Front. Biol. China (2006) 2:142–150
DOI 10.1007/s 11515-006-0009-8

RESEARCH ARTICLE

Yi Lan, You Wenhui, Song Yongchang

Soil animal communities at five succession stages in the litter of the evergreen broad-leaved forest in Tiantong, China

Abstract Soil animals are abundant in forest litter layer, but little attention has been paid to the vertical distribution of community structure of soil animals in the layers at different plant community succession stages. The forest litter layer can be divided into fresh litter layer (L), fermentation layer (F) and humus layer (H), which may represent different litter decomposition stages. The aim of the study is to ascertain the vertical distribution features of soil animal communities among the three litter layers and the change in the succession process of the Evergreen Broad-Leaved Forest (EBLF) in Tiantong, Zhejiang Province, China. Soil animal communities in the five plant communities at different succession stages were investigated during the 2003 winter. Soil animals, which were collected by using Tullgren funnels, amounted to a total of 13 381 individuals falling into 2 phyla, 8 classes and 20 orders. The dominant groups were Acarina and Collembola, accounting for 94.24% of the total individuals, with the number of Acarina individuals 7.66 times than that of Collembola. The common group was Diptera. The results indicated that there was a distinctive vertical distribution of the soil animal communities in the forest litter layer, but it differed from that in soil below the litter layer. In contrast to those in the soil, the soil animals in the litter layer generally tended to increase in both group abundance and density from the top fresh litter layer to the bottom humus layer. Altogether 19 groups and 59.03% of total individuals were found in the bottom layer, while only 8 groups and 5.35% of the total individuals in the top. Moreover, there were some variations in the distribution of the soil animals at different plant succession stages. 85.19% of Homoptera and 100% of Symphyla were found in the litter layer at the climax succession stage, while 75.61% of Thysanoptera at the intermediate succession stage. Therefore, these groups might be seen as indicative groups. The total numbers of soil animal groups and individuals in the litter layers greatly changed in the succession process of the EBLF. They both were greatest at the climax, moderate at the intermediate and smallest at the primary succession stage. However, the main soil animal groups in the litter at the different succession stages were essentially the same. They were Acarina, Collembola, Diptera and Lepidoptera. Although similarity analysis revealed that the soil animal communities in the litter at the intermediate succession stage were most similar to those at the climax succession stage, they differed greatly from each other in the Shannon-Wiener diversity index. The Shannon-Wiener index was highest at the climax succession stage and lowest at the intermediate succession stage. Finally, the paper discusses the following three questions: the role of soil animals as indicators for plant community succession; the role of different soil animal groups in the litter decomposition at different stages; and the major factors affecting the composition and distribution of soil animals in the litter.

This paper provides a new perspective for the research on the succession mechanism of plant communities and the decomposition functions of soil animals.

Keywords soil animal community, the litter layer, vertical distribution, forest succession stage, Evergreen Broad-Leaved Forest, Tiantong

1 Introduction

The accumulation and decomposition of litter is the most important source of soil fertility in the forest, and soil animals play a rather important role in the decomposition process of the litter. They can modify nutrient mineralization (and the spatial distribution of nutrients in soil), microbial commuaity structure in the rhizosphere, and plant hormones status, thus indirectly affect plant competition, and therefore plant community composition

Translated from *Acta Ecologica Sinica*, 2005, 25 (3) [译自：生态学报，2005,25(3)]

Yi Lan , You Wenhui (✉), Song Yongchang
Department of Environmental Science, East China Normal University, Shanghai 200062, China
E-mail: yilanllol@sina.com, youwh@yjsy.ecnu.edu.cn

(Kreuzer et al., 2004). In recent years, the linkages between soil animal community and plant community have gradually drawn the attention of researchers worldwide (Wardle 1999; Copley 2000; Gange 2000; Bradford et al., 2002; Gang and Brown 2002; Addison et al., 2003; Bardget and Wardle 2003; De Deyn et al., 2003; Sugden et al; 2004; Wardle et al., 2004). However, the influences of soil animals on plant community succession have received little attention up to the present (Brown and Gange 1989, 1992), and the role of soil animals has been rarely involved in exploration of plant community succession mechanisms. Yet an investigation of soil animal communities in plant communities at different succession stages is of great significance to understand the succession mechanism. The succession of plant community directly affects the composition, quantity and quality of the litter, which contains an abundance of soil animals. Therefore, the changes in the litter will inevitably influence the soil animals in it. Meanwhile, as there is a distinct vertical distribution of the litter in forest, representing different decomposition stages of litter, Nevertheless, not much attention has been devoted to soil animal communities in the different litter layer. Although some researches have involved soil animals in the litter (Li et al., 1997; Liao et al., 1997; Wang et al., 2001; Yang et al., 2001; Zhang et al., 2001; Xu et al., 2002; Wang et al., 2003), it has only been treated as one layer rather than different layers. No detailed investigation on the forest litter by layers has been reported in China apart from the research conducted in Mao'er Mountain (Yin et al., 2001).

Zhang et al. (1999) has done a research on the quantity and dynamic decomposition of the litter in the plant communities at the major succession stages of Evergreen Broad-Leaved Forest (EBLF) in Tiantong, Zhejiang Province, China, but no report has been seen on the soil animal communities in the aforementioned litter. The litter is relatively thick and has distinct layers This paper conducts a detailed investigation on soil animal communities in the litter by layers in five plant communities at major succession stages during winter so as to reveal the ir structural features, probe into the succession of soil animal communities along with the succession of plant communities, its indicative implications of animal groups during in succession, and the groups which play major roles at different decomposition stages.

