 m × 2 m的样方, 草本层设置5个1 m × 1 m的样方, 分种记录种名、高度、盖度和多度。

1.2.2 文献资料收集整理

基于全球1 km的土地利用数据(AVHRR_1 km_LANDCOVER_1981_1994.GLOBAL), 选取与神农架自然遗产地同纬度的30°–35° N带, 提取30°–35° N

带土地利用类型中的常绿落叶阔叶林信息。同时, 收集整理《中国植物地理》(应俊生和陈梦玲, 2011)、《湖南植被》(祁承经, 1990)、《湖南森林》(湖南森林编委会, 1991)、《安徽森林》(安徽森林编委会, 1990)、《安徽植被》(安徽植被编委会, 1983)、《江西森林》(江西植被编委会, 1983)、《陕西植被》(雷明德, 1999)、《陕西森林》(陕西森林编委会, 1989)、《湖北森林》(湖北森林编委会, 1990)、《贵州森林》(贵州森林编委会, 1989)、《四川森林》(四川植被编委会, 1983)、《神农架自然保护区科学考察集》(朱兆泉和宋朝枢, 1999)、《神农架地区自然资源综合调查报告》(廖明尧, 2015)等书籍以及相关文献(谭景燊等, 1982; 李晓东, 1985; 吴国芳等, 1988; 田自强, 2002; 何飞, 2006), 整理分析全球生物地理区划(Udvardy)中东方落叶林生物地理省内已有世界自然遗产地和世界自然遗产预备清单中主要山地植被垂直带谱的群落类型、物种组成等资料。

1.2.3 对比分析

世界自然遗产的遴选有4条标准, 即美学、地质、生物生态学和栖息地标准。世界自然遗产地全球突出普遍价值(outstanding universal value)的提炼, 是世界自然遗产地遴选及保护的关键。全球生物地理区划(Udvardy)为国际自然保护联盟(IUCN)和联合国教科文组织(UNESCO)世界遗产中心遴选世界自然遗产地的重要科学依据。依据全球自然地理环境特征和生物群落类型, Udvardy把全球地表划分为8个生物地理区(biogeographical realm)、14个生物群区(biome)和193个生物地理省(biogeographical province)(Udvardy, 1975)。自然遗产地在美学、地质、生物生态学和栖息地等某一方面或几方面的遗产价值在其所在生物地理省具有突出性和唯一性, 且其遗产价值完整, 则该项自然遗产地具有全球突出普遍价值。神农架自然遗产地位于全球生物地理区划193个生物地理省的东方落叶林生物地理省(Oriental Deciduous Forest Biogeographical Province)。本研究收集了东方落叶林生物地理省已有世界自然遗产地中国黄山、三清山、九寨沟, 日本白神山、日本富士山, 以及世界自然遗产地预备清单中的中国太白山、梵净山、八大公山等山地植被垂直带谱组成等数据, 对比分析了神农架自然遗产地与东方落叶林生物地理省内已有世界自然遗产地和预备世界自然遗产地海拔梯度上植被垂直带谱的完整性, 并分析了其植被垂直带谱的保护状态。

2 研究结果

2.1 神农架自然遗产地保存有北半球同纬度少有的地带性常绿落叶阔叶混交林

受副热带高压的控制, 全球30°–35° N大部分地段主要植被类型为疏林、荒漠植被(表1; 图1), 仅中国神农架, 美国东南部大烟山, 地中海沿岸, 以及日本本州、四国、九州和琉球群岛北部等地, 分布有地带性常绿落叶阔叶混交林。神农架自然遗产地地跨中亚热带和北亚热带, 青藏高原的隆起使神农架自然遗产地北坡保存有全球同纬度最为完好的地带性常绿落叶阔叶混交林带, 其既不同于地中海型耐旱热的硬叶常绿林, 也不同于北半球同纬度的亚热带、热带荒漠植被。常绿落叶阔叶混交林是遗产地北坡的基带植被类型, 也是北亚热带的地带性代表类型。神农架自然遗产地常绿落叶阔叶混交林带以壳斗科树种为主, 其中落叶的主要为栎属(*Quercus*)和水青冈属(*Fagus*)等, 常绿的则以青冈属(*Cyclobalanopsis*)、栲属(*Castanopsis*)和石栎属(*Lithocarpus*)等为主, 其优势树种完全不同于美国东南部大烟山, 地中海沿岸, 以及日本本州、四国、九州和琉球群岛北部等地的优势树种。其中, 日本本州、四国、九州和琉球群岛北部地带性常绿落叶阔叶混交林主要为以*Castanopsis cuspidata*、*C. cuspidate* var. *sieboldi*、*Quercus salicina*、*Q. acuta*、*Q. sessilifolia*、*Machilus thunbergii*等为优势的栲类、润楠类常绿落叶林(何飞, 2006)。地中海沿岸的地带性植被类型则为在地中海气候下形成的常绿落叶阔叶混交林, 主要为以*Q. coccifera*、*Q. ilex*、*Q. suber*和*Pistacia lentiscus*等为优势种的硬叶常绿阔叶林(Walter, 1984)。美国东南部大烟山的常绿阔叶落叶混交林主要以*Q. borealis*、*Tilia heterophylla*、*Betula allegheniensis*和*Acer rubrum*等为优势种(Whittaker, 1956)。

2.2 神农架自然遗产地展示了东方落叶林生物地理省植被垂直带谱的物种更替过程

神农架自然遗产地植被垂直带谱在海拔梯度上呈现出随海拔升高优势树种种类和数量逐渐更替的生态学过程: 遗产地南坡为中亚热带北缘, 发育的常绿阔叶林带优势种主要为青冈(*Cyclobalanopsis glauca*)、曼青冈(*C. oxyodon*)、小叶青冈(*C.*

