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海南琼北地区不同植被类型物种多样性与土壤肥力的关系

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摘要：研究海南岛琼北弃荒坡耕地不同植被类型植物多样性与土壤肥力演变的相互关系的结果表明，不同植被类型的 α-多样性指数的增加和土壤肥力（有机质含量和氮含量）的增加正相关明显，β-多样性指数在草本植物群落与灌丛的过渡区变化较强烈，而土壤有机质含量变化较大的地方则是在疏灌丛与密灌丛之间，表现出在植被恢复的同时，土壤有机质含量也会有所增加，但后者一般稍滞后一段时间。在对土壤肥力与植被性状的关系进行多元回归分析后发现，土壤有机质含量主要与演替后期植物种类的发展有关；而土壤全氮则与群落覆盖度、木本植物种数和演替后期植物种数等多个因素有关；全磷稍与物种多样性有关。土壤全钾和 pH 值的变化比较复杂，与植物组成性状的关系没有选择项。

关键词：生物多样性；土壤肥力；植被类型；弃荒坡耕地；海南岛

The Relationship Between Biodiversity and Soil Fertility Characteristics on Abandoned Fields in the Tropical Region of Southern China

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Abstract: Hainan Island is the biggest tropical region in the South of China. In the island, soil erosion and degradation are important ecological problems related to the increase of population and land use in the last 30 years. In order to evaluate the fertility of soil and set up the model for recovering the forest vegetation, a study was carried out on old-fields abandoned 2 to 20 years ago, near the Haikou city (20°02′N, 110°15′E, altitude 30～40 m a. s. l) The area belongs to the wet tropical monsoon region. Mean annual rainfall is 1650 mm, and mean annual temperature is 23.6℃. The relationship between different vegetation features and soil fertility has been investigated. The vegetation data include community coverage, number of plant species, number of woody species, number of late successional species and index of plant-diversity. The data on soil include content of organic matter, nitrogen, phosphate and potassium.

The lowland tropical rainforests were disappeared in the area because of human impact, however some tropical rainforest tree are still growing in the abandoned fields, such as *Schefflera octophylla*, *Ilex shimeica*, *Actinodaphne pilosa*, *Radermachera hainanensis* and *Pithecellobium lucidum*.

The the following secondary vegetation types were defined by vegetation analysis: (1) Association. *Fimbristylis tristachya*, *Kyllinga brevifolia*. (2) Association. *Miscathus sinensis*, *Imperata cylindrical*. (3) Association. *Eupatorium odoratum* (grassland). (4a) Association. *Casearia glomerata*, *Psychotria rubra*.

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(4b) Association. *Lannea coromandelica*, *Streblus asper*. (5) Association. *Rhodomyryus tomentosa*, *Aporusa dioica*. (6) Association. *Cratoxylon conchinchinense*, *Rapanea linearis* (shrub forest) (7) Association. *Lannea coromandelica*, *Litsea glutinosa*, *Cratoxylon conchinchinense* (Woodland forest). At present the shrub formations are the main vegetation types on these old-fields. The process of the secondary succession can be summarized into 4 stages: lower grassland, high grassland, shrubland and woodland.

Based on the investigation, 503 vascular plant species have been found. 15 species are pteridophyte belonging to 11 genera and 10 families, 488 species are angiosperm that belong to 335 genera and 92 families.

The results showed that change in β-plant diversities in the process of vegetation recover on the abandoned fields. The β_C and β_R index of β-plant diversities of neighbored communities were small because of many plants of the same species (there were many same species in two communities), such as 1-2, 1-3, 2-3, 5-6, 5-7 and 6-7; and these index were large between different successional stages because of few same plant species, such as 1-4, 1-5, 1-6, 1-7 and 2-7. But the C_S and C_N index of β-plant diversities of neighbored communities increased in the process of vegetation succession on these old-fields.