2 Materials and methods

2.1 Study site

We selected a study site (29° 48′ N, 121° 47′ E) in Tiantong National Forest Park located in the east of Ningbo, Zhejiang Province, China. The study site has a typical subtropical monsoon climate, with an annual average temperature of 16.2℃ and a monthly average temperature of 4.1℃ in January. It has an annual rainfall of 1 374.7 mm and an annual evaporation capacity of 1 320.1 mm. It is both cold and dry in winter, and rainfall accounts for only 10%~15% of the annual total during this period. The soil is mainly of mountain yellowish red type, with an average pH value of 4.5~5.0, showing to be slightly acidic. The zonal vegetation is Evergreen Broad-leaved Forest in the north fringe of central subtropics (Song and Wang 1995), and is presently all secondary. It had developed well due to the protection from Tiantong Temple in the past, and after a series of catastrophes, had evolved into the current form of vegetation. It is currently dominated by EBLF, followed by secondary bushwood, planted forest (like Chinese fir forest, *Pinus massoniana* forest and bamboo forest) as well as plant communities at different succession stages from secondary bushwood to EBLF(Ding 1999).

Table 1 Litter layer of the Evergreen Broad-Leaved Forest at five succession stages in winter in Tiantong

succession stages	thickness of each layer/cm			Composition of the litter
	L	F	H	
Ⅰ	2	3	2	Mainly composed of the litter of A,B,Cand D，followed by that of E and F as well as a small amount of that of G, H, I, and J
Ⅱ	1.5	3	1.5	Mainly composed of the litter of B, followed by that of A, C, K, and L as well as a small amount of that of M, H, J, N, D ,O and E
Ⅲ	1.5	4	3	Mainly composed of the litter of B and A, in which B dominates, followed by that of C, N,, P ,M ,Q, R, I and S, as well as a small amount of that of D, T ,G, O, H ,U and K
Ⅳ	3	4	2	Mainly composed of the litter of A and B , in which A dominates, followed by that of D, C P, N and T, as well as a small amount of that of H and V
Ⅴ	3	4	5	Mainly composed of the litter of N, followed by that of X, P, A, M, Y, T and I, as well as a small amount of that of H, Z, D, U, AA, S, AB, AC and AD

Note: I: *Lithocarpus glaber*-*Loropetalum chinense* community; Ⅱ: *Pinus massoniana* community; Ⅲ: *Schima superba*-*Pinus massoniana* community; Ⅳ: *Schima superba* community; Ⅴ: Castanopsis fargesii community.
L: Fresh litter layer; F: Fermentation layer; H: Humus layer.
A: *Schima superba*; B: *Pinus massoniana*; C: *Castanopsis sclerophylla*; D: *Lithocarpus glaber*; E: *Pleioblastus amarus*; F: *Cunninghamia lanceolata*; G: *Symplocos stellaris*; H: *Symplocos sumuntia*; I: *Smilax china*; J: *Vaccinium mandarinorum*; K: *Myrica rubra*; L: *Loropetalum chinense*; M: *Camellia fraterna*; N: *Castanopsis fargesii*; O: *Symplocos lancifolia*; P: *Eurya spp*.; Q: *Cyclobalanopsis gilva*; R: *Litsea elongate*; S: *Woodwardia japonica*; T: *Cyclobalanopsis myrsinaefolia*; U: *Castanea seguinii*;V: *Quercus stewardiana*; X: *Castanopsis carlesii*;Y: *Cinnamomum camphora*; Z: *Liquidambar formosana*; AA: *Machilus thumbergii*; AB: *Neolitsea aurata* var. *chekiangensis*; AC: *Daphniphyllum macropodum*; AD: *Symplocos laurina*

Five plant communities at major succession stages were selected as study plots. They were arranged successively as follows: *Lithocarpus glaber-Loropetalum chinense* community (I), *Pinus massoniana* community (II), *Schima superba-Pinus massoniana* community (III), *Schima superba* community (IV) and *Castanopsis fargesii* community (V) (Ding 1999, 2001). Of these plant communities, the *Lithocarpus glaber-Loropetalum chinense* community was at the initial succession stage, while the *Castanopsis fargesii* community was at the climax. The composition and thickness of the litter layer in the five plant communities are shown in Table 1.

2.2 Sampling procedure

Samples were taken from the three natural layers (Xin 1986; Yin 2000) of the litter at the above mentioned five succession stages: in the fresh litter layer (L), leaves remained fresh, undecomposed and undamaged; in the fermentation layer (F), the litter appeared half decomposed (mostly with mildew) in which most leaf blades were stuck together, the tissue structures of the plant residues discernible to the naked eye, and no inorganic soil was mixed up; in the humus layer (H), the litter was completely decomposed, with structural features of the original plants indiscernible to the naked eye, and a small amount of inorganic soil was mixed up. At each stage, mixed samples were taken at three spots in the same sample plot, with every two spots over 5 m away from each other, and a sampling area of 20cm × 20cm for each layer. The large soil animals were immediately sorted by hand and put into a bottle with alcohol (75%). Right after being brought back to the Tiantong Ecological Station by bags, the samples collected were separated by using Tullgren funnels under light from 60 W filament lamps for 48 hours, and were identified and counted under a binocular dissecting microscope (Yin et al., 1998; Zheng and Gui 1999).

2.3 Data analysis

To calculate the similarity index, diversity index, homogeneity, dominance and abundance separately by using the following formulae:

Sorenson similarity index:

$$C_s = 2j / (a + b) \quad (1)$$

in which, j is the number of common groups shared by two communities; a and b are the numbers of groups in plot A and plot B respectively.