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表1 神农架及北半球同纬度典型地区概况

Table 1 Overview of Shennongjia and its counterparts in the same latitude

国家 Country	地区 Area	植被类型 Vegetation type	位置 Location	海拔 Altitude (m)	年平均气温 Mean annual temperature (℃)	年降水量 Mean annual precipitation (mm)	优势种 Dominant species	土壤类型 Soil type
中国 China	神农架 Shennongjia	常绿落叶阔叶混交林 Evergreen deciduous broad-leaved mixed forest	31.27° N, 110.48° E	1 670	10.6	1 200	米心水青冈，青冈 *Fagus engleriana*, *Cyclobalanopsis glauca*	山地黄棕壤 Mountain yellow brown soil
日本 Japan	本州南部低地，四国，九州和琉球群岛的北部 The southern lowlands of Honshu, north part of Shikoku, Kyushu and Ryuryu	常绿阔叶林 Evergreen broad-leaved forest	26.58°–35.5° N, 130°–140° E	250–1 100	13–21	1 300–2 500	*Castanopsis cuspidata*, *C. cuspidate* var. *sieboldii*, *Quercus salicina*, *Q. acuta*, *Q. sessilifolia*, *Machilus thunbergii*	棕壤 Brown soil
法国、意大利、西班牙、希腊 France, Italy, Spain, and Greece,	地中海沿岸 Mediterranean	硬叶常绿阔叶林 Sclerophyllous evergreen broad-leaved forest	30.25°–45.83° N, 0°–30° E	300–2 800	16–20	300–1 000	*Quercus coccifera*, *Q. ilex*, *Q. suber*, *Pistacia lentiscus*	红壤和黄壤 Red soil and yellow soil
美国 USA	大烟山 Great Smoky Mountains	温带阔叶林 Temperate broad-leaved forest	35.6° N, 83.48° W	1 830	12	1 270–2 030	*Quercus borealis*, *Tilia heterophylla*, *Betula alleghenicnsis*, *Acer rubrum*	山地棕壤 Mountain brown soil
北非 North Africa	撒哈拉沙漠北部 North of the Sahara Desert	荒漠 Desert	25°–35° N, 15°W–50° E	–	＞30	90–450	金合欢属，蒿属，三芒草属，画眉草属，稷属 *Acacia*, *Artemisia*, *Aristida*, *Eragrostis*, *Panicum*	石漠(岩漠)、砾漠和沙漠 Rock desert (rock desert), gravel desert and desert

表中资料参考: UNESCO官方网站(http://whc.unesco.org)数据库以及相关文献，如何飞(2006)。

Information in the table is from UNESCO official website (http://whc.unesco.org) and related published literature, e.g., He (2006).

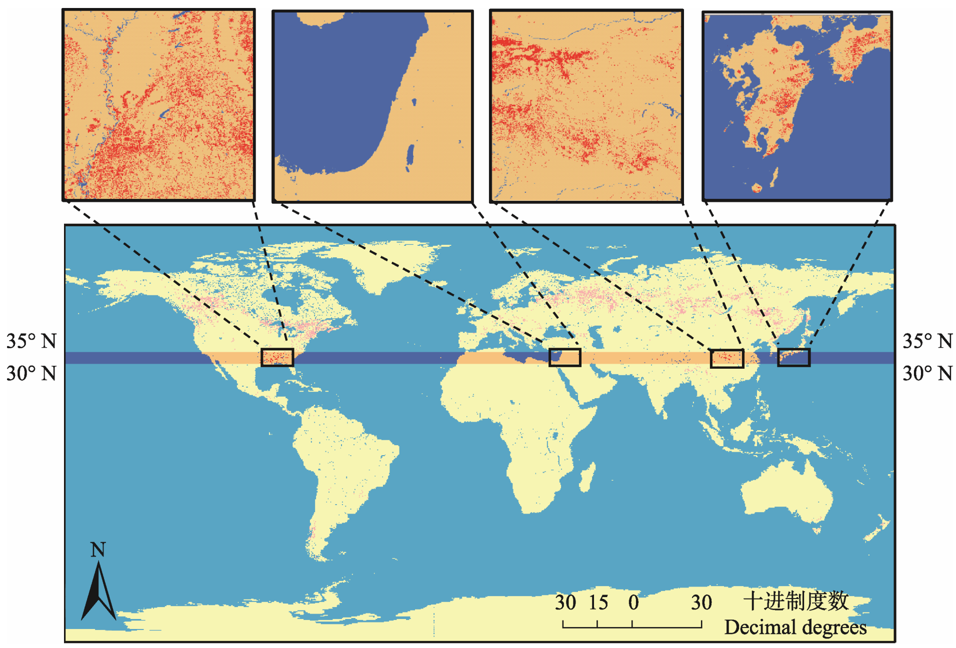

图1 全球30°–35° N带上常绿落叶阔叶混交林的分布(红色代表混交林)。

Fig. 1 The distribution of evergreen deciduous broad-leaved mixed forests (red areas) along the belt of 30°–35° N in the Northern Hemisphere.

