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Carbon storage of ecosystems in holly hill and barren hill karst area

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Abstract: Holly hill and barren hill both exist in karst landform, karst forest is a fragile and low-biomass ecosystem with barren soil and low resilience and resistance capabilities to disturbance. The holly hill is the place where the vegetation is well protected by the indigenous people who live nearby based on their beliefs, the barren hill is comprised of rocky karst formations that contain the areas of exposed bedrock due to human disturbance. The study is about comparison of carbon storage of ecosystem in holly hill and barren hill, the carbon stocks of holly hill and barren hill ecosystems were studied through field work, laboratory analysis and statistic at Luocheng, Guangxi, China. The results showed that vegetation, soil and litter carbon storage of holly hill ecosystems were 7.42, 5.9 and 1.1 times those of barren hill ecosystems respectively. Carbon storage were 137.06, 93.73 t · hm^{-2} at holly hill and barren hill ecosystems respectively, soil carbon storage contributed most in the two ecosystems, and understory and litter contributed less. The comparison of carbon storage of holly hill and barren hill reflects the importance of protecting karst forest, keeping traditional aboriginal culture means a lot for protecting ecological environment and improving carbon sequestration.

Key words: carbon storage, biomass, holly hill, barren hill, karst

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喀斯特风水林和荒山生态系统碳储量的研究

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摘 要: 所研究的风水林和荒山属于喀斯特地貌。喀斯特森林是一种脆弱的低生物量生态系统,土壤贫瘠,自我修复能力低,易受人为因素干扰。风水林指人们居住地附近的一片茂盛的森林,认为有神居住而崇拜,严禁被砍伐和破坏。荒山是喀斯特森林植被在人为干扰后出现岩石裸露产生的石漠化现象。该研究通过野外调查、实验室分析、数理统计等对广西罗城喀斯特风水林和荒山生态系统碳储量进行对比性研究。结果表明:喀斯特风水林植被、土壤和枯落物碳储量分别是荒山的 7.42 倍、5.9 倍和 1.1 倍,风水林和荒山生态系统碳储

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量分别为 137.06、93.73 t · hm^{-2}，其中土壤碳库贡献率最高，而林下植被和枯落物却较低，表明风水林森林生态系统碳储量明显高于荒山。通过风水林和荒山的碳储量比较研究，为评价风水林碳汇提供依据，为制定森林管理政策、保护村社水平的植被提供数据参考。此外，还探讨了少数民族朴素的生态伦理思想在保护森林和增汇方面的作用，丰富了生态伦理学内容，对传承和弘扬少数民族传统文化、恢复生态具有重要意义。

关键词：碳储量，生物量，风水林，荒山，喀斯特

Holly hill, known as sacred groves or dragon hill, is a place whose vegetation is well conserved by the indigenous people who live nearby. The villagers worship it because they believe a god lives there and therefore, no one is allowed to cut plants or damage the hills. Such traditional culture has existed for centuries in some ethnic groups in China. It is high in species richness and contains complicated vegetation community structure (Zhou et al, 2002). Zhuang and Melao minority groups in Guangxi maintain animism in their traditional culture, believing that all things in the holly hill are the reincarnation of gods that will bless their safety, health and prosperity if the holly site is protected. This tradition of protecting forest ecosystems based on ecological ethics constitutes part of the culture of these indigenous people.

Holly hill vegetation is a vital part of the agricultural and forest ecosystems for the people who live in the area and plays a very important role in water and soil conservation, such as regulating the microclimate and maintaining soil stability. Previous research showed that the biodiversity of the protection area was protected relatively well, which plays an expanded role in the protection of biodiversity at landscape scales (Liu et al, 2000).

The barren hill is comprised of rocky karst formations that contain extensive areas of exposed bedrock. Desertification has occurred in this region as a result of extensive vegetation removal, which has led to the degradation of the land and reduced soil productivity (Yang, 1995). Karst forest is a fragile ecosystem where soils take an extremely long period of time to form, site resources for plant productivity are low, extensive areas of barren soil exist where soil erosion occurs, and has low resilience and resistance capabilities to disturbance. Karst forest ecosystems usually take longer to recover once the vegetation is removed. The restoration of the karst forest ecosystems usually requires the establishment of several different successional stages, which can significantly influence the ecosystem functions of these vegetative systems (Wang et al, 2008).