Shannon-Wiener diversity index:

$$H' = -\sum n_i / N \ln (n_i / N) \quad (2)$$

in which n_i is the number of individuals of group i; N is the total number of individuals of all the groups in a community.

Pielou evenness:

$$J_{ws} = H' / \ln S \quad (3)$$

in which S is the number of groups.

Simpson dominance index:

$$C = \sum P_i^2 \text{, in which } P_i = n_i / N \quad (4)$$

Marglef abundance index:

$$D = (S - 1) / \ln N \quad (5)$$

3 Results

3.1 Composition of community

Soil animals, captured in the litter at five succession stages during winter, amounted to a total of 13 381 in number, falling into 2 phyla, 8 classes and 20 orders. The dominant groups were Acarina and Collembola, accounting for 94.24% of the total individuals, with the number of Acarina individuals 7.66 times that of Collembola. The common group was Diptera, and the others were rare groups (Table 2). Hence Acarina, Collembola and Diptera made up the main components of the soil animal communities in the litter in Tiantong during winter.

Soil animal communities in the litter varied remarkably with the succession of plant communities in terms of the relatively big difference in their numbers of groups and individuals. The numbers of groups (16) and individuals (33.2%) were both highest for the *Castanopsis fargesii* community at climax, moderate for the *Schima superba-Pinus massoniana* community (15, 29.24%) at the intermediate stage, and smallest for the *Lithocarpus glaber-Loropetalum chinense* community (6, 8.12%) at the initial stage. However, in terms of order in the hierarchy of classification, soil animal communities in the litter at the different succession stages basically shared the principal groups, namely: Acarina, Collembola, Diptera and Lepidoptera. In addition, A/C (the proportion of Acarina to Collembola, Table 2) in the litter during winter was very high in all cases, particularly in the *Pinus massoniana* community and the *Schima superba-Pinus massoniana* community, amounting to 11.12 and 10.72 respectively. Thus, Acarina was the only dominant group in the two plant communities. A/C gradually fell along with the process of succession, with that of *Castanopsis fargesii* at climax stage being the lowest and standing at 5.20. Common groups were mostly seen in the *Pinus massoniana* community, and rare groups in the *Castanopsis fargesii* and *Schima superba-Pinus massoniana* communities. Rare groups were seldom seen, however, in the *Lithocarpus glaber Loropetalum chinense* community at the initial stage of succession.

3.2 Analysis of community similarity and diversity

Similarity analysis indicated that the most similar soil animal communities were those found in the litter of the

Table2 Group composition and their quantitative distribution of soil animal in three litter layers of the Evergreen Broad-Leaved Forest at five succession stages in winter in Tiantong, Zhejiang, Province, China

Groups	I				II				III				Ⅳ				V				%	Abu-ndan-ce
	L	F	H	Total	L	F	H	Total	L	F	H	Total	L	F	H	Total	L	F	H	Total		
Acarina	64	368	471	903	84	1180	915	2179	248	1128	2010	3386	52	648	411	1111	60	644	2871	3575	83.36	+++
Collembola	24	48	46	118	52	84	60	196	64	120	132	316	8	52	79	139	20	120	547	687	10.88	+++
Diptera		36	17	53	12	84	48	144	12	64	71	147		60	20	80			6 1	61	3.62	++
Lepidoptera			2	2		28	1	29		28	3	31		8	2	10		20	3	23	0.71	+
Thysanoptera				0		20	11	31		4		4			3	3	3			3	0.31	+
Coleoptera		8		8		4		4			2	2				0			1	1	0.10	+
Hymenoptera				0			6	6			4	4				0			18	18	0.01	+
Protura				0	4		1	5			7	7				0			8	8	0.15	+
Pseudoscorpiones				0			1	1		4		4				0		4	5	9	0.10	+
Homoptera			2	2				0			1	1			1	1			23	23	0.20	+
Hemiptera				0				0	4		1	5				0				0	0.04	+
Lithobiomorpha				0				0				0				0			1	1	0.01	+
Geophilomorpha				0				0			1	1				0				0	0.01	+
Oligochaeta opisthopora				0				0		2	1	3				0			1	1	0.03	+
Polydesmida				0				0			1	1				0			1	1	0.01	+
Symphyla				0				0				0				0			25	25	0.19	+
Tetramerocerata				0				0				0				0			1	1	0.01	+
Araneae				0				0				0				0	4		1	5	0.04	+
Isopoda				0				0				0	1			1				0	0.01	+
Psocoptera				0			1	1				0				0				0	0.01	+
A/C				7.65				11.12				10.72				7.99				5.20		

Note: +++ Dominant groups (its percentage to total>10%) ; ++ Common groups (its percentage to total :1%～10%) ; + Rare groups (its percentage to total＜1%)

Schima superba - Pinus massoniana community at the intermediate succession stage compared to those in the litter of the *Castanopsis fargesii* community at climax. The moderately similar communities were those in the *Lithocarpus glaber-Loropetalum chinense* community at the early succession stage compared to those in the *Schima superba* community at the later succession stage, and those in the *Pinus massoniana* community compared to those in the *Schima superba-Pinus massoniana* community, both of which were at the intermediate succession stage. The least similar communities were those in the *Schima superba* community compared to those in the *Castanopsis fargesii* community (Table 3).