myrsinifolia)、巴东栎(*Quercus engleriana*)等壳斗科的常绿树种。随海拔升高, 部分常绿优势树种逐渐被锐齿槲栎(*Q. aliena* var. *acutiserrata*)和米心水青冈(*Fagus engleriana*)等落叶树种代替, 形成了常绿和落叶树种混交的常绿落叶阔叶混交林带。随着海拔的进一步升高, 常绿优势树种逐渐减少, 锐齿槲栎、米心水青冈等落叶树种成为优势种, 形成了落叶树种为优势种的落叶阔叶林带; 海拔升高到2 200–2 600 m时, 以落叶树种为优势种的落叶阔叶林带中出现针叶树种, 落叶阔叶林逐渐被以巴山冷杉(*Abies fargesii*)和红桦(*Betula albosinensis*)为优势种的针、阔叶混交林带所替代。海拔2 600 m以上的地段, 以巴山冷杉和红桦为优势种的针阔混交林带中的红桦基本被针叶树种替代, 形成了以巴山冷杉为优势的寒温带针叶林。海拔3 000 m以上的地段, 优势树种巴山冷杉逐渐被粉红杜鹃(*Rhododendron hypoglaucum*)、香柏(*Sabina squamata* var. *fargesii*)、箭竹(*Fargesia spathacea*)和野古草(*Arundinella hirta*)等灌草优势种替代, 形成了高山灌丛草甸植被带(图2, 图3)。

2.3　神农架自然遗产地很好地保存了东方落叶林生物地理省完整的植被垂直带谱

比较分析神农架自然遗产地植被垂直带谱与东方落叶林生物地理省内世界自然遗产地及预备世界自然遗产地的植被垂直带谱(表2)发现: 神农架自然遗产地垂直高差达2 700 m, 形成了完整的山地植被垂直带谱, 山地自下而上依次发育有常绿阔叶林带(遗产地南坡)、常绿落叶阔叶混交林带、落叶阔叶林带、针阔混交林带、针叶林带及亚高山灌丛和草甸带(图3)。与神农架海拔梯度上植被垂直带相比, 安徽黄山、江西三清山海拔带上无温性针阔混交林带和寒温性针叶林带, 黄山海拔800–1 800 m分布的黄山松林、三清山1 400–1 700 m分布的黄山松林均为暖性至中温性针叶林(蒋木青等, 1982)。湖南八大公山海拔带上无温性针阔混交林带和寒温性针叶林带。梵净山的植被垂直带谱为以梵净山冷杉为优势种的针阔混交林, 分布于较窄的2 100–2 350 m海拔范围内, 植被垂直带谱中缺少寒温性针叶林带。日本白神山地带性植被类型为落叶阔叶林, 但其植被垂直带谱中缺少常绿阔叶林带和常绿落叶阔叶混交林带(表2)。日本富士山地带性植被类型为温带落叶阔叶林, 其垂直带谱缺失常绿阔叶林带、常绿落叶阔叶混交林带以及针阔混交林带(Ohsawa, 1984)(表2)。四川九寨沟地带性植被类型为温性针阔混交林, 其植被垂直带谱中缺少落叶阔叶林带、常绿落叶阔叶混交林带和常绿阔叶林带(表2)。与神农架自然遗产地相比, 秦岭太白山植被垂直带谱也比较完整, 但由于长期的人类活动, 其地带性常绿落叶阔叶混交林带已被严重破坏, 目前无完好的成片的常绿落叶阔叶混交林带分布, 现存植被类型主要为马尾松(*Pinus massoniana*)林、麻栎(*Quercus acutissima*)林等(表2)。比较分析结果表明, 神农架自然遗产地在较小的水平距离内浓缩了亚热带、暖温带、中温带和寒温带的典型植被类型, 保存有完整的植被垂直带谱, 在东方落叶林生物地理省中具有唯一性和代表性。

3　讨论

随着海拔升高, 山地气温、气压和地表面积下降, 山地环境条件发生显著变化(Korner, 2007)。植被垂直带谱是山地海拔梯度上生物和非生物因素综合作用的结果(He *et al*., 2016)。海拔梯度以较小的地理尺度, 在相似的环境条件下呈现出较大的气候梯度, 浓缩了不同的植被类型, 是众多生物生态学过程的集中展示场所, 也是研究生物生态学过程随气候变化的理想场所(Malhi *et al*., 2010)。青藏高原的隆起, 使受副热带高压控制下的东亚亚热带形成全球独一无二的东亚季风型(夏季湿润、冬季干冷)亚热带常绿阔叶林, 其既不同于地中海型耐旱热的硬叶常绿林, 也不同于北半球同纬度的亚热带、热带荒漠植被(中国科学院中国植被图编辑委员会, 2007)。神农架自然遗产地地跨中亚热带和北亚热带, 孕育了北半球典型的地带性常绿落叶阔叶混交林。同时, 神农架自然遗产地的海拔梯度在较小的水平距离范围内浓缩了中亚热带、北亚热带、暖温带、温带和寒温带等气候类型, 孕育了全球生物地理区划东方落叶林生物地理省内完整的植被垂直带谱, 形成了从低海拔到高海拔的常绿阔叶林、常绿落叶阔叶混交林、落叶阔叶林、针阔混交林、针叶林及亚高山灌丛和草甸等植被类型, 展示了东方落叶林生物地理省典型的生物生态学过程。

神农架自然遗产地海拔梯度上完好的植被垂直带谱, 展示了全球生物地理区划东方落叶林生物地理省的植物群落优势种和功能群随海拔梯度的更替

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过程。研究发现: 山地海拔梯度上的植被垂直带谱展示了植物群落优势种和功能群随海拔梯度变化的更替过程(Whittaker, 1956; Sundqvist *et al*., 2013), 是研究功能性状随气候变化的理想场所。神农架自然遗产地低海拔分布的常绿阔叶林群落, 其优势种主要为青冈、曼青冈、小叶青冈和巴东栎等壳斗科的常绿树种, 比叶面积高, 叶氮含量高, 单位叶面积营养元素含量高。随海拔升高, 群落优势种逐渐被比叶面积低、叶氮含量低、单位叶面积营养元素含量低(nutrient amounts per leaf area)的物种所替代(Vitousek *et al*., 1988; Tanner *et al*., 1998; Salinas *et al*., 2011), 如锐齿槲栎、米心水青冈、红桦等落叶