The carbon storage of holly hill and barren hill ecosystems were studied in this paper. This study is aimed to compare the carbon storage of two ecosystems and their carbon storage spatial distributions, which could contribute to the understanding of the important significance for protecting community forests in karst harsh habitat, and it also provides the comparative data to develop proper management strategies for these ecosystems and the community forest.

1 Methods

1.1 Description of study area

The study area (108°48′ E, 24°59′ N) is located in the northern part of Luocheng Melao Autonomous County, Guangxi, China, which lies to the south of Jiuwan Mountain. This region is characterized by a subtropical climate with high humidity, rain and fog. The annual average temperature is 18.8 ℃, with extreme highest and lowest temperatures of 38 ℃ and −4 ℃, respectively. The average annual rainfall is 1 630.6 mm, with an average relative humidity of 78% and 300 frost-free days.

Holly hill and barren hill are situated in Sibao Village, Luocheng County, Guangxi, China, which is inhabited by the Melao, Zhuang, Yao, Dong and Miao minority groups. The Melao and Zhuang comprise more than 50% of total population in Sibao Village.

Holly hill and barren hill are dominated by limestone soil with extremely uneven soil depth and exposed rocks. The elevation ranges from 280 m to 318 m with steep slopes (20°−40°) and soil depths of 3−50 cm. The vegetation occurs in relatively small patches or niches in such areas as stone facings or surfaces, soil, channels carved into stone over time, and cracks and crevices in stones. Three holly hill sites which contain lush vegetation, surround Sibao Village and called Lion Hill, Temple Hill and Laojie Hill by arborigines. The primary species of woody plants which occur there mainly include *Cinnamomum camphora*, *Celtis sinensis*, *Ulmus castaneifolia*, *Sapium rotundifolium*, *Tirpitzia ovoidea*, *Radermachera sinica*, *Broussonetia papyrifera*, *Alangium chinense*, *Cudrania tricuspidata*, *Alchornea trewioides*, *Crassocephalum crepidioides*, *Trachelospermum jasminoides*, *Melastoma intermedium*, *Mallotus philippensis*, *Koelreuteria integrifoliola*, *Ervatamia divaricata*, *Oreocnide frutescens*, main species of herbaceous plants are *Hoya carnosa*, *Pyrrosia lingua*, *Rubus corchorifoliu*, *Elatostema balansae*, *Dicranopteris dichotoma*, *Eragrostis pilosa*, *Arthraxon hispidus*, *Microstegium vagans*, *Ishaemum indicum* and *Arundinella hirta*.

Local farmers cut firewood and planted crops for a long time in the barren hill before forest conservation became a concern, which has created areas of exposed bedrock and desertification. The vegetative communities have been partly restored since the involvement by the government in conservation practices. At the present time these communities primarily consist of woody and herbaceous plants. According to its community physiognomy, the dominant species and habitat types, the karst vegetation was divided into five successional stages: (1) herb community, (2) herb-shrub community, (3) shrub community, (4) sub-climax community and (5) climax community of evergreen-deciduous broad-leaved mixed forests (Xia, 2010). Only the herb community and herb-shrub community existed in barren hills during the time that this study was implemented.

The primary woody species that occurred in the barren hills mainly include *Alchornea trewioides*, *Alangium chinense*, *Callicarpa macrophylla*, *Millettia nitida*, *Jasminum seguinii*, *Vitex negundo*, *Broussonetia papyrifera*, *Oreocnide frutescens*, *Strophanthus divaricatus*, *Platycarya strobilacea*, *Cudrania tricuspidata*, *Rhus chinensi*, *Rosa laevigata*, *Sterculia euosma*, *Chukrasia tabularis*, *Ulmus parvifolia*, *Laplacea indica*, and main species of herbs are *Pteridium revolutum*, *Litsea cubeba*, *Miscanthus floridulu*, *Microstegium vagan*, *Bidens pilosa*, *Erigeron komarovii*, *Elatostema balansae*, *Imperata cylindrica*, *Rubus corchorifoliu*, *Eragrostis pilosa* and *Arthraxon hispidus*.

