

中国主要灌丛植被碳储量

胡会峰¹ 王志恒² 刘国华^{1*} 傅伯杰¹

(¹ 中国科学院生态环境研究中心系统生态国家重点实验室, 北京 100085)

(² 北京大学环境学院生态学系, 北京大学生态学研究与教育中心, 北京大学地表过程分析与模拟教育部重点实验室, 北京 100871)

摘要 在广泛收集资料的基础上, 利用植被平均碳密度方法, 估算了我国 6 种主要灌丛植被的碳储量, 并分析了其区域分布特征。主要结果如下: 1) 6 种灌丛植被总面积为 $15\,462.64 \times 10^4 \text{ hm}^2$, 总碳储量为 $1.68 \pm 0.12 \text{ Pg C}$ ($1 \text{ Pg} = 10^{15} \text{ g}$), 灌丛植被平均碳密度为 $10.88 \pm 0.77 \text{ Mg C} \cdot \text{hm}^{-2}$ ($1 \text{ Mg} = 10^6 \text{ g}$), 不同植被类型差异较大, 在 $5.92 \sim 17 \text{ Mg C} \cdot \text{hm}^{-2}$ 之间波动。2) 从区域分布来看, 西南 3 省(云南、贵州、四川)既是我国灌丛主要的分布地区之一, 分布面积占 6 种灌丛总面积的 23.5%, 又是我国灌丛碳储量的主要库, 碳储量占整个 6 种灌丛碳储量的 1/3 (32.6%), 适宜的水热条件决定了该地区的植被平均碳密度要高于全国平均水平。3) 与我国森林和草地的植被碳储量相比, 这些灌丛碳储量相当于我国森林和草地碳储量的 27%~40% 和 36%~55%。

关键词 灌丛 植被碳储量 碳密度

VEGETATION CARBON STORAGE OF MAJOR SHRUBLANDS IN CHINA

HU Hui-Feng¹ WANG Zhi-Heng² LIU Guo-Hua^{1*} and FU Bo-Jie²

(¹ State Key Laboratory of Systems Ecosystem, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China)

(² Department of Ecology, College of Environmental Sciences, Center for Ecological Research & Education, and Key Laboratory for Earth Surface Processes of the Ministry of Education, Peking University, Beijing 100871, China)

Abstract Background and Aims Shrublands is one of the major types of terrestrial ecosystems, which widely distributes from tropical to polar regions. Due to their largely distributional area in China, it is very important for us to exactly estimate their carbon storages and spatial distributions. Answers to the following questions were sought: (a) How much is the vegetation carbon storage of major shrublands in China? (b) How are their spatial distributions in China?

Methods Based on published biomass data in shrublands and 1:4 000 000 digital vegetation map of China, carbon storage of major shrublands in China was estimated using the method of mean biomass carbon density for different shrublands types.

Key Results The carbon storage of six shrublands in China is $1.68 \pm 0.12 \text{ Pg C}$ ($1 \text{ Pg} = 10^{15} \text{ g}$) with an total area of $15\,462.64 \times 10^4 \text{ hm}^2$. The average vegetation carbon density is $10.88 \pm 0.77 \text{ Mg C} \cdot \text{hm}^{-2}$, varying from 5.92 to 17.00 $\text{Mg C} \cdot \text{hm}^{-2}$ for different shrubland types. The distribution of shrublands is spatially heterogeneous in the country. Shrublands in three provinces (Yunnan, Guizhou and Sichuan) in Southwest China occupies 23.5% of the total area and contributes to approximately one-third (32.6%) of the total carbon storage of six shrubland types in China due to favorable climate and soil conditions. The area of six shrubland types in Inner Mongolia is the second largest among all the provinces. However, the vegetation carbon storage in Inner Mongolia shrublands is only 84.81 Tg C ($1 \text{ Tg} = 10^{12} \text{ g}$), following that of Yunnan, Guizhou, Sichuan, Jiangxi, and Hunan. The probable reason is ascribed to its arid or semiarid climatic conditions. Although shrublands hold about 1.5 times the area of forests in China, the carbon storage of shrublands corresponds 27%–40% of forests because carbon density of shrublands accounts for only one-fifth of forests. Similarly, the proportion of vegetation carbon storage of shrublands to that of grasslands in China varies from 36% to 55% due to the different areas of grasslands used in previous studies.