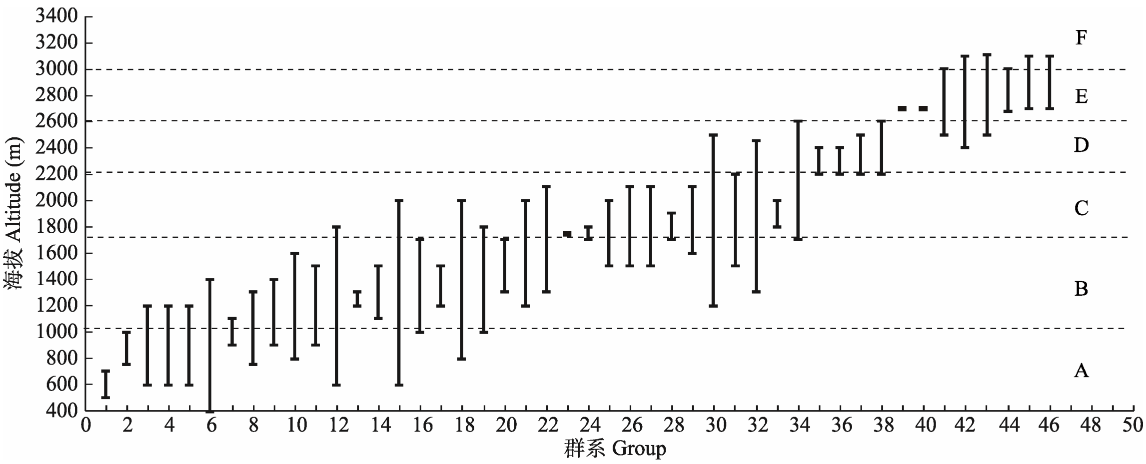

图2 神农架海拔梯度上主要植物群系分布图。大写英文字母对应各垂直带: A, 亚热带常绿阔叶林带; B, 北亚热带常绿落叶阔叶混交林带; C, 暖温带落叶阔叶林带; D, 温带针阔混交林带; E, 寒温带针叶林带; F, 亚高山灌丛、草甸带。 横坐标数字对应群系: 1, 蜡梅灌丛; 2, 楠木、小叶青冈为主的常绿阔叶林; 3, 马桑、毛黄栌灌丛; 4, 马尾松、栓皮栎林; 5, 杉木林; 6, 栓皮栎林; 7, 香叶树、小叶青冈、化香树、亮叶桦林; 8, 马尾松林; 9, 尖齿高山栎灌丛; 10, 曼青冈、水丝梨、巴东栎、青冈林; 11, 乌冈栎、岩栎、鹅耳枥、化香树林; 12, 野核桃林; 13, 栓皮栎、锐齿槲栎、茅栗林; 14, 巴东栎、曼青冈、亮叶桦、化香树林; 15, 刺叶栎林; 16, 短柄枹林; 17, 茅栗林; 18, 巴山松林; 19, 亮叶桦、化香树、鹅耳枥林; 20, 华山松、糙皮桦林; 21, 锐齿槲栎林; 22, 秦岭冷杉林; 23, 川榛、鸡树条荚蒾、湖北海棠灌丛; 24, 薹草、地榆、香青、血见愁老鹳草草甸; 25, 野漆树、锐齿槲栎、灯台树、化香树林; 26, 芒、蕨草丛; 27, 美丽胡枝子、绿叶胡枝子灌丛; 28, 薹草、葱状灯芯草、长叶地榆、柳兰沼泽化草甸; 29, 华山松、锐齿槲栎林; 30, 华山松林; 31, 米心水青冈林; 32, 秦岭冷杉、青扦林; 33, 锐齿槲栎、米心水青冈、红桦林; 34, 红桦林; 35, 华山松、山杨、红桦林; 36, 华山松、山杨林; 37, 中华黄花柳、华中山楂、湖北花楸灌丛; 38, 巴山冷杉、红桦、槭类林; 39, 杯腺柳灌丛; 40, 直穗小檗灌丛; 41, 箭竹灌丛; 42, 平枝荀子灌丛; 43, 巴山冷杉林; 44, 粉红杜鹃灌丛; 45, 香柏灌丛; 46, 印度三毛草、紫羊茅、糙野青茅草甸。群系海拔分布信息主要参考田自强(2002)。