1.2 Methods of estimating tree biomass in holly hills

Lion Hill, Temple Hill and Laojie Hill were chosen to represent the holly hill study areas. A total of 27 sample plots (20 m × 30 m) were established along an elevational gradient of 50–80 m vertical distance. Within each plot, total tree height and diameter at breast height (*dbh*) were measured on all trees with $dbh>2$ cm. The aboveground biomass of trees were estimated with biomass equations published by Zhu et al (1995) for Guizhou karst forests (Table 1). The underground biomass of trees were estimated by the root-shoot ratio (0.231 8) reported by Qi & Tang (2008) for Xishuangbanna karst forests.

Table 1 Equations[1,2] used to estimate the forest biomass in holly hills

Forest component	Model coefficients		
	a	*b*	*r*-value
Tree trunk	0.041 4	0.935 4	0.994 5
Branch	0.032 0	2.339 9	0.939 1
Foliage	0.137 7	3.725 6	0.848 7

Note: [1] $W=a(D^2H)^b$, where W=biomass (kg), $D=dbh$ (cm), and H=total height (m); [2] Equations from Zhu et al, 1995.

1.3 Methods of estimating biomass of understory and litter in holly hills

Three 4.0 m^2 and three 1.0 m^2 subsample plots were established in each sample plot for the purpose of estimating herbaceous and woody understory biomass, and litter biomass, respectively. In each 4.0 m^2 subsample plot, the herbaceous and woody plants were clipped and weighed to the nearest 0.1 g to acquire a fresh weight. All litters were collected down to the mineral soil in each 1.0 m^2 subsample plot and weighed to the nearest 0.1 g to attain a total fresh weight. An approximate 30% subsample of these fresh weight field samples were brought back to the laboratory and dried at 80 ℃ until a constant weight was achieved to determine the moisture content. The determined moisture content percentage was applied to the fresh weight samples to achieve a dry weight and converted into unit area ovendry biomass weight of understory and litter ($t \cdot hm^{-2}$). The belowground biomass of woody stems was estimated by using the root-shoot ratio (1 ∶ 1) reported by Tu & Yang (1995) for Guizhou karst forests.

1.4 Methods of estimating biomass of litter, woody and herbaceous plants in barren hills

Barren hills are currently in vegetation restoration stages as part of the effort to reverse the karst rocky desertification that has occurred there. As a result, two successional stages existed and were investigated in this study, which included the herb-shrub and the herb communities. Three 4.0 m^2 subsample plots were established in each sample plot to estimate woody, herbaceous and litter biomass. The procedure to determine the fresh and dry weight of woody and herbaceous plants and litter was performed according to the same method as described for the holly hills.

1.5 Methods of measuring carbon content

Samples materials of litter, woody and herbaceous plants of holly hill and barren hill were dried, crushed and sieved. For soil samples, three soil samples were placed in each replicate plots randomly, and sampled by the cutting rings at 0-20 cm, 20-40 cm soil depth, soil samples were brought back to the laboratory to determine the soil bulk density, the carbon content of different components and soils were analyzed through the potassium dichromate oxidation-hydration heating.

1.6 Methods of estimating carbon storage

The carbon storage of holly hill and barren hill ecosystems consists of tree, understory, litter and soil (no tree layer existed in unprotected site). The carbon stored in ecosystems can be estimated by multiplying the biomass of different forest components by their carbon content, typically 0.5, which was used in this study. The estimation of soil carbon storage was determined with the following equation (Zhong et al, 2008) : $S_{SOD}=\sum_{i=1}^{n}(C_i\times p_i\times T_t)\times 10^{-1}$.

In the equation, S_{SOD} = soil carbon storage density ($t \cdot hm^{-2}$), C_i = carbon mass fraction in i soil depth ($g \cdot kg^{-1}$), P_i = soil bulk density in i soil depth ($g \cdot cm^{-3}$), T_i = thickness of soil in i soil depth (cm), and n is the number of soil depth layers.

1.7 Data processing

Excel and SPSS 17.0 statistical software were utilized in the data analysis.

2 Results and Analyses

2.1 Carbon contents of litter, woody and herbaceous plants

2.1.1 Carbon contents of litter and understory in holly hills Carbon contents of understory of Lion Hill, Temple Hill and Laojie Hill ranged from 37.51% to 43.05% , with no significant difference between each site ($P>0.05$). The carbon content of litter ranged from 38.9% to 45.54%, with no significant difference between each site. The carbon content in 0-20 cm soil depth at the three protected sites ranged from 2.53% to 3.18%, and ranged from 1.98% to 2.25% within the 20-40 cm soil depth soil (Table 2).