The soil data indicated that the contents of the organic matter and nitrogen were increasing during the vegetation succession. The increase of content of organic matter in the 0～20 cm topsoil from the early stages to the latest stages was from 1.44% to 3.98%, while for nitrogen it ranges from 0.015% to 0.033%. This increase of soil fertility might have been associated with the progressive development of the plant vegetation. The results showed that the greatest change of the index of β-plant diversities occurred between the grassland stage to shrubland stage. The results also showed that the greastest change of contents of organic matter occurred between the shrubland stage to the woodland stage. Many grass species disappeared from the shrubland to the woodland stage. The content of organic matter increased in later stages because of the litter accumulation. These changes occurred in two stages. One was the grassland stage that had more nitrogen fixation plants, the other was the shrubland stage which had more litter. These results showed that vegetation recover speed was faster than the recover speed of soil fertility on the abandoned fields. Nitrogen fixation and litter accumulation are very important for the soil amendment on the old-fields.

The relationship between characteristics of plant communities and soil fertility were analyzed on the abandoned fields. The results showed that the coefficients of vegetation were from 0.9221 to 0.9919. There were close relationships between content in organic matter and the features of vegetation. But we can not see regularities in change of phosphate and potassium contents, and regularities in change of pH value on the early successional seres from grassland to woodland forest. The regression equation are: (1) $Y1 = 1.163682 + 0.1292752X4 \quad R = 0.8961$, (2) $Y2 = 0.07186 - 0.001129X1 + 0.0006633X3 + 0.0008639X4 \quad R = 0.99723$, (3) $Y3 = 0.04278684 + 0.010622X5 \quad R = 0.854606$. The results showed that the content of organic matter was related to the number of plants appearing in the latest stage of the succession, while the content of the nitrogen was related to the cover ratio and number of woody plants. It revealed that the increment of soil fertility was related to the recovery of vegetation on the abandoned fields.

But these linear relationships on the early successional seres will become more complex with the progress of the vegetation succession. Progress of zonal vegetation succession is determined by the climatic conditions, namely water and heat. But the soil conditions will also affect the development of plant communities and speed of the progress of the same zonal vegetation succession. Soil properties relate to the vegetation characters on the zonal vegetation successional series too, particularly during early successional stages, meanwhile vegetation recovery will lead to the soil improvement. Due to different intensities of land use on the abandoned fields, these relationships are very complex. Therefore additional studies are neces-

sary for describing these complex relationships.

Changes of the vegetation and soil fertility, during early stages of the vegetation succession from grassland to woodland forest, were tested clearly.

Number of the plant species increaseed on these successional series. The increase of the content of organic matter was closely related to the increase of the late successional species. The content of nitrogen was related to the community coverage, to the number of woody species and late successional species.

Key words: bio-diversity; soil fertility; vegetation types; abandoned field; Hainan Island

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因过渡开垦,水土流失、土壤肥力严重下降等,而不得不放弃和丢荒的耕地是目前海南省主要的弃荒坡耕地类型。由于弃荒年代不一,在弃荒坡耕地上,不同植被类型的发生、发展速度和土壤肥力的恢复具有一定的差异。同时,由于植被类型的空间差异性,土壤肥力也呈现出明显的空间变化特征。总之,土壤与植物组成性状之间的相互关系是非常复杂的。为了能更好地对热带地区弃荒坡耕地上的灌丛和草地生态系统进行土壤退化评价,建立退化土壤系统恢复重建的方法和途径,开展代表性地区弃荒坡耕地的植物多样性与土壤肥力的相互关系的详细研究是必要的。为此,本文是在研究琼北地区弃荒坡耕地次生植被特点及各植被类型之间关系的基础上[1],以植物群落物种多样性指数(α-植物多样性指数、β-植物多样性指数)为主要植物群落特征开展弃荒坡耕地的植物多样性(物种多样性指数、植物种数、木本植物种数、演替后期植物种数等)与土壤肥力的相互关系研究。

1 样地概况

琼北地区的弃荒坡耕绝大多数是由于毁林或过渡的开垦后,于20世纪70年代初陆续丢荒形成的,在海口市的西南部和澄迈县的北部均有分布,40多平方公里。研究样地均为20世纪70年代后弃荒的坡耕地,位于海口市西南部,地处北纬20°02′,东经110°15′。东西取向3 km,南北取向1.5 km,总面积4.5 km^2。过去10 a的年平均温度为23.6℃,平均年降雨量1650 mm(海南气象局资料)。地形为琼北羊山小丘陵地,有褶皱。土壤类型为玄武岩发育砖红壤和浅海沉积物发育砖红壤。该地区的植被特点、各植被类型间的植物组成与群落结构间的关系等已经开展过较为深入的研究[1]。