Fig. 2 The distribution of main plant formations in Shennongjia along the elevation gradient. Capital English letters represent vertical vegetation zones: A, subtropical zone of evergreen broad-leaved forest; B, north subtropical zone of Mixed evergreen and deciduous broad-leaved forest; C, warm temperate zone of broadleaved deciduous forest; D, temperate zone of mixed broadleaf-conifer forest; E, cold temperate zone of coniferous forest; F, subalpine zone of shrub meadow. The abscissa represents different formations: 1, Form. *Chimonanthus praecox;* 2, Form. *Phoebe zhennan, Cyclobalanopsis gracilis;* 3, Form. *Coriaria sinica, Cotinus coggyqria* var. *pubescens;* 4, Form. *Pinus massoniana, Quercus variabilis;* 5, Form. *Cunninghamia lanceolata;* 6, Form. *Quercus variabilis;* 7, Form. *Lindera communis, Cyclobalanopsis gracilis, Platycarya strobilacea, Betula luminifera;* 8, Form. *Pinus massoniana;* 9, Form. *Quercus acrodonta;* 10, Form. *Cyclobalanopsis oxyodon, Sycopsis chinense, Quercus engleriana, Cyclobanopsis myrsinaefolia;* 11, Form. *Quercus philyraeoides, Q. acrodonta, Carpinus* sp., *Platycarya strobilacea;* 12, Form. *Juglans cathayensis;* 13, Form. *Quercus variabilis, Q. aliena* var. *acuteserrata, Castanea segyinii;* 14, Form. *Quercus engleriana, Cyclobalanopsis oxyodon, Betula luminifera, Platycarya strobilacea;* 15, Form. *Quercus spinosa;* 16, Form. *Quercus glandulifera* var. *brevipetiolata;* 17, Form. *Castanea seguinii;* 18, Form. *Pinus henryi;* 19, Form. *Betula luminifera, Platycarya strobilacea, Carpinus* sp.; 20, Form. *Pinups armandii, Betula utilis;* 21, Form. *Quercus aliena* var. *acuteserrata;* 22, Form. *Abies chensiensis;* 23, Form. *Corylus heterophylla* var. *sutchuenensis, Viburnum opulus* var. *calvescens, Malus hupehensis;* 24, Form. *Carex* sp., *Sanguisorba officinalis* var. *longifolia, Anaphalis sinica, Geranium henryi;* 25, Form. *Rhus verniciflua, Quercus acutidentata, Cornus controversa, Platycarya strobilacea;* 26, Form. *Miscanthus sinensis, Pteridium aquilinum* var. *latiusculum;* 27, Form. *Lespedeza formosa, L. buergeri;* 28, Form. *Carex* sp., *Juncus concinus, Sanguisorba officicnalis* var. *longifolia, Chamaenerion angustifolium;* 29, Form. *Pinus armandii, Querus aliena* var. *acuteserrata;* 30, Form. *Pinus armandii;* 31, Form. *Fagus engleriana;* 32, Form. *Abies chensiensis, Picea wilsonii;* 33, Form. *Quercus aliena* var. *acuteserrata, Fagus engleriana, Betula albosinensis;* 34, Form. *Betula albosinensis;* 35, Form. *Pinus armandii, Populus davidiana, Betula albosinensis;* 36, Form. *Pinus armandii, Populus davidiana;* 37, Form. *Salix carprea* var. *inica, Crataegus wilsonii, Sorbus hupehensis;* 38, Form. *Abies fargesii, Betula albosinensis, Acer* sp.; 39, Form. *Salix cupularis;* 40, Form. *Berberis dasystachya;* 41, Form. *Sinarundinaria nitida;* 42, Form. *Cotoneaster horizontalis;* 43, Form. *Abies fargesii;* 44, Form. *Rhododendron fargesii;* 45, Form. *Sabina pingii* var. *wilsonii;* 46, Form. *Trisetum clarkei, Festuca rubra, Deyeuxia scabrescens.* Formation distribution along the elevation was based on Tian (2002).

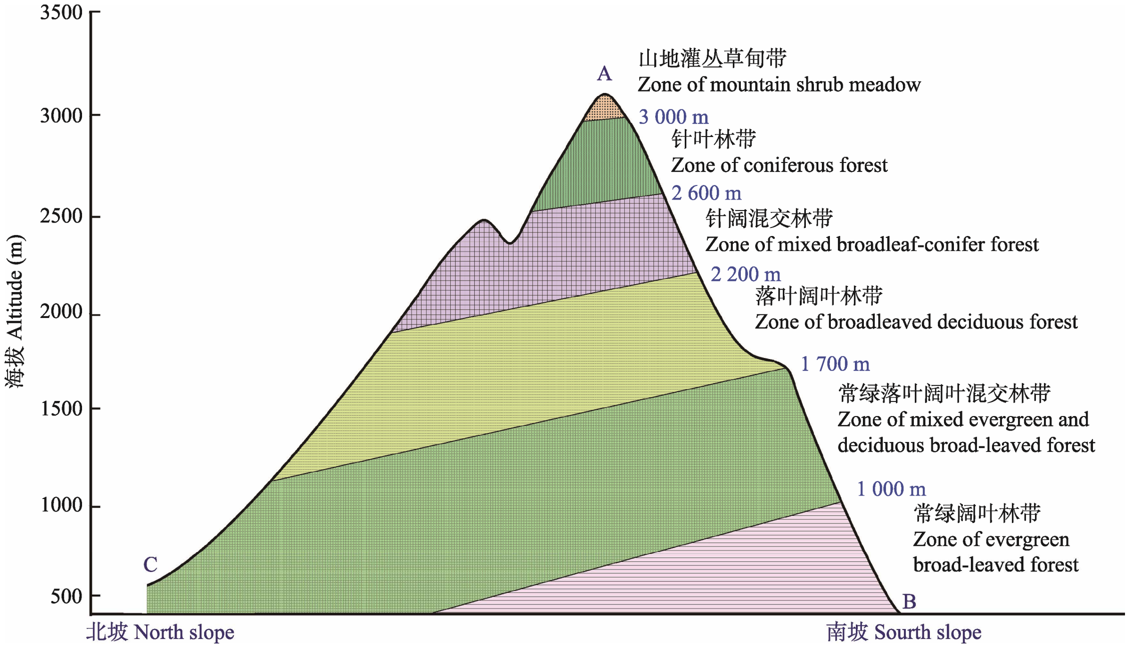

图3　神农架山地示意图。A，神农顶，神农架遗产地最高点，海拔3 106.2 m；B，下谷坪，神农架遗产地南坡最低点，海拔400 m；C，韩家坪，神农架遗产地北坡最低点，海拔600 m。

Fig. 3　Sketch map of Shennongjia mountain. A, Shennongding, the summit of the heritage site with the elevation of 3 106.2 m; B, Xiaguping, the lowest point of the south slope of the heritage site with the elevation of 400 m; C, Hanjiaping, the lowest point of the north slope of the heritage site with the elevation of 600 m.