Conclusions This study draw the following conclusions: (a) As important ecosystem types in China, shrublands hold large vegetation carbon storage, which is main component of China's vegetation carbon storage. (b) Because of different climatic and soil conditions, their distributions are spatially heterogeneous in China and

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* 通讯作者 Author for correspondence E-mail: ghliu@rcees.ac.cn

The average vegetation carbon density varies greatly for different shrubland types.

Key words Shrublands , Vegetation carbon storage , Carbon density

灌丛是自然界中一种广泛分布的陆地生态系统类型,由于具有种类繁多、分布广泛、生命力强、萌生力强、生产力高、适生范围宽等特点,不仅在群落的演替过程中扮演着极其重要的角色,而且在区域生态环境保护和替代能源方面也起着非常重要的作用¹⁾。自 20 世纪 60 年代国际生物圈计划(IBP)实施后,国外就开始了灌丛生物量和生产力方面的研究(Whittaker , 1961 , 1962 ; Forrest , 1971 ; Connolly-McCarthy & Grigal , 1985)。国内这方面的研究最早开始于 20 世纪 80 年代初(姜凤岐和卢凤勇 , 1982) ,此后各地有关灌丛生物量的研究陆续报道出来(上官铁梁和张峰 , 1989 ; 戴晓兵 , 1989 ; 贺金生等 , 1997 ; 刘国华等 , 2003a , 2003b)。在全球气候变暖的影响下,灌丛分布范围不仅有所扩大(Sturm *et al.* , 2001) ,而且由于入侵导致的植被演替引起了北半球局部区域碳储量的变化,从而成为科学家关注的新焦点(Goodale & Davidson , 2002 ; Jackson *et al.* , 2002)。作为世界上灌丛分布面积最广泛的国家之一,中国有灌丛面积近 $2 \times 10^8 \text{ hm}^2$ (侯学煜 , 1982) ,占中国陆地总面积的 1/5 强,是全国现存森林面积的近 2 倍,因此在全球气候变化的影响下我国灌丛分布面积和地区的消长,对正确评价中国陆地生态系统的碳储量和碳交换具有重要的影响。

目前,为正确评价我国陆地生态系统在全球及区域碳循环和碳平衡中的作用,我国科学家先后估算了中国森林植被(刘国华等 , 2000 ; 周玉荣等 , 2000 ; Fang *et al.* , 2001 ; 王效科等 , 2001 ; 赵敏和周广胜 , 2004) ,以及草地植被(Ni , 2002 , 2004) 的碳储量和碳密度,但是对灌丛植被的碳储量研究几乎没有(Ni , 2001)。本文通过收集我国不同地区样地水平上的灌丛生物量进行汇总,研究了我国主要灌丛类型的生物量及其碳储量,以期为准确估算中国陆地生态系统碳储量提供基础数据。

1 研究资料和研究方法

1.1 研究资料

本研究中所采用的基本资料是近些年有关全国各样地水平上的灌丛生物量和生产力的研究资料和数据,即文献调研资料,其中全国和各省(区)的灌丛

植被类型面积是根据数字化的全国 1:400 万的中国植被图(侯学煜 , 1982) ,在 ArcGIS 中计算得到的。本文所采用的灌丛分类原则是根据 1:400 万植被图的三级分类标准进行选取的,其中涉及到灌丛的有八大类,即热带海滨硬叶常绿阔叶灌丛、矮林,温带、亚热带落叶灌丛、矮林,温带、亚热带亚高山落叶灌丛,亚热带、热带石灰岩具有多种藤本的常绿、落叶灌丛、矮林,亚热带、热带酸性土常绿、落叶阔叶灌丛、矮林和草甸结合,亚热带高山、亚高山常绿革质叶灌丛、矮林,温带高山矮灌木苔原和温带、亚热带高山垫状矮半灌木、草本植被。由于缺乏温带高山矮灌木苔原类型的实测生物量数据,再加上其所占面积较小($0.33 \times 10^4 \text{ hm}^2$) ,所以本文没有考虑其碳储量,对温带、亚热带高山垫状矮半灌木、草本植被而言,尽管其分布面积较大($4400 \times 10^4 \text{ hm}^2$) ,但由于该类型主要包括垫状点地梅(*Androsace tapete*) 蚤缀(*Arenaria serpyllifolia*) 等垫状植被,植被覆盖度很低,生物量少,再加上缺乏实测数据,因此没有考虑其碳储量。本文主要研究了前 6 种灌丛植被类型的生物量和碳储量。