植被类型的代表植物群落 草地 (1)飞机草群丛(Association. *Eupatorium odoratum*),这一群丛主要分布在农耕闲地和弃荒3 a左右的坡耕地里。(2)芒、白茅群丛(Association. *Miscathus sinensis*, *Imperata cylindrica*),这一群丛主要分布在弃荒8~10 a的坡耕地里。草灌丛 (3)黄牛木、柳叶密花树群丛(Association. *Cratoxylon conchinchinense*, *Rapanea linearis*),这一群丛主要分布在弃荒8~10 a的弃荒坡耕地里。(4)桃金娘、银柴群丛(Association. *Rhodomyryus tomentosa*, *Aporosa dioica*),这一群丛主要分布在弃荒15 a左右的坡耕地里。(5)加赐树、九节木群丛(Association. *Casearia glomerata*, *Psychotria rubra*)等,这一群丛亦主要分布在弃荒20 a左右的弃荒坡耕地里。(6)厚皮树、鹊肾树群丛(Association. *Lannea coromandelica*, *Streblus asper*),这一群丛主要分布于弃荒约15 a之久的坡耕地里。次生疏林 (7)厚皮、潺稿木姜、黄牛木群丛(Association. *Lannea coromandelica*, *Litsea glutinosa*, *Cratoxylon conchinchinense*),这一群丛主要分布在弃荒约20 a之久的坡耕地里[1]。

2 研究方法

2.1 植物生态学研究方法

运用样方法对样地各种植被类型(除湿生草地外)进行基本特征调查[1]。

(1) α-植物多样性指数 利用Simpson指数和Shannon-Weiner指数[2]及其相应的指数分别测定物种多样性。

(2) β-植物多样性指数 利用β_c、β_R、C_s和C_N多样性指数[3]测定不同植被类型间物种多样性变化。

2.2　土壤研究方法

土壤的取样方法是每个样地分 0～20 cm，20～30 cm 和 30～40 cm 3 个土层分别随机取 11 个点的混合样；土壤有关的化学性质分析方法见参考文献[4]。

2.3　植被与土壤的相关性分析方法

植被和土壤的相关分析采用多元线性回归分析方法[5]，同时重点分析植物多样性与土壤肥力属性之间的关系。

3　研究结果与分析

3.1　不同类型植物群落的物种多样性

3.1.1　α 多样性　弃荒坡耕地退化生态系统的恢复过程中，随着植物群落发育、植物种类更替和植物种类的增加，特别是木本植物的增加等带来了植物群落内的组成成分和结构的变化。表 1 反映的琼北地区弃荒坡耕地不同植物群落类型的物种多样性、差异性表明了随着植物群落木本种数和个体数的增加，植物 α 多样性指数有较明显的升高。

3.1.2　β 多样性　β 多样性的二元属性数据指标的测度是 β 多样性的一个非常重要的测度手段，其结果能反映植物群落沿某一环境梯度其植物组成的差异和植物群落的变化情况。从表 2 的数据可以看到在弃荒坡耕地的植被恢复过程中，各植物群落类型间的 β 多样性变化有一定的规律性。如果仅从二元属性数据测度看，演替阶段接近的植物群落间的相同种较多，β_C、β_R 多样性指数较小，如(1)-(2)，(1)-(3)，(2)-(3)，(5)-(6)，(5)-(7)，(6)-(7)等；相隔较远的植物群落类型的相同种较少，β_C、β_R 多样性指数较大，如(1)-(4)，(1)-(5)，(1)-(6)，(1)-(7)，(2)-(7)等；同时发现 β_C、β_R 多样性指数变化较大的地方是在群落(3)和(4)之间，是草本植物群落与灌丛的过渡类型。这说明了，随着植物群落发育的进展，植物种类更替明显，特别是生态过渡类型是植物种类增加较快和更替最强烈的类型。同时，从群落的相似性指数的比较和从数量测度的比较却发现，发育阶段接近的植物群落间的(多样性指数(C_S 和 C_N)较大，而且随着植物群落的进展，该指数在增大。说明了由于人类对系统的干扰程度的不同，在弃荒坡耕地的植被恢复过程中，植物群落类型多样性较大，在本底情况较为一致的弃荒坡耕地上，发育相近的植物群落其组成和结构较为相似。在同一气候区内，植物群落的方向是一致的，且最终往地带性植被—热带低地雨林方向发展，与此同时，植物群落土壤性质亦发生着与植物群落物种多样性指数、群落覆盖度、木本植物种类和演替后期种等特征相关的变化。