树种以及巴山冷杉等寒温带针叶树种。高海拔地段植被群落主要为矮化优势种组成，如粉红杜鹃、香柏、箭竹和野古草等，其功能群生长率低，适应高海拔胁迫环境。

神农架自然遗产地海拔梯度上不同植被带内的动物类群，展示了东方落叶林生物地理省不同功能动物类群随海拔梯度变化的更替过程。已有研究发现，海拔垂直梯度上动物群落主要通过改变其多度及物种更替适应海拔梯度上的不同环境条件(Hodkinson, 2005; Sanders *et al*., 2007; McCain, 2009)。不同功能群的动物分布于不同的海拔带，每种动物占据一定的海拔范围并与其他类群的物种以一定多度共存(Hodkinson, 2005)。神农架自然遗产地植被垂直带谱中，常绿阔叶林内的常见动物有猕猴(*Macaca mulatta*)、麝鼩(*Crocidura* spp.)、喜鹊(*Pica pica*)、家燕(*Hirundo rustica*)等。随着海拔升高，一些适应高海拔寒冷气候条件的动物逐渐出现，如寒温带针叶林巴山冷杉林和高山灌丛和草甸内的主要动物类群为金丝猴(*Rhinopithecus roxellana*)、秦岭鼠兔(*Ochotona huangensis*)等兽类以及普通朱雀(*Carpodacus* spp.)、褐冠山雀(*Parus dichrous*)、灰头灰雀(*Pyrrhula erythaca*)等鸟类(李义明等, 2003；章波, 2014)。

神农架自然遗产地海拔梯度上不同植被带内的土壤动物和微生物的种类和数量，展示了东方落叶林生物地理省的土壤动物和微生物随海拔变化的生物生态学过程。研究发现，山地植被垂直带谱的土壤动物和微生物的种类和数量也随海拔梯度变化发生相应的变化(Olson, 1994; Gonzalez *et al*., 2007; Bahram *et al*., 2012)。某些特定的微生物群落只分布于一定的海拔范围(Gomez-Hernandez *et al*., 2012)。土壤白蚁群落的物种组成随海拔梯度变化更替不明显(Palin *et al*., 2011)，但其凋落物分解者的种类更替随海拔变化较显著，土壤微生物功能群的生物量和多度随海拔梯度的变化也比较显著(Olson, 1994)。研究发现，真菌与细菌的生物量比随海拔升高而变大(Wagai *et al*., 2011)，这主要是因为高海拔环境胁迫压力大，以真菌为主的微生物群落的土壤养分循环能较好地适应不良的环境条件(Wardle, 2002)。

神农架自然遗产地完整的植被垂直带谱，充分代表并展示了全球生物地理区划中东方落叶林生物地理省的山地植被垂直带谱的完整性及其孕育的生物生态学过程，是东方落叶林生物地理省山地生态系统垂直分异生态学过程的天然实验场所。为此，神农架自然遗产地完整的植被垂直带谱也成为神农

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表2 Udvardy东方落叶林生物地理省内主要山地的现存植被垂直带谱
Table 2 The altitudinal vegetation zonation of the Eastern Deciduous Forest Biogeographic Province in the Classification of the Biogeographical Provinces of the World by Udvardy