Table3 Similarity indices of soil animal communities in the litter layer at five succession stages

Succession stages	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ
Ⅰ *Lithocarpus glaber-Loropetalum chinense* ommunity		0.625	0.571	0.769	0.545
Ⅱ *Pinus massoniana* community			0.720	0.588	0.692
Ⅲ *Schima superba-Pinus massoniana* communnity				0.545	0.774
Ⅳ *Schima superba* community					0.522
Ⅴ *Castanopsis fargesii* community					

Diversity analysis revealed that the Shannon-Wiener diversity index (*H'*) of the soil animal community was highest in the litter of the *Castanopsis fargesii* community, but it was lowest in the litter of the *Schima superba-Pinus massoniana* community which had risen to approach the level of the *Castanopsis fargesii* community in the number of its species and individuals (Table 4). The number of Acarina was highest in the *Schima superba-Pinus massoniana* community, and was the only dominant group in the community, accounting for 86.55% of its total number of individuals, with its A/C standing at 10.72, and Simpson dominance index (*C*) reaching the highest level. Although it was second only to the *Castanopsis fargesii* community in Margalef abundance index, its number of individuals in different groups distributed quite unevenly, which resulted in the lowest Pielou evenness index (*Jsw*) of only 0.202, with an *H'* value lower than those of other communities. As for the *Lithocarpus glaber-Loropetalum chinense* and the *Schima superba* communities, they were smallest in the number of groups and, accordingly, lowest in their Margalef abundance index. But they were highest in the Pielou evenness index, which made their *H'* values even higher than that of the *Schima superba-Pinus massoniana* community, one with a relatively high Margalef abundance index. Therefore, the Shannon-Wiener diversity index could well represent the diversity of soil animals in the litter and was in close negative correlation with the Simpson dominance index, but not in close positive correlation with the Pilou evenness and Margalef abundance indices (Fig. 1).

Table 4 Diversity indices of soil animal communities in the litter layers at five succession stages

Succession stages	*H′*	*Jsw*	*D*	*C*	Total number of groups	Percentage of total individuals
Ⅰ *Lithocarpus glaber-Loropetalum chinensec* ommunity	0.6014	0.3356	0.7153	0.7056	6	8.12
Ⅱ *Pinus massoniana* community	0.6476	0.2813	1.1448	0.7136	10	19.40
Ⅲ *Schima superba-Pinus massoniana* communnity	0.5469	0.202	1.6925	0.7572	15	29.24
Ⅳ *Schima superba* community	0.6211	0.3192	0.8329	0.6966	7	10.05
Ⅴ *Castanopsis fargesii* community	0.6743	0.2432	1.786	0.672	16	33.19

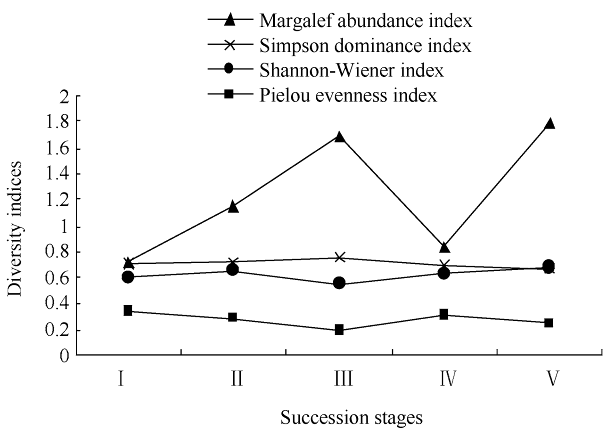
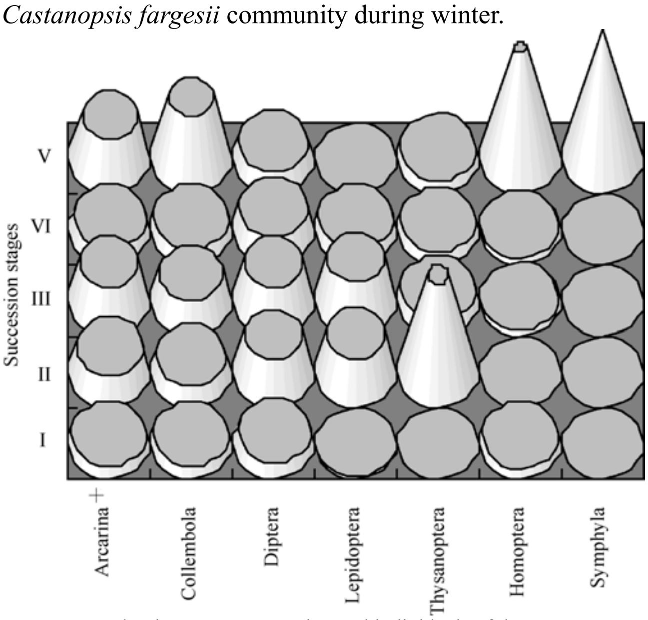


Fig.1 Changes of diversity indices of soil animal communities in the litter layers at five succession stages

3.3 Distribution of main soil animal groups in the litter at five succession stages

Soil animals varied from one group to another in their distribution in the litter at different succession stages (Fig. 2): (1) Acarina and Collembola were mostly found in the litter of the *Castanopsis fargesii* community (A:32.05%， C:47.18%), followed by the *Schima superba-Pinus massoniana* community (A:30.36%，C:21.70%), and observed the least in the *Lithocarpus glabre-Loropetalum chinense* community (A:8.10%，C:8.10%); (2) Diptera and Lepidoptera were mainly seen in the *Schima superba-Pinus massoniana* (D: 30.31%, L: 32.63%) and the *Pinus massoniana* communities (D: 29.69%, L: 30.53%), in which

Pinus massoniana dominated, and observed the least in the *Lithocarpus glabre-Loropetalum chinense* community (D: 10.93%, L: 2.11%); (3) Thysanoptera mostly emerged in the *Pinus massoniana* community, in which 75.61% of the total was captured, and thus it can be taken as the indicative group of soil animals in the litter of the *Pinus massoniana* community during winter. In addition, 85.19% of Homoptera and all Symphyla were distributed in the *Castanopsis fargesii* community, which can also be seen as the indicative groups of soil animals in the litter of the *Castanopsis fargesii* community during winter.