表 1　弃荒坡耕地不同植物群落类型物种 α 多样性

Table 1　The plant α-diversity of the different succession stages on abandoned field vegetation

植被类型 Vegetation types	样地面积 (m^2) Area of plots	木本植物种数(个) Species number(N)	个体数(个) Individual number(N)	Simpson index	Shannon-Wiener index
(1)	500	5	19	2.443	1.628
(2)	500	12	56	5.532	2.830
(3)	500	17	131	7.091	3.307
(4)	500	29	322	8.500	3.919
(5)	500	38	503	11.687	4.299
(6)	500	43	537	13.983	4.551
(7)	500	42	499	13.190	4.433

表 2　弃荒坡耕地不同植物群落间植物 β-多样性的发展状态*

Table 2　The situation of development of β diversity in the different succession stages in the abandoned fields

植被类型对 Pair of vegetations	多样性指数 Index of β-biodiversities			
	β_C	β_R	C_S	C_N
1-2	27.00	47.01	0.3864	0.2954
1-3	25.50	44.43	0.3544	0.4051
1-4	59.00	107.52	0.2027	0.1486
1-5	57.50	105.28	0.2177	0.1633
1-6	62.00	114.72	0.1842	0.1711
1-7	62.50	113.24	0.2236	0.0869
2-3	31.50	76.98	0.4324	0.3243
2-4	47.50	83.58	0.4379	0.1889
2-5	53.00	93.28	0.3765	0.1676
2-6	52.50	92.33	0.4000	0.1630
2-7	62.00	109.83	0.3261	0.1969
3-4	51.00	89.74	0.4270	0.1637
3-5	44.50	79.16	0.5028	0.2000
3-6	50.00	88.22	0.4565	0.2286
3-7	49.50	87.82	0.4870	0.2391
4-5	43.50	83.88	0.6360	0.3598
4-6	42.00	82.01	0.6557	0.1639
4-7	46.50	88.87	0.6324	0.3229
5-6	31.50	70.30	0.7407	0.4280
5-7	35.00	74.57	0.7222	0.4206
6-7	43.50	85.80	0.6615	0.5214

* β_C为 Cody 多样性指数；β_R为 Routledge 指数；C_S为 Srenson 指数；C_N为 Bray-Cutis 指数. β_C is index of Cody; β_R is index of Routledge; C_S is index of Srenson; C_N is index of Bray-Cutis

3.2 植物多样性指数与土壤肥力的相关性

表 3 的数据表明，坡耕地弃荒后土壤有机质和全氮的含量随着植被的演替和发展有所增加，土壤肥力得到一定程度的恢复。土壤表层（0～20 cm）的有机质的变化范围为 1.44%～3.98%，全氮的变化范围是 0.015%～0.033%。表现出在草本植被类型到森林植被类型土壤肥力明显增加的变化规律。

土壤肥力与植物群落类型间的(多样性指数的关系见图 1，图 2，从图 1，图 2 中发现 6 个群落间的(多样性指数变化较大的地方是在群落（3）和（4）之间，就草本植物群落与灌丛的过渡区；而土壤肥力（有机质）变化较大的地方是在群落（5）与（6）之间，稍滞后一些。因此说，随着植物群落的发生和发展，植物种之间发生更替，群落间(多样性指数和土壤有机质含量和全氮含量等都发生有规律的变化，但全钾和全磷的变化缺少规律性。同时，植物群落间的相似性和土壤肥力都在增大，而且植物群落类型间的(多样性指数变化比土壤肥力变化超前，意味着植物群落类型的恢复和发展是土壤肥力恢复的前提条件。这一研究结果说明了，在已经遭到破坏的弃荒坡耕地上，没有植被的恢复也就没有土壤肥力的恢复。