Table 2 Carbon contents of understory, litter and soil in holly hills

Sample	Carbon content (%)			
	Understory[1]	Litter	0-20 cm	20-40 cm
Lion Hill	43.05	45.54	2.79	2.25
Temple Hill	37.51	39.75	3.18	2.22
Laojie Hill	41.07	38.90	2.53	1.98
Average	40.54	41.40	2.83	2.15

Note: [1] Understory includes herbaceous and woody plants. The same below.

2.1.2 Carbon contents of litter, woody and herbaceous plants inbarren hills Carbon contents of litter, woody and herbaceous plants in herb-shrub community were higher than what was found in the herb community but were not significantly different at $P = 0.05$ (Table 3). The carbon contents in the soil layers of 0-20 cm and 20-40 cm depths were higher in the herb-shrub community compared to the herb community, and in both vegetation communities the soil carbon decreases with soil depth.

Table 3 Carbon contents of understory, litter and soil in barren hills

Vegetation community	Carbon content (%)			
	Understory[1]	Litter	0-20 cm	20-40 cm
Herb-shrub	41.14	38.50	2.89	1.88
Herb	36.48	33.66	1.40	0.91
Average	38.81	36.08	2.15	1.40

2.2 Carbon storage

2.2.1 Carbon storage of holly hills The carbon stored in the trees of holly hills ranged from 21.76 t · hm^{-2} to 51.4 t · hm^{-2}; carbon storage of the understory ranged from 1.32 t · hm^{-2} to 2.92 t · hm^{-2}; carbon stored in the litter ranged from 0.77 t · hm^{-2} to 4.86 t · hm^{-2}; and soil carbon ranged from 86.43 t · hm^{-2} to 112.64 t · hm^{-2}. The total carbon stored in the protected ecosystems ranged from 113.47 t · hm^{-2} to 149.92 t · hm^{-2}(Table 4).

2.2.2 Carbon storage of barren hills The carbon stocks of woody and herbaceous plants in herb-shrub community were higher than those of the herb community (Table 5). However, the carbon stocks of the litter component in the herb community were higher than what was found in the herb-shrub community. The total soil carbon stored in herb-shrub community and herb communities were 117.78 t · hm^{-2} and 58.63 t · hm^{-2}, respectively. The total ecosystem carbon stored in the herb-shrub and herb communities were 126.53 t · hm^{-2} and 60.93 t · hm^{-2}, respectively. Because the trees that occurred in the herb-shrub community were small, they were combined with the woody and herbaceous plant species.

2.2.3 Comparison of carbon storages of holly hill and barren hill ecosystems Carbon stored in the tree layer of holly hill ecosystems accounted for 25.83% of the total ecosystem carbon (Table 4), the carbon stored in the woody and herbaceous plants was less than that of the barren hill. However the carbon stored within the litter layer of holly hill ecosystem was greater than that in the litter layer of the barren hill. Soil carbon stored at holly hill within both the 0-20 cm and 20-40 cm layers were greater than what was found in the soil layers at barren hill. The total carbon stored in the holly hill ecosystem was 1.46 times greater than the total barren hill ecosystem (Table 6).

3 Discussion

3.1 Carbon storage of holly hills

Because holly hills are considered a sacred area, the Sibao Village Committee did not allow the authors to harvest tress to measure biomass out of respect for the worship and taboos of the local residents. The aboveground biomass of trees were therefore estimated by biomass equation published by Zhu et al(1995), and underground biomass of trees were calculated by a specified root-shoot ratio (Qi & Tang, 2008).The use of biomass regression models to estimate the biomass of different tree species usually introduces error by the nature of their estimation, but due to the high species diversity and few numbers of individuals within species in karst forest ecosystem, it is difficult to create good regression models as might be performed in plantation settings. Yang & Cheng (1991) indicated that karst forest populations had similar biological features due to the long-term adaptation to the harsh karst environment, Whittaker & Woodwell (1968) found that there was a significant and similar correlation between biomass and diameter of similar species of trees. Therefore, we believe that the application of uniform biomass regression models to similar species is reasonable for this study.