Note: by the percentage to the total individuals of the group

Fig.2 Distribution of main soil animal groups in the litter layers at five succession stages

3.4 The vertical distribution of soil animal community in the litter

The number of soil animal groups had a tendency to increase from top to bottom in the litter of each succession stage. There was a roughly similar trend in the vertical distribution of the number of individuals (Fig. 3), but a larger proportion of individuals were found in the middle fermentation layer (F) in the *Pinus massoniana* and the *Schima superba* communities, amounting to 53.93% and 57.10% respectively, mainly due to the presence of a large number of Acarina in that layer. In addition, there was a distinct regular pattern in the vertical distribution of the number of dominant groups and common groups at different succession stages (Fig. 4): (1) The distribution of the number of Acarina appeared to be identical to that of the entire soil animal community; (2) The distribution of the number of Collembola tended to increase from the top to the bottom, except in the case of the *Lithocarpus glabre-Loropetalum chinense* and the *Pinus massoniana* communities, in which the number of Collembola seemed to be slightly larger in the middle fermentation layer than in the bottom humus layer; (3) The distribution of Diptera was different from that of either Acarina or Collembola. Diptera was mostly seen in the middle fermentation layer in the *Lithocarpus glabre-Loropetalum chinense*, the *Pinus massoniana* and the *Schima superba* communities, while it was almost exclusively seen in the bottom humus layer of the *Castanopsis fargesii* community.

Generally speaking, the number of groups and individuals of soil animals in the litter during winter had a tendency to increase as you go down the layers: for groups, 19 distributed in the bottom humus layer and 8 either in the top layer or the middle layer; in terms of individuals, 59.03% were seen in the bottom humus layer, only 5.35% in the fresh litter layer and the rest in the middle fermentation layer. Nearly 60% of either Acarina or Collembola captured were found in the bottom humus layer, followed by some in the middle fermentation layer, but only a few in the fresh litter layer (where most common animals observed were various species of large-sized Entomobryomorpha with densely covered long brown hair). Symphyla and Homoptera were only present in the bottom humus layer, and 80% of the captured Protura were found in the same layer. But 88.42% of Lepidoptera, 58.54% of Thysanoptera and 50.31% of Diptera were mostly distributed in the middle fermentation layer.

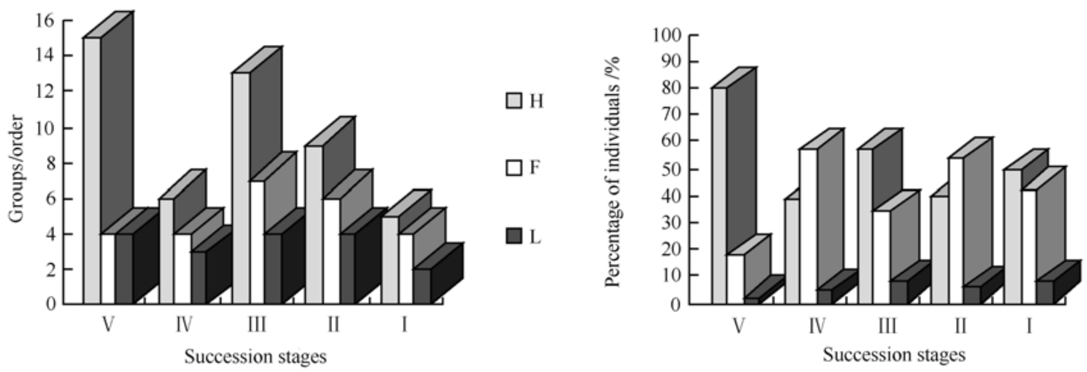


Fig.3 Vertical distribution of soil animal groups and individuals

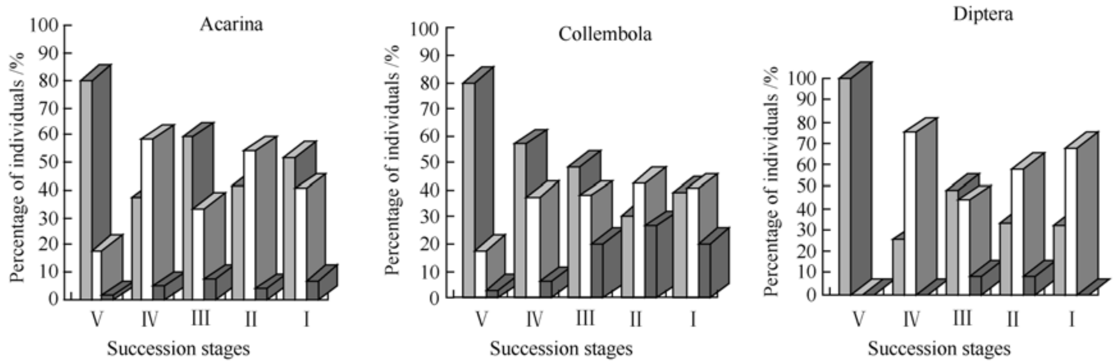


Fig.4 Vertical distribution of dominant and common soil animal groups

4 Discussion

4.1 The changes of soil animal communities in the succession of plant communities and their indicative implications for succession