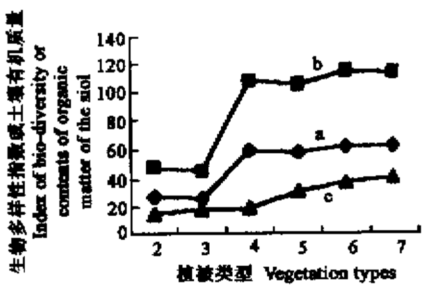

图 1 植被类型 1 与其它植被类间的 β_c（a 线）和 β_R（b 线）多样性指数与土壤有机质变化（‰）（c 线）的关系

Fig. 1 The relationship between indexes of β_c(a-line), β_R(b-line) diversity and the contents of the organic matter of soil (‰) (c line) in the abandoned field Hainan Island

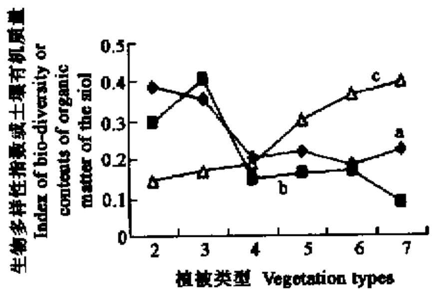

图 2 植被类型 1 与其它植被类间的 C_N（a 线）和 C_S（b 线）多样性指数与土壤有机质变化（%）（c 线）的关系

Fig. 2 The relationship between indexes of C_N(a-line) C_S(b-line)diversity and the contents of the organic matterof soil (%)(c line) in the abandoned field Hainan Island

3.3 植被特征及物种数与土壤肥力多元相关分析

植被特征及物种数指标[1]和土壤特征数据（表 3）的多元相关分析（相关系数见下面半矩阵）表明，在植被类型的发展过程中，不仅各个变化中的植物组成性状之间相关密切，群落覆盖度、植物种数、木本植物种数、演替后期植物种数和物种多样性指数每两个性状之间的相关系数均达 0.9221 以上，而且除了土壤全钾含量外，土壤中有机质含量、全氮含量和全磷含量亦均与植物各组成性状间达到显著相关水平。另外，在草地? 疏林的早期演替序列中，pH 值没有一定的变化规律。

经多元逐步回归分析，土壤有机质含量、全氮含量与植物组成性状间的回归方程分别为：

$$Y1 = 1.163682 + 0.1292752X4 \quad R = 0.8961 \tag{1}$$

$$Y2 = 0.07186 - 0.001129X1 + 0.0006633X3 + 0.0008639X4 \quad R = 0.99723 \tag{2}$$

可见，有机质含量在与植物群落多个特征关系中，主要与植物种类的发展有关；全氮含量却略有不同，它与群落覆盖度、木本植物种数和植物种类的发展等多个因素有关。因此，总体来说，土壤肥力的恢复与植被的组成性状、生物多样性的增加紧密相关。在退化生态系统的恢复初期阶段，它们之间的相互关系可看成是呈线性关系，但是随着演替的进展，这种关系会变得更加复杂，有待进一步研究。

热带弃荒坡耕地不同植被类型的植物组成特征与土壤肥力的相关系数如下：

(X1)	1									
(X2)	0.9794	1								
(X3)	0.9716	0.9825	1							
(X4)	0.9864	0.9566	0.9471	1						
(X5)	0.9513	0.9919	0.9830	0.9221	1					
(Y1)	0.8801	0.7877	0.8494	0.8951	0.7505	1				
(Y2)	0.8825	0.9121	0.9601	0.8779	0.9413	0.8115	1			
(Y3)	0.7692	0.8254	0.8042	0.8244	0.8539	0.6051	0.8599	1		
(Y4)	−0.4234	−0.4937	−0.5765	−0.2967	−0.5457	−0.3332	−0.5823	−0.1708	1	
(Y5)	0.0346	0.2303	0.1448	−0.0217	0.3058	−0.3965	0.1658	0.3186	−0.3281	1

其中，$X1$ 为群落覆盖度，$X2$ 为植物种数，$X3$ 为木本植物种数，$X4$ 为演替后期植物种数，$X5$ 为物种多样性指数(J_{S-W})，$Y1$ 为有机质含量，$Y2$ 为全氮含量，$Y3$ 为全磷含量，$Y4$ 为全钾含量，$Y5$ 为 pH 值。

表 3　弃荒坡耕地植被类型土壤化学性状的随机取样测定值

Table 3　The chemical properties of the soil in the abandoned field vegetation types