	神农架 Shennongjia	黄山 Huangshan	梵净山 Fanjingshan	白神山 Shirakami-Sanchi	三清山 Sanqingshan	八大公山 Badagongshan	九寨沟 Jiuzhaigou	太白山 Taibaishan	富士山 Mount Fuji
位置 Location	31.7° N, 110.58° E	30.13° N, 118.17° E	27.88° N, 108.68° E	40.47° N, 140.12° E	28.8° N, 117.97° E	29.65° N, 109.68° E	33.07° N, 103.92° E	33.67° N, 107.32° E	35.35° N, 138.72° E
山地矮林与灌丛草甸带 Zone of mountain coppice and shrub meadow	3 000–3 106 m为寒温性亚高山灌丛草甸，主要有粉红杜鹃灌丛、香柏灌丛、野古草、三毛草 3 000–3 106 m, cold and warm subalpine shrub meadow, mainly *Rhododendron oreodoxa* var. *fargesii* shrub, *Sabina pingii* var. *wilsonii* shrub, *Arundinella anomala, Trisetum bifidum*	1 400–1 800 m为暖温性山地灌丛草甸。1 400–1 650 m为山地矮林和灌丛，主要有黄山栎；1 650–1 800 m为山地草甸 1 400–1 800 m, warm temperate mountain shrub meadow. 1 400–1 650 m, mountain shrub and coppice, mainly *Quercus stewardii;* 1 650–1 800 m, mountain meadow	2 350–2 572 m为中温性至寒温性山地灌丛草甸，主要有杜鹃、箭竹 2 350–2 572 m, medium temperature to cold temperate mountain shrub meadow, mainly *Rhododendron simsii, Fargesia spathacea*	2 500 m以上为寒性山地灌丛草甸 Over 2 500 m, cold mountain shrub meadow	1 400–1 817 m为暖温性山地矮林、灌丛、草甸，主要有杜鹃花山地矮林，箭竹灌丛，沼泽 1 400–1 817 m, warm temperate mountain dwarf forest, shrub, meadow, mainly *Rhododendron simsii* mountain dwarf forest, *Fargesia spathacea* shrub and wetlands	1 700–2 003 m为暖温性山地灌丛，主要有杜鹃、八角、黄杨、马醉木 1 700–2 003 m, warm temperate mountain shrub, mainly *Rhododendron simsii, Illicium verum, Buxus sinica, pieris japonica*	3 600 m以上为寒性高山灌丛草甸，主要有金露梅、香柏、杜鹃、高山绣线菊 Over 3 600 m, cold alpine shrub meadow, mainly *Potentilla fruticosa, Sabina pingii, Rhododendron simsii, Spiraea alpin*	3 400–3 767 m为寒性高山灌丛草甸 3 400–3 767 m, cold alpine shrub meadow	2 500 m以上为高山矮曲林，主要有*Aconogonum weyrichii* var. *alpinum*、齿叶南芥 Over 2 500 m, alpine krummholz, mainly *Aconogonum weyrichii* var. *alpinum, Arabis serrata*
针叶林带 Zone of coniferous forest	2 600–3 000 m为寒温性针叶林，主要有巴山冷杉林、秦岭冷杉林 2 600–3 000 m, cold temperate coniferous forest, mainly *Abies fargesii* forest, *A. chensiensis* forest	800–1 800 m为暖性至中温性针叶林，无寒温性针叶林，主要有黄山松林 800–1 800 m, warm to medium temperature coniferous forest without cold temperate coniferous forest, mainly *Pinus taiwanensis*	无 None	1 000–2 500 m为寒温性针叶林，主要有*Abies veitchii*、*Tsuga sieboldii* 1 000–2 500 m, cold temperate coniferous forest, mainly *Abies veitchii, Tsuga sieboldii*	1 400–1 700 m为暖性至中温性针叶林，无寒温性针叶林，主要有黄山松林 1400–1700 m, warm to medium temperature coniferous forest without cold temperate coniferous forest, mainly *Pinus taiwanensis* forest	无 None	2 800–3 600 m为寒温性针叶林，主要有岷江冷杉、云杉、鳞皮云杉、紫果云杉 2 800–3 600 m, cold temperate coniferous forest, mainly *Abies faxoniana, Picea asperrata, P. retroflexa, P. purpurea*	2 650–3 000 m为寒温性常绿针叶林，主要有巴山冷杉；3 000–3 400 m，寒温性落叶松林 2 600–3 000 m, cold temperate evergreen coniferous forest, mainly *Abies fargesii;* 3 000–3 400 m, cold and temperate larch forest	1 600 (1 700)–2 500 m为寒温性针叶林，主要有*Tsuga diversifolia*、日本落叶松、岳桦、*Abies veitchii*、*Abies homolepis* 1 600 (1 700)–2 500, cold temperate coniferous forest, mainly *Tsuga diversifolia, Larix kaempferi, Betula ermanii, Abies veitchii, A. homolepis*

表2 (续)　Table 2 (continued)

	神农架 Shennongjia	黄山 Huangshan	梵净山 Fanjingshan	白神山 Shirakami-Sanchi	三清山 Sanqingshan	八大公山 Badagongshan	九寨沟 Jiuzhaigou	太白山 Taibaishan	富士山 Mount Fuji
针阔混交林带 Zone of mixed broadleaf-conifer forest	2 200–2 600 m为温性针阔混交林, 主要有巴山冷杉-鄂西杜鹃林、巴山冷杉-槭树林、华山松-山杨林 2 200–2 600 m, mixed temperate broadleaf-conifer forest, mainly dominated by *Abies fargesii*-*Rhododendron praeteritum* forest, *Abies fargesii*-*Acer* forest, *Pinus armandii*-*Populus davidiana* forest	无 None	2 100–2 350 m为温性针阔混交林, 主要有梵净山冷杉、铁杉 2 100–2 350 m, temperate mixed broadleaf-conifer forest, mainly dominant species are *Abies fabri, Tsuga chinensis*	无 None	1 100–1 500 m为暖温性针阔混交林, 主要有黄山松林、华东黄杉林 1 100–1 500 m, temperate mixed broadleaf-conifer forest, mainly dominant species are *Pinus taiwanensis* forest, *Pseudotsuga gaussenii* forest	无 None	1 900–2 800 m, 主要有针叶的油松、华山松、紫果云杉、云杉等与阔叶的色木槭、桦属、槭属 1 900–2 800 m, dominant coniferous species are *Pinus tabulaeformis, Pinus armandii, Picea purpurea, Picea asperata;* dominant broadleaved species are *Acer mono, Betula, Acer*	1 300–2 650 m, 主要有华山松、油松和栓皮栎、锐齿槲栎、红桦 1 300–2 650 m, mainly dominant species are *Pinus armandii*, *P. tabulaeformis, Quercus variabilis, Q. aliena* var. *acuteserrata, Betula albosinensis*	无 None
落叶阔叶林带 Zone of broadleaved deciduous forest	1 700–2 200 m为暖温性落叶阔叶林, 主要有短柄枹栎林、茅栗林、锥栗林、锐齿槲栎林 1 700–2 200 m, warm temperate deciduous broad-leaved forest, mainly dominated by *Quercus glandulifera* var. *brevipetiolata* forest, *Castanea seguinii* forest, *C. henryi* forest, *Q. aliena* var. *acuteserrata* forest	1 100–1 400 m, 主要有千金榆、米心水青冈、川榛、短柄枹栎 1 100–1 400 m, mainly dominated by *Carpinus cordata, Fagus engleriana, Corylus heterophylla* var. *sutchuenensis, Quercus glandulifera* var. *brevipetiolata*	1 900–2 100 m, 主要有米心水青冈、扇叶槭、中华槭、山樱花 1 900–2 100 m, mainly dominant species are *Fagus engleriana, Acer flabellatum, A. sinense, Cerasus serrulata*	400–1 000 m, 主要有*Fagus crenata*、水青冈、蒙古栎 400–1 000 m, mainly dominant species are *Fagus crenata, F. longipetiolata* and *Quercus mongolica*	无 None	1 500–1 700 m, 主要有光叶水青冈 1 500–1 700 m, mainly dominant species is *Fagus lucida*	无 None	1 000–1 300 m, 主要为栓皮栎林 1 000–1 300 m, mainly dominated by *Quercus variabilis* forest	830 (900)–1 600 (1 700) m为温性落叶阔叶林, 主要有*Quercus mongolica* ssp. *crispula*、*Fagus crenata* 830 (900)–1 600 (1 700) m, temperate deciduous broad-leaved forest, mainly dominatded by *Quercus mongolica* ssp. *crispula, Fagus crenata*