The findings of the investigation on soil animal communities in the litter layer at five different succession stages revealed that along with the succession of plant communities, marked changes had also taken place in the succession of soil animal communities. At the initial stage of succession, the smallest were the numbers of groups and individuals of soil animal, which were mainly Acarina and Collembola with wide distribution and high adaptability. With the progress in the succession of plant community, the number of groups and individuals of soil animals gradually increased, until the intermediate succession stage, when they went up to approach those at climax, along with the emergence of quite a few rare groups. The highest was the similarity index between soil animal communities at the intermediate succession stage and those at the climax stage, but with very big difference in their Shannon-Wiener diversity indices (H'). H' value was lowest at the intermediate succession stage, but highest at the climax. It was found that the similarity index could not represent the quantitative distribution of these groups among communities, as calculated based on the number of the same groups shared by different communities. Despite a relatively high similarity index between two communities, but because of different quantitative distribution of the same groups, the lowest H' value was that of soil animal communities unevenly distributed at the intermediate succession stage. The findings also indicated that the succession of plant community was a process in which the habitat had been constantly improved, for the plant community at climax was able to provide a stable food source and habitat for soil animals, which through long-term selection and adaptation/accommodation helped to form relatively stable soil animal communities with high H', thus maintaining the steady and normal ecological functions of the ecosystem. The differences in the composition of soil animal community and the quantity of their individuals in the litter at different succession stages of plant communities will affect the decomposition rate of litter and nutrient cycling, thus producing some influences on the succession of plant communities. Knowledge on the relationship between soil animal communities and plant communities will contribute to understanding the succession mechanism of plant communities.

There were different soil animal groups in the EBLF at different succession stages, which was related to their own biological features on the one hand, and to the living environment furnished by plant communities during succession on the other. As certain groups only emerged at a particular succession stage, they were of some indicative significance to the succession process. In the present study, Homoptera and Symphyla can be regarded as the indicative groups for the EBLF at climax, and Thysanoptera for that at the intermediate succession stage. However, what needs to be stressed is that due to the different life cycles of soil animals, there will be some differences between indicative groups during the various seasons, hence it is necessary to make investigations during different seasons so as to find out the indicative groups for different seasons. This will be of some significance in exploring soil animals as indicators for vegetation recovery or degeneration.

4.2 Soil animal groups that play major roles at different stages of litter decomposition

In the studies of the decomposition function of soil animals, the method of litter-bag collection has its advantages in quantitative studies, but due to time limits and difficulty in sampling accuracy, it was generally very difficult to finish a complete decomposition process. Yet by making use of an investigation on soil animal communities in the different litter layers in the field conditions, substituting space for time will be able to make up the defects and deficiency inherent in the method of litter-bag collection. The three layers of litter from the fresh litter layer which were not decomposed (L), through the fermentation layer which was half decomposed (F), to the humus layer which was completely decomposed (H), represented the whole process of decomposition in the litter. The results of the investigation on the different litter layers in the EBLF in Tiantong during winter showed that despite the different composition of soil animal communities at different stages of litter decomposition, Acarina and Collembola enjoyed an overwhelming quantitative predominance at the initial, intermediate and later stages of decomposition. At the initial stage of litter decomposition, the number of groups and individuals of medium and small-sized soil animals were relatively small, with Acarina and Collembola dominating the microorganism feeders. In this stage, decomposition was done mainly by the cracking of litter by large-sized soil animals, releasing of soluble elements in the litter, and decomposing of what was decomposable in the litter by microorganisms (Ke et al., 2001). At the intermediate decomposition stage, as the change in the texture and quality of the litter provided source of food and suitable habitats for many soil animals, the number of groups and individuals of soil animals greatly increased, dominated by some groups that fed on fragments of plants and microorganisms. In addition to Acarina and Collembola, there were large numbers of Diptera, Lepidoptera, Thysanoptera and Coleoptera, all of which were soil animal groups that played major roles in the intermediate decomposition stage. They attacked the xylem that was hard to decompose, thus setting the stage for continuous decomposition by microorganisms. Also, at this stage, quite a few predatory Pseudoscorpions appeared. At the later decomposition stage, an even larger number of soil animals were observed, with their number of groups and individuals reaching the highest. Specimens of Acarina, Collembola, Diptera, Hymenoptera, Homoptera, Symphyla, and Protura were the most commonly observed, followed by some Thysanoptera, Lepidoptera and Pseudoscorpiones, as well as a good number of rare groups. In the humus layer, due to the movement of these soil animals, the organic matter in the soil were fully mixed with the inorganic soil, thus improving the physico-chemical properties of the layer. A series of important biochemical reactions had also taken place in that layer. For example, assisted by soil enzymes and microorganisms, organic soil matter continued to produce humus, which under the given conditions would be decomposed and release nutrients for the growth of plants (Yan 1997). Will a large number of soil animals living in that layer influence these processes? What roles would they play? All these are questions that need to be studied further.