1.2 研究方法

本文采用植被平均生物量方法来计算各种灌丛类型的碳储量。由于灌丛一般是木本植物,因此其生物量和碳储量的转换率采用与森林植被一样的转换率 0.5(Fang *et al.* , 2001)。由于许多研究只是测量了地上灌丛的生物量,缺乏地下生物量数据。为了更准确的估算地下生物量,根据已有地下生物量实测数据,本文采用了不同的估算方法来推算其它地下生物量数据:首先根据某一种灌丛类型地上和地下都齐全的资料,进行回归拟合,如果有显著的相关关系,就用回归方程来推算该类型其它样方的地下生物量,计算总生物量,否则求出两者的生物量之比,然后根据这个比值,推算该类型其它样方的地下生物量,进而得到整个类型的生物量(表 1 , 图 1)。

2 实验结果

2.1 全国主要灌丛植被的碳密度和碳储量(表 2)

由表 2 可知,我国 6 种主要灌丛类型的总面积为 $15462.64 \times 10^4 \text{ hm}^2$,占整个中国陆地面积的

1) Liu GH(刘国华)(2004) . Study on shrub aboveground biomass and its relationships with environmental factors-the upper Minjing River region , China as a case . PhD thesis of Research Center for Eco-Environmental Sciences , Chinese Academy of Sciences . (in Chinese with English abstract)

表 1 计算我国主要灌丛植被生物量的基本参数
Table 1 Basic parameters of calculating major shrublands vegetation biomass

灌丛类型 Shrublands types	生物量 Biomass (t·hm ⁻²)		地下(B)和地上(A)的关系 The relationship between belowground(B) and aboveground(A)		
	样本数 Samples	平均 ± 标准差 Mean ± SE	关系 Relationship		
热带海滨硬叶常绿阔叶灌丛、矮林 ¹⁾	3	11.84 ± 1.36	A/B = 2.10 n = 3		
温带、亚热带落叶灌丛、矮林 ²⁾	78	12.48 ± 1.25	$B = -1\,558.15 + 1.97A$ $R^2 = 0.785$ $p < 0.01$ $n = 8$		
温带、亚热带亚高山落叶灌丛 ³⁾	55	15.49 ± 1.83	$B = 678.56 + 1.22A$ $R^2 = 0.578$ $p < 0.01$ $n = 13$		
亚热带、热带石灰岩具有多种藤本的常绿、落叶灌丛、矮林 ⁴⁾	8	24.22 ± 4.22	A/B = 1.40 n = 7		
亚热带、热带酸性土常绿、落叶阔叶灌丛、矮林和草甸结合 ⁵⁾	17	34.00 ± 4.64	A/B = 0.62 n = 7		
亚热带高山、亚高山常绿革质叶灌丛、矮林 ⁶⁾	10	23.48 ± 3.48	A/B = 1.17 n = 8		
总计 Total	171	21.76 ± 1.10			

1) Sclerophyllus evergreen broadleaf scrubs and dwarf forests on seashore in tropical zone 2) Deciduous scrubs and dwarf forests in temperate and subtropical zones 3) Subalpine deciduous scrubs in temperate and subtropical zones 4) Evergreen and deciduous scrubs and dwarf forests on calcareous soil in subtropical and tropical zones 5) Broadleaf evergreen and deciduous scrubs and dwarf forests on acid soil in subtropical and tropical zones 6) Alpine and subalpine sclerophylla evergreen scrubs and dwarf forests in subtropical zones SE : Standard error