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表2(续) Table 2 (continued)

	神农架 Shennongjia	黄山 Huangshan	梵净山 Fanjingshan	白神山 Shirakami-Sanchi	三清山 Sanqingshan	八大公山 Badagongshan	九寨沟 Jiuzhaigou	太白山 Taibaishan	富士山 Mount Fuji
常绿落叶阔叶混交林带 Zone of mixed evergreen and deciduous broad-leaved forest	1 000–1 700 m, 主要有米心水青冈-多脉青冈林、华中山柳-灰柯林、曼青冈-化香林 1 000–1 700 m, mainly dominated by *Fagus engleriana -Cyclobalanopsis multinervis* forest, *Clethra fargesii-Lithocarpus henryi* forest, *Cyclobalanopsis oxyodon-Platycarya strobilacea* forest	900–1 100 m, 主要有常绿的细叶青冈、交让木、豹皮樟等, 落叶的枫香、糙叶树、水青冈等 900–1 100 m, dominant evergreen species are *Cyclobalanopsis gracilis, Daphniphyllum macropodum, Litsea coreana* var. *sinensis*, etc; dominant deciduous species are *Liquidambar formosana, Aphananthe aspera, Fagus longipetiolata,* etc.	1300–1 900 m, 主要有常绿的青冈、厚皮锥、巴东栎等; 落叶的水青冈、中华槭、野茉莉、山樱花等 1 300–1 900 m, dominant evergreen species are *Cyclobalanopsis glauca, Castanopsis chunii, Quercus engleriana,* etc.; dominant deciduous species are *Fagus longipetiolata, Acer sinense, Styrax japonicas, Cerasus serrulata,* etc.	无 None	900–1 400 m, 主要有水青冈-交让木林、多脉青冈-缺萼枫香林、小叶青冈-鹅耳枥林、猴头杜鹃林 900–1 400 m, mainly dominated by *Fagus longipetiolata-Daphniphyllum macropodum* forest, *Cyclobalanopsis multinervis-Liquidambar acalycin* forest, *C. myrsinifolia-Carpinus turczaninowii* forest; *Rhododendron simiarum* forest	1 100–1 500 m, 主要有常绿的多脉青冈、包果柯、厚皮锥, 落叶的光叶水青冈、香桦、鹅耳枥等 1 100–1 500 m, dominant evergreen species are *Cyclobalanopsis multinervis, Lithocarpus cleistocarpus, Castanopsis chunii;* dominant deciduous species are *Fagus lucida, Betula insignis, Carpinus turczaninowii*	无 None	600–1 000 m, 原生常绿落叶阔叶混交林几乎无存, 现存植被主要为马尾松林、麻栎林 600–1 000 m, almostly no remaining native evergreen and deciduous broad-leaved mixed forests, the existed forests are mainly *Pinus massoniana* forest, *Quercus acutissima* forest	无 None
常绿阔叶林带 Zone of evergreen broad-leaved forest	400–1 000 m, 主要有青冈、楠木、小果润楠、水丝梨 400–1 000 m, mainly dominated by *Cyclobalanopsis glauca, Phoebe zhennan, Machilus microcarpa, Sycopsis sinensis*	600–900 m, 主要有青冈、甜槠、小叶青冈 600–900 m, mainly dominated by *Cyclobalanopsis glauca, Castanopsis eyrei, Cyclobalanopsis myrsinifolia*	500–1 300 m, 主要有栲、青冈、柯、润楠、樟、八角 500–1 300 m, mainly dominated by *Castanopsis fargesii, Cyclobalanopsis glauca, Lithocarpus glaber, Machilus pingii, Cinnamomum camphora* and *Illicium verum*	无 None	450–900 m, 主要有甜槠、木荷、青冈、毛竹 450–900 m, mainly dominant species are *Castanopsis eyrei, Schima superba, Cyclobalanopsis glauca* and *Phyllostachys heterocycla*	346–1 100 m, 主要有栲、青冈、石栎、樟 346–1 100 m, mainly dominant species are *Castanopsis fargesii, Cyclobalanopsis glauca, Lithocarpus glaber* and *Cinnamomum camphora*	无 None	无 None	无 None

表中资料参考吴国芳等(1988)、李晓东(1985)、应俊生和陈梦玲(2011)、湖南森林编委会(1991)、祁承经(1990)、安徽森林编委会(1990)、安徽植被编委会(1983)、江西植被编委会(1983)、雷明德(1999)、陕西森林编委会(1989)、四川森林编委会(1983)。括号内数值为主坡面外其他坡面垂直带的海拔。
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架自然遗产地遗产价值的重要组成部分。进一步掌握神农架山地植被垂直带谱的生物生态学过程及其驱动机制是今后神农架自然遗产地研究和保护的重要内容, 也是神农架自然遗产地科学管理急需解决的重要问题。

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