Karst forest typically is considered as a low-biomass forest ecosystem (Yu et al,2010), whose biomass and carbon were particularly lower than those of evergreen broad-leaved forest ecosystem in the same climatic zones (Li et al, 2015; Zhang et al, 2014). The low biomass and carbon stocks are due to the harsh ecological environment found in the karst ecosystems, such as barren soil, water stress, and frequent natural and human disturbances. This harsh environment causes vegetation to grow very slowly, creating a short ecological life for plants. In addition, the development history of secondary forests in these systems is very short (Zhu et al,1995).

Table 4　Carbon storage and percentage of components of holly hill ecosystem

Sample	Tree		Understory[1]		Litter		Soil (t·hm^{-2})		Total soil		Total carbon (t·hm^{-2})
	(t·hm^{-2})	%	(t·hm^{-2})	%	(t·hm^{-2})	%	0-20 cm	20-40 cm	(t·hm^{-2})	%	
Lion Hill	51.4	34.28	2.92	1.95	4.86	3.24	49.96	40.78	90.74	60.53	149.92
Temple Hill	33.06	22.37	1.32	0.89	0.77	0.52	70.88	41.76	112.64	76.22	147.79
Laojie Hill	21.76	19.18	4.2	3.7	1.08	0.95	46.42	40	86.43	76.17	113.47
Average	35.41	25.83	2.81	2.05	2.24	1.63	55.76	40.85	96.6	70.48	137.06

Table 5　Carbon storage of ecosystem component and percentage of the total in barren hill ecosystem

Vegetation type	Vegetation		Litter		Soil (t·hm^{-2})		Total soil		Total carbon (t·hm^{-2})
	(t·hm^{-2})	%	(t·hm^{-2})	%	0-20 cm	20-40 cm	(t·hm^{-2})	%	
Herb-shrub	8.43	6.66	0.32	0.25	67.99	49.79	117.78	93.08	126.53
Herb	1.86	3.05	0.44	0.72	34.66	23.97	58.63	96.23	60.93
Average	5.15	5.49	0.38	0.41	51.33	36.88	88.21	94.1	93.73

Table 6　Carbon storage comparison of ecosystem component in two different ecosystems

Ecosystem component	Holly hill (t·hm^{-2})	Barren hill (t·hm^{-2})
Tree	35.41	—
Woody and herbaceous plants	2.81	5.15
Litter	2.24	0.38
Soil		
0-20 cm depth	55.76	51.33
20-40 cm depth	40.85	36.88
Total soil	96.60	88.21
Total ecosystem	137.06	93.73

Tian et al (2011) studied the carbon stocks of different vegetation components in karst area, Guizhou Province, and they found that soil carbon accounted for over 94.01% of whole ecosystem while vegetation carbon stocks accounted for 0.82%-5.64%. The carbon stored in trees at protected sites in this study accounted for 25.83% of whole ecosystem, while the carbon in the soil, understory vegetation, and litter accounted for 70.48%, 2.05% and 1.63%, respectively. It is evident that the carbon sequestered and stored in the soil of these ecosystems contributes significantly to these ecosystems, followed by the tree layer, understory vegetation and litter.

Carbon stored in the soil of holly hills decreased with the increase of soil depth. This study found that the soil carbon within 0-20 cm layer in holly hills (46.62 t·hm^{-2}) was higher than what has been reported for soil carbon of the karst rocky desertification comprehensive treatment demonstration area in Guizhou Province and lower than soil carbon in the karst non-rocky desertification (Zhou et al, 2011). The soil carbon of holly hills was also lower than the soil carbon found in different ecosystem restoration treatments in Guizhou (Tian et al, 2011). Many different factors can influence soil carbon storage, such as plant species, forest age, climate, soil conditions, and any soil treatment before afforestation. Zhang et al (2009) studied the factors that effect soil carbon storage in Guangxi, Guizhou and Yunnan Province, and found that temperature and soil parent material were primary factors that influence the amount of soil carbon with temperature having a greater influence than parent materials.