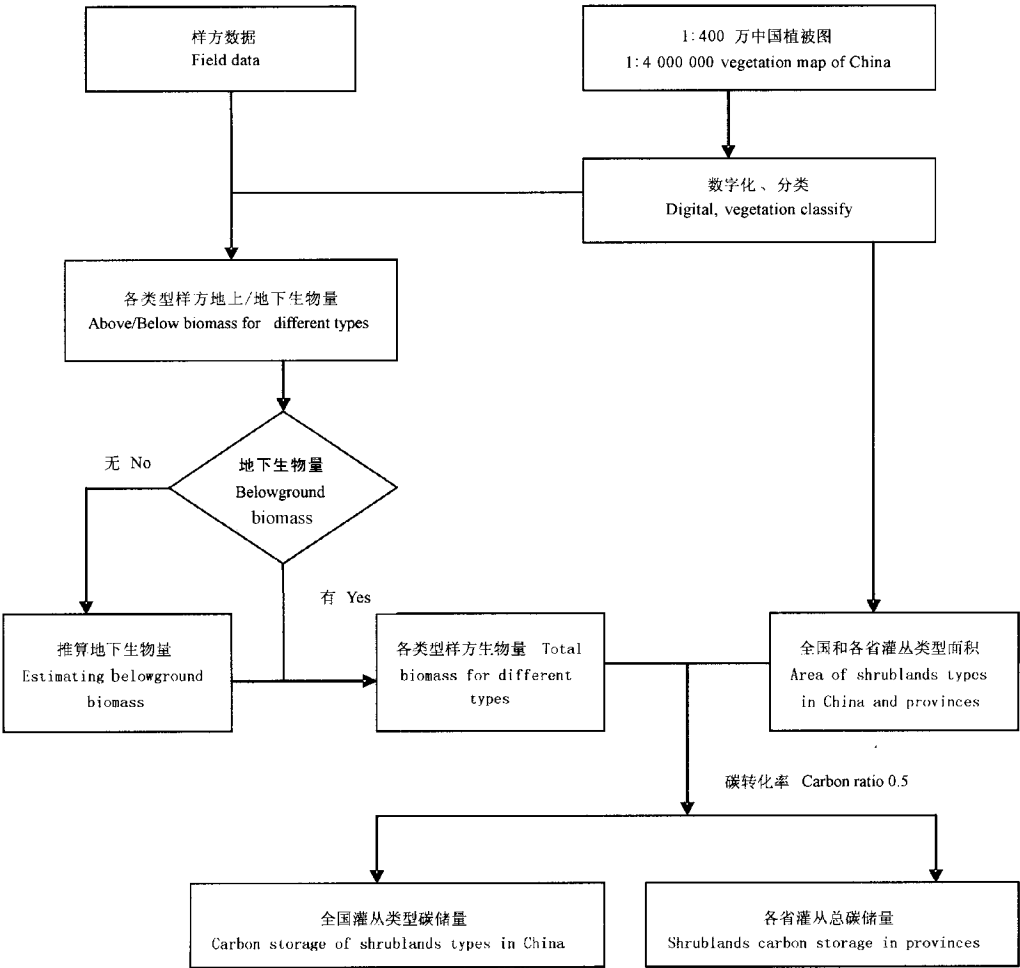


图 1 研究分析的流程图
Fig.1 The flow chart of the research

表 2 我国主要灌丛植被类型的碳密度和碳储量
Table 2 The carbon density and the storage of Chinese major shrublands types

灌丛类型 Shrublands types	面积 Area (10 ⁴ hm ²)	碳密度 Carbon density (Mg C·hm ⁻²) Mean ± SE	碳储量 Carbon storage (Tg C) Mean ± SE
热带海滨硬叶常绿阔叶灌丛、矮林 ¹⁾	0.26	5.92 ± 0.96	0.02
温带、亚热带落叶灌丛、矮林 ²⁾	7 476.35	6.24 ± 0.88	462.80 ± 65.79
温带、亚热带亚高山落叶灌丛 ³⁾	563.48	7.74 ± 1.30	43.64 ± 7.32
亚热带、热带石灰岩具有多种藤本的常绿、落叶灌丛、矮林 ⁴⁾	1 539.51	12.11 ± 2.99	186.45 ± 46.03
亚热带、热带酸性土常绿、落叶阔叶灌丛、矮林和草甸结合 ⁵⁾	5 598.52	17.00 ± 3.28	951.67 ± 183.63
亚热带高山、亚高山常绿革质叶灌丛、矮林 ⁶⁾	284.53	11.74 ± 2.46	33.40 ± 7.00
总计 Total	15 462.64	10.88 ± 0.77	1 681.98 ± 119.06