4.3 The major factors affecting the composition and distribution of soil animal communities in the litter

In the present study, soil animal communities in the litter at different succession stages were different from each other in their composition, and distinctive in the vertical distribution of the number of their groups and individuals, with a general tendency of increasing from the top going down, showing no difference with the results of the research done by Yin in Mao'er Mountain (Yin et al., 2001). The litter provides an abundant source of food and habitat for soil animals, and its composition, quality, thickness (see Table 1), and the degree of decomposition of each layer all produce very important influences on the composition of soil animal communities, the number of individuals, and their distribution. Firstly, with the succession of plant community, the composition of the litter grows increasingly complex, which provides a more varied and diverse source of food in addition to the gradually improved mini-habitat, and changes have taken place in the soil animal communities in the litter as a result. Extremely rich and varied was the composition of the litter in the *Castanopsis fargesii* community at climax, in which the number of groups and individuals of soil animals all reached the highest, while at the later succession stage the composition of the litter was relatively simple in the *Schima superba* community, in which the number of soil animal groups and individuals were quite small, approaching those at the early succession stage. Secondly, the thickness of each litter layer had a great influence on the number of soil animal individuals. An investigation on the thickness of each litter layer at different succession stages had shown that the thickness of the fresh litter, fermentation, and humus layers generally increased with the succession of plant communities, but in the *Pinus massoniana* and the *Schima superba* communities the middle fermentation layer was relatively thick while the fresh litter layer and the humus layer were quite thin, which was one of the reasons why soil animals were concentrated in the middle humus layer in the two plant communities. Thirdly, the litter at varying degrees of decomposition provided soil animals a source of food and a mini-habitat with different textures and quality, which determined the vertical distribution of the numbers of soil animal groups and individuals in the litter and the concentration of a great number of medium and small-sized soil animals in the half and completely decomposed litter. In addition, low surface temperature in winter had made plenty of soil animals move downward, thus causing mass concentration of soil animals in the middle fermentation layer and the bottom humus layer. It is rather dry in that region during winter, therefore rainfall is not the major factor affecting the distribution of soil animals in the litter during winter. The effect of the quality of the litter on soil animal communities in it is anissue that should be probed further.

Acknowledgements This study was part of the National Natural Science Key Foundation of China program (No.30130060) directed by Song Y.-C., Shanghai, China, which is greatly acknowledged for financial support. Lots of thanks are due to Yin W.-Y., Ke X. for help with providing study chance and Xie R.-D. for help in identification of the species .We are grateful to Tang X.-Y., Xiong Y., Zhen D.-H., Zhang Y.-P., Xu X.-J. for help with sampling in field, to Wang L.-Y. and Wang A.-C. for help in daily life in Tiantong.We are also grateful to Yu H.-C. for improvement of the English language.

References

Addison J.-A., Trofymow J.-A., Marshall V.-G., Functional role of Collembola in successional coastal temperate forests on Vancouver Island ,Canada, Appl. Soil Ecol., 2003, 24: 247–261

Bardget R.-D. and Wardle D.-A., Herbivore-mediated linkages between aboveground and belowground communities, Ecology, 2003, 84(9): 2258–2268

Bradford M.-A., Jones T.-H., Bardgett R.-D., Black H.-I.-J., Boag B., Bonkowski M., Cook R., Eggers T., Gange A.-C., Grayston S.-J., Kandeler E., McCaig A.-E., Newington J.-E., Prosser J.-I., Setälä H., Staddon P.-L., Tordoff G..-M., Tscherko D., Lawton J.-H., Impacts of soil faunal community composition on model grassland ecosystems, Science, 2002, 298: 615–618

Brown V.-K. and Gange A.-C., Differential efffects on above-and below-ground insect herbivory during early plant succession, Oikos, 1989, 54: 67–76

Brown V.-K. and Gange A.-C., Secondary plant succession: how is it modified by insect herbivory? Vegetation, 1992, 101: 3–13

Copley J., Ecology goes undergrand, Nature, 2000, 406: 452–454

De Deyn G.-B., Raaijmakers C.-E., Zoomer H.-R., Berg M.-P., de Ruiter P.-C., Verhoef H.-A., Bezemer T.-M., van der Putten W.-H., Soil invertebrate fauna enhances grassland succession and diversity, Nature, 2003, 6933: 711–713

Ding Q.-Y., Mathematics Ecology of Insect, Beijing: Science Press, 1994 [丁钦岩，昆虫数学生态学，北京：科学出版社，1994]

Ding S.-Y., Comparison of soil characteristics under different successive communities of Evergreen Broad-Leaved Forest, J. Henan Univ. (Nature Science), 1999, 29(3): 92–96 [丁圣彦，常绿阔叶林演替系列群落下土壤性质的比较，河南大学学报（自然科学版），1999,29（3）：92–96]

Ding S.-Y., The causes of Castanopsis fargasii and Schima superba being dominant species of series of Evergreen Broad-Leaved Forest in Zhejiang ,Tiangtong, J. Henan Univ. (Nature Science), 2001,31 (1): 79–83 [丁圣彦，浙江天童常绿阔叶林演替系列栲树和木荷成为优势种的原因，河南大学学报（自然科学版），2001,31（1）：79–83]

Gange A.-C. and Brown V.-K., Soil food web components affect plant community structure during early succession, Ecol. Res., 2002, 17(2): 217–227

Gange A.-C., Arbuscular mycorrhizal fungi, Collembola and plant growth, Trends Ecol. Evol., 2000, 15(9): 369–372

Ke X., Zhao L.-J., Yin W.-Y., Succession of collembola community structure during decomposition of leaves in Cyclobalanopsi sglauca forest, Acta Ecol. Sinica, 2001, 21(6): 982–987 [柯欣，赵立军，尹文英，青冈林土壤跳虫群落结构在落叶分解过程中的变化，生态学报，2001，21（6）：982–987]