3.2 Carbon storage of barren hills

The carbon storage of woody and herbaceous plants of barren hills was higher than what was found in holly hills. Because, once trees begin to dominate an ecosystem, understory plants begin to have difficulty in surviving and decrease in their productivity due to a combination of the harsh karst environment and the development of forest canopy. On the other hand, in the herb-shrub community stage, woody and herbaceous plants will both exist, allowing for higher net productivity and subsequently higher amounts of biomass.

The average carbon of woody and herbaceous plants in barren hills accounted for 5.9% of whole ecosystem, and carbon stored within the litter comprised only 0.44% of the entire ecosystem. The total carbon stock within the herb-shrub community was higher than that in the herb community (126.93 t · hm^{-2}>60.93 t · hm^{-2}), which can be attributed to the higher soil carbon within the herb-shrub community compared to the herb community. Soil carbon stocks in herb-shrub community and herb community were 117.78 t · hm^{-2} and 58.63 t · hm^{-2}, accounting for 93. 08%, 96. 23% of each ecosystem, respectively. The carbon stored in soil accounted for the majority of the carbon stored within barren hill ecosystem, whereas the carbon stored in the vegetation and litter contributed much less to the total carbon stock.

Soil carbon within 0–20 cm depth in the herb community and the herb-shrub community were 34.66 t · hm^{-2} and 67.99 t · hm^{-2}, respectively. Soil carbon stocks increased with the succession of different successional stages. Yan et al (2011) reported that the soil carbon stored in different rocky desertification grades ranged from 5.2 t · hm^{-2} to 169.1 t · hm^{-2}, and that the soil carbon stock decreased as rocky desertification became more serious. Liu et al (2006) thought that soil not only affected vegetation community occurrence, development and rate of succession, but also had an important influence on the process, productivity and structure of ecosystems. As succession progressed, the dynamics of the vegetation community enriched soil resources, increased spatial heterogeneity, and maintained the relationship between different species of plants and biodiversity.

3.3 Comparison of carbon storage between holly hill and barren hill ecosystems

The total carbon stocks of holly hill and barren hill ecosystems were 137.06 t · hm^{-2} and 93.73 t · hm^{-2}, respectively, both well below the reported average of 258.83 t · hm^{-2} for forest ecosystems in China (Zhou et al, 2000). This is partly due to the fact that the soil carbon found in this study (88.21–96.6 t · hm^{-2}) is much lower than the average soil carbon reported for China forest ecosystem (193. 55 t · hm^{-2}). These low soil carbon stocks may be the following results: (1) The harsh karst habitats affect ecosystem carbon storage, the land use change after karst desertification affect significantly the soil organic carbon, as land use intensity increases, the occurrence of herbaceous plants will increase at the expense of woody plants. One of the highest impacts of land use change that causes the greatest alteration to natural vegetation and ecosystem process is the conversion of natural plant communities to farmland. Eswaran et al (1993) demonstrated that destroying or converting forest land to other land uses can reduce the soil carbon by as much as 20%–50%. Land use changes often damage the soil aggregate structure, and rate of carbon sequestration was lower than the rate observed in aboveground vegetation. (2) The rate of soil respiration is higher in middle subtropical climate zone and rainfall amounts are high. This causes more CO_2 release into atmosphere following decomposition of litter which means less carbon accumulates in the soil, which is a common feature of soil in middle subtropical climate regions of China.

4 Conclusion

Comparing to barren hill ecosystem, the carbon storage of holly hill ecosystem was higher, 1.46 times that of barren hill, and the carbon content of understory, litter and soil were higher than those of barren

hill. The carbon storage of soil and trees were the main carbon pool in the holly hill ecosystem, soil carbon storage contributed most, accounting for 70.48% of ecosystem, carbon stocks of understory and litter contributed less. Soil carbon storage contributed most in the barren hill ecosystem, accounting for 94.1% of ecosystem. Soil carbon storage decreased as soil depth increase in two ecosystems. As a fragile ecosystem, karst vegetation once destroyed, it will take a long time to recover, furthermore, manpower, materials and finance need to be input during treating rocky desertification, local villagers protect karst forest ecosystems well by their simple ecological ethics, which has important significance for protecting community forests at community level, especially in karst harsh habitat, the function of these traditional aboriginal knowledge cannot be ignored. Qualifying carbon storage of these two ecosystems can offer the reference for managing community forest, making policies and carbon sequestration improvement.

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