植被类型 Vegetation types	取样层 (cm) Layers	水 pH Water	有机质(%) Organic matter	全氮(%) Nitrogen	全磷(%) Phosphate	全钾(%) Potassium
(1)	0～20	5.9	1.436	0.0154	0.032	0.158
	20～30	6.8	1.219	0.0148	0.03(1)	0.135
	30～40	6.7	1.219	0.0234	0.03(2)	0.122
(3)	0～20	6.1	1.707	0.0253	0.084	0.150
	20～30	6.1	1.707	0.0234	0.086	0.009
	30～40	5.7	1.653	0.0199	0.086	0.096
(4)	0～20	5.8	1.832	0.0263	0.076	0.144
	20～30	6.2	1.725	0.0233	0.062	0.105
(5)	0～20	6.3	1.869	0.0271	0.086	0.110
	20～30	6.2	1.653	0.0166	0.093	0.120
	30～40	6.0	1.680	0.0226	0.095	0.160
(6)	0～20	6.0	3.657	0.0333	0.080	0.060
	20～30	6.4	3.199	0.0096	0.080	0.030
	30～40	6.3	1.409	0.0211	0.051	0.039
(7)	0～20	5.9	3.982	0.0308	0.101	0.161
	20～30	6.0	2.411	0.0173	0.093	0.028
	30～40	6.0	2.140	0.0289	0.080	0.010

4　讨论

土壤是植物群落的主要环境因子之一，土壤的理化性质、土壤种子库的特性等影响着植被发生、发育和演替的速度，同时也因植被的演变而发生改变，土壤的性质与植物群落组成结构和植物多样性有着密切的关系，且多年来一直是生态学家研究的热点[6,7,8]。

在较多的情况下，随着演替的进展，土壤的厚度、碳酸钙的含量、有机质和全氮等在递增，但是有机质和全氮达到一定的时期又有所下降。特别是固氮演替先锋植物增加了土壤中的氮素含量，改善了土壤等环境条件，为后来的植物定居创造了有利的条件，从而使先锋植物在竞争中失去了优势而让位于后来者，植物种类替代加速，从而促进植物群落生物种类多样化和结构复杂化，进而加速土壤中物质的分解率和生物归还率，促进土壤物质循环，土壤环境得到进一步的改善[9,10]。研究结果亦表明在海南琼北地区的弃荒坡耕

地上,植物群落性质与土壤性质存在这一种关系。

除此之外,研究结果进一步表明了:(1)在弃荒坡耕地里的植被演替过程中,植物种数增加的速度较快,除藤本植物较特殊外,其它几种性状的植物都有所增加;(2)α-多样性指数的增加、β-多样性变化较强烈的阶段是草本植物群落与灌丛的过渡区,表明在弃荒坡耕地的植被恢复过程中,随着演替的进展,植物种类在不断地发生更替,而且是从草本植物群落进入灌丛植物群落的生态过渡区是植物种类增加较快和更替最强烈的区域;(3)在植被恢复的同时,土壤肥力也得到恢复,但后者稍滞后一段时间,土壤恢复的速度较快的情况是发生在灌丛植物群落阶段;(4)进一步的分析还表明,在多个植物群落性状因子中,土壤有机质含量主要与植物种类的发展和多样性有着密切的关系;全氮含量则与群落覆盖度、木本植物种数和植物种数的多样性等多个因素密切相关。

因此说,随着植物群落的发生和发展,植物种之间发生更替,植物群落内α-多样性指数、植物群落间多样性指数和土壤肥力都发生有规律的变化(全钾和全磷的变化缺少规律性),植物群落间的相似性和土壤肥力都在增大,而且生物多样性指数的变化(α-多样性指数、β多样性指数)比土壤肥力变化超前。这意味着植被的恢复是土壤恢复的前提条件,在自然环境中,没有植被的恢复也就没有土壤肥力的恢复,特别是从草本植物群落进入灌丛植物群落阶段是一个较敏感的生态过渡区,具有重要的土壤与植被恢复生态学意义。但是必须指出,在退化生态系统的恢复的初期阶段(从草本植物群落到疏林植物群落阶段),它们之间的相互关系可看成是线性关系,但是随着植物群落的发展,这种关系会变得更加复杂,有待进一步研究。

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