1)~6),SE 同表 1 See Table 1

16.1% ,总碳储量为 1.68 ± 0.12 (Mean ± SE) Pg C (1 Pg = 10¹⁵ g)。灌丛植被平均碳密度为 10.88 ± 0.77 Mg C·hm⁻² (1Mg = 10⁶g) ,从热带海滨硬叶常绿阔叶灌丛、矮林(5.92 Mg C·hm⁻²)到亚热带、热带酸性土常绿、落叶阔叶灌丛、矮林和草甸结合(17.00 Mg C·hm⁻²)变化很大 ,后者碳密度几乎是前者的 3 倍。就面积分布而言 ,温带、亚热带落叶灌丛、矮林是 6 种灌丛类型中分布面积最大的 ,占到了总面积 48.4% ,其次是亚热带、热带酸性土常绿、落叶阔叶灌丛、矮林和草甸结合(36.2%)以及亚热带、热带石灰岩具有多种藤本的常绿、落叶灌丛、矮林(10%) ,3 者合计就占到了 6 种灌丛类型总面积的 94.5% ,构成了我国灌丛的主要分布类型。就碳储量而言 ,由于亚热带、热带酸性土常绿、落叶阔叶灌丛、矮林和草甸结合具有分布面积广、碳密度高的特点 ,因此是 6 种灌丛类型中碳储量最大的 ,达到了 0.95 ± 0.18 Pg C ,占到了 6 种灌丛总碳储量的一半以上 (56.6%) ,其次是温带、亚热带落叶灌丛、矮林 (27.5%) 和亚热带、热带石灰岩具有多种藤本的常绿、落叶灌丛、矮林(11.1%) ,3 者合计达到了总碳储量的95.2% ,构成了我国主要的灌丛植被碳库。

2.2 各省(区)主要灌丛植被的碳储量(表 3)

表 3 给出了 6 种灌丛类型在全国各个省(区)的分布面积和碳储量 ,从中可以看出 ,我国灌丛主要分布在西南 3 省(云南、贵州、四川)和内蒙古、黑龙江等地。西南 3 省 6 种灌丛面积占了全国这些灌丛总面积的 23.5% ,内蒙古的灌丛分布也很广 ,有灌丛面积 1 358.33 × 10⁴ hm² ,仅次于云南省(1 484.23 × 10⁴ hm²)。灌丛分布最少的省(区)除天津和北京两个直辖市外)为江苏 ,仅有 5.51 × 10⁴ hm² ,其次是宁夏(30.30 × 10⁴ hm²)和海南(120.23 × 10⁴ hm²)等。就灌丛植被碳储量来看 ,西南 3 省(云南、贵州、四川)和江西、湖南是主要的碳储量省(区) ,西南3省

表 3 各省(区)主要灌丛植被类型的碳储量
Table 3 The carbon storage of major shrublands types in different provinces

各省区 Province	总面积 Area (10 ⁴ hm ²)	总碳量 Total (Tg C)
安徽 Anhui	368.30	40.55
北京 Beijing	73.07	4.56
福建 Fujian	587.42	99.74
甘肃 Gansu	382.09	25.79
广东 Guangdong ^a	520.19	86.67
广西 Guangxi	529.27	74.84
贵州 Guizhou	1 129.35	174.38
海南 Hainan	120.23	20.23
河北 Hebei	527.66	32.95
黑龙江 Heilongjiang	827.29	51.65
河南 Henan	434.94	27.16
湖北 Hubei	693.33	49.09
湖南 Hunan	660.34	103.13
江苏 Jiangsu ^b	5.51	0.34
江西 Jiangxi	680.40	113.27
吉林 Jilin	402.17	25.11
辽宁 Liaoning	424.32	26.49
内蒙古 Inner Mongolia	1 358.33	84.81
宁夏 Ningxia	30.30	1.89
青海 Qinghai	267.71	18.61
山东 Shandong	134.90	8.42
陕西 Shaanxi	704.34	45.69
山西 Shanxi	643.71	40.19
四川 Sichuan ^c	1 022.34	138.27
天津 Tianjin	2.58	0.16
新疆 Xinjiang	508.27	31.73
西藏 Xizang	471.09	42.55
云南 Yunnan	1 484.23	236.01
浙江 Zhejiang	468.98	77.70
全国 All	15 462.64	1 681.98

a :包括香港和澳门 Including Hong Kong and Macao b :包括上海 Including Shanghai c :包括重庆 Including Chongqin