Kreuzer K., Bonkowsk M., Langel R., Scheu S., Decomposer animals (*Lumbricidae,Collembola*) and organic matter distribution affect the performance of *Lolium perenne* (Poaceae) and *Trifolium repens* (Fabaceae), Soil Biol. Biochem., 2004, 36(12): 2005–2011

Li C.-D., Xiao N.-N., Yang D.-R., Kuang P.-R., Comparison of the community component of soil animals on the fragments of tropical rain forest in Xishuangbanna,Yunnan, Zool. Res., 1997, 18(1): 45–49 [李朝达，肖宁年，杨大荣，匡薄人，西双版纳片断热带雨林土壤运动组成的比较，动物学研究，1997，18（1）：45–49]

Liao C.-H., Li J.-X., Huang H.-T., Soil animal community diversity in the forest of the southern subtropical region, China Acta Ecol. Sinica, 1997, 17(5): 449–555 [廖崇惠，李健雄，黄海涛，南亚热带森林土壤动物群落多样性研究，生态学报，1997，17（5）：449–555]

Song Y.-C. and Wang X.-R., Vegetation and flora of Tiantong National Forest Park Zhejiang Province, Shanghai: Shanghai Scientific Technology Document Press, 1995 [宋永昌，王祥荣，浙江天童国家森林公园的植被和区系，上海：上海科学技术文献出版社，1995]

Sugden A., Stone R., Ash C., Ecology in the underworld, Science, 2004, 304: 1613

Wang Q.-F. and Wang Z.-Y., Study on the soil animal community in Lushan Mountain, J. Anhui Normal Univ. (Natural science), 2003, 26(2): 180–185 [汪权方，王宗英，庐山土壤动物群落结构研究，安徽师范大学学报（自然科学版），2003，26（2）：180–185]

Wang Z.-Y., Zhu Y.-H., Lu Y.-C., Nie X.-Z., Chen J.-X., Meng W.-X., Huang C., The ecological distribution of soil collembola in Jiuhua Mountain, Acta Ecol. Sinica, 2001, 21(7): 1142–1147 [王宗英，朱永恒，路有成，聂献忠，陈健秀，孟文新，黄诚，九华山土壤跳虫的生态分布，生态学报，2001,21（7）：1142–1147]

Wardle D.-A., Bardgett R.-D., Klironomos J.-N., Setälä H., Van der Putten W.-H., Wall D.-H., Ecological linkages between aboveground and belowground biota, Science, 2004, 304: 1629–1633

Wardle D.-A., How soil food webs make plants grow?, Trends Ecol. Evol., 1999, 14(11): 418–420

Xin J.-L., Knowledge About Soil Animals, Beijing: Science Press, 1986 [忻介六，土壤动物知识，北京：科学出版社，1986]

Xu G.-L., Huang Z.-L., OuYang X.-J., Fang Y.-T., Peng S.-J., Diversity of aboveground invertebrates in Dinghushan and its correlation with the litter, Zool. Res., 2002, 23(6): 477–482 [徐国良，黄忠良，欧阳学军，方运霆，彭闪汇，鼎湖山地表无脊椎动物多样性及其与凋落物的关系，动物学研究，2002，23（6）：477–482]

Yan D.-R., A study on humus characteristic of artifical forest and soil enzyme activity, Foresty Sci. Technol., 1997, 22(5): 10–12 [闫德仁，人工林土壤腐殖质特性和土壤酶活性的研究，林业科技，1997，22（5）：10–12]

Yang X.-D. and Sha L.-Q., Species composition and diversity of soil mesofauna in the “HolyHills” fragmentary tropical rain forest of Xishuangbanna, China, Chineses J. Appl. Ecol., 2001, 12(2): 261-265 [杨效东，沙丽清，西双版纳“龙山”片断热带雨林中小型土壤动物群落组成与多样性研究，应用生态学报，2001，12（2）：261–265]

Yin W.-Y., Shen Y.-F., Wang Z.-Z., Soil Animals of China, Beijing: Science Press, 2000 [尹文英，等著，中国土壤动物，北京：科学出版社，2000]

Yin W.-Y., Song D.-X., Zhang C.-Z., Pictorical Keys of Soil Animals of China, Beijing :Science Press, 1998 [尹文英，等著，中国土壤动物检索图鉴，北京：科学出版社，1998]

Yin X.-Q., Chen P., Hou W.-L., Study on forest soil animals in the northeast of China. Changchun: Northeast Normal University Press, 2001 [殷秀琴，东北森林土壤动物研究，长春：东北师范大学出版社，2001]

Zhang Q.-F, Song Y.-C., Wu H.-Q., You W.-H., Dynamics of the litter amount and its decomposition in different successional stages of Evergreen Broad-Leaf Forest in Tiantong, Zhejiang Province, Acta Phytoecol. Sinica, 1999, 23(3): 250–255 [张庆费，宋永昌，吴化前，由文辉，浙江天童常绿阔叶林演替过程凋落物数量及分解动态，植物生态学，1999，23（3）：250–255]

Zhang X.-P., Hou W.-L., Chen P., Soil animal guilds and their ecological distribution in the northeast of China, Chin. J. Appl. Environ. Biol., 2001, 7(4): 370–374 [张雪萍，侯威岭，陈鹏，东北森林土壤动物同功能种团及其生态分布，应用与环境生物学报，2001，7（4）：370–374]

Zheng L.-Y. and Gui H., Insect Classification, Nanjing Normal University Press, 1999 [郑乐怡，归鸿，昆虫分类，南京：南京师范大学出版社，1999]