大多地处亚热带地区 ,水热条件比较优越 ,因此植被的平均生物量明显高于全国其它地区 ,其 6 种灌丛植被碳储量因此占到了全国 6 种灌丛总碳储量的 1/3 (32.6%)。尽管内蒙古的灌丛分布面积居全国第二 ,但由于该地区大多处于干旱、半干旱地区 ,降

雨量成为限制植被生长的主要因子,植被生物量不高,因此其灌丛碳储量仅为 84.81 Tg C(1 Tg = 10¹²g),位于云南、贵州、四川、江西和湖南之后,居全国第六位。与分布面积类似,灌丛碳储量最少的省(区)(除天津和北京市外)为江苏,仅有 0.34 Tg C,其次是宁夏(1.89 Tg C)和山东(8.42 Tg C)等。

3 讨 论

灌丛是我国分布面积较广的一种植被类型,在我国其分布面积仅次于草地,而高于森林(表 4)。

表 4 我国森林、草地、灌丛和世界灌丛植被碳储量
Table 4 The carbon storage of Chinese forests, grasslands and shrublands and world shrublands

植被类型 Vegetation types	总面积 Area (M hm ²)	碳密度 (Mg C·hm ⁻²) Carbon density	总碳量 (Pg C) Carbon storage	文献来源 References
森林 Forests	105.82	44.91	4.75	Fang <i>et al.</i> , 2001
	108.64	38.67	4.20	刘国华等 2000 ;Liu <i>et al.</i> , 2000
	108.62	57.07	6.20	周玉荣等 2000 ;Zhou <i>et al.</i> , 2000
		41.32	3.78	赵敏和周广胜 2004 ;Zhao & Zhou, 2004
草地 Grasslands	406.00	11.50	4.66	Ni 2001
	299.00	11.50	3.06	Ni 2002
灌丛 Shrublands	175.78	45.60	8.02	Ni 2001
	154.63	10.88	1.68	本文 This paper
世界灌丛 World shrublands	2 650		27.90	Woodwell <i>et al.</i> , 1978 ^a

a：包括森林和灌丛、荒漠灌丛 Including woodland and shrubland, desert scrub

(2001)采用的植被碳密度是根据 Olson 等(1983)和 Prentice 等(1993)得到的,并没有依据我国的实测数据,所以产生了较大的差异。与我国森林植被碳储量相比,尽管本文计算的 6 种灌丛面积接近于我国森林面积的 1.5 倍,但由于植被碳密度仅相当于森林植被碳密度的 1/5 左右(19% ~ 28%),因此灌丛植被碳储量仅相当于森林碳储量的 27% ~ 40%。与我国草地植被碳储量相比,Ni(2001,2002)虽然均采用了植被平均碳密度方法,但统计的草地面积不同,因此草地的植被碳储量变化较大,灌丛植被碳储量相当于草地植被碳储量的比例也在 36% ~ 55% 之间波动。

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Woodwell 等(1978)估算了全球 2.65 × 10⁹ hm² 灌木林和沙漠灌丛的植被碳储量为 27.9 Pg C,平均碳密度为 10.5 Mg C·hm⁻²,与我们估算的中国 6 种主要灌丛植被的平均碳密度相当。与本文相同,Ni(2001)也利用了我国 1:400 万植被图(侯学煜,1982),并采用平均碳密度方法计算了中国陆地生态系统的碳储量,其中得到的灌丛面积(175.78 × 10⁶ hm²)与本文统计的 6 种灌丛面积相当,但由于其估计的灌丛植被平均碳密度是本文的 4.5 倍,因此得到的植被碳储量是本文的 5 倍左右,究其原因,主要是由于 Ni

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