PALYNOLOGY
https://doi.org/10.1080/01916122.2018.1549117

Comparison between two kinds of natural pollen traps in tropical China: ants' nests on tree branches versus surface soil

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ABSTRACT
Natural pollen traps have been known for many years. This study analyzed the palynological characteristics of 12 ant nests on branches and 12 surface soil samples, collected from tropical areas of Yunnan and Hainan in China. Pollen grains and spores of 21 taxa belonging to 21 families were recorded from Xishuangbanna Tropical Botanical Garden and 30 taxa from 27 families were recorded from Xinglong Tropical Botanical Garden. Ant nests yielded nine taxa belonging to nine families from the Geopark in Haikou. There is a close relationship between the pollen assemblages from ant nests and those from surface soil. Although the average similarity of pollen taxa between them reaches approximately 70%, surface soil proves to be a more effective trap than ants' nests.

KEYWORDS
Ant nest; surface soil; botanical garden; pollen trap; pollen rain

1. Introduction

A variety of natural pollen traps have been widely recognized and applied to studies of modern pollen rain, e.g. surface soils, moss and lichen cushions, leaves, bark (Faegri and Iversen 1989; Groenman-vanWaateringe 1998) and spiders' webs (Bera et al. 2002; Song et al. 2007). In this study, we consider the possibility that ants' nests in the tropics may also be a natural trap recording the local pollen rain. In tropical areas like the Amazonian forests, ants often build nests on an elevated support (Martius 1994) or on tree branches, which represents a strategy to avoid sporadic flooding during the rainy season (Martius 1994). In order to construct a nest on the branches, they usually pull leaves together and then use lots of larval silk expelled by nearly mature larvae to bind the leaves into place (Hölldobler and Wilson 1983). After that, worker ants also collect particles of soil and bark, wood chips, or dried leaf material to reinforce the nests (Hölldobler and Wilson 1983). During this seemingly slow building, pollen grains produced by plants can be trapped on the threads of silk in the processes of secreting and binding them. To investigate this phenomenon, we collected ant nests on tree branches from tropical China and treated them for pollen analysis. As a comparison, surface soil samples (the typical representative of local pollen rain) were also collected from locations corresponding to each ant nest sample. The results demonstrate a correlation between the pollen assemblages obtained from the ants' nests and local pollen rain.

2. Regional setting

Chinese tropical areas include southeastern Xizang (Tibet), southwestern to southeastern Yunnan, southwestern Guangxi, southern Guangdong, southern Taiwan, and Hainan (Zhu 2017). A borderline at c. 22.5°N was suggested as the northern boundary of the tropical zone in south and southeastern China mainly based on the dominance of tropical genera in this area (Zhu et al. 2007; Zhu 2013). The Chinese tropical zone is basically regarded as south of the Tropic of Cancer in terms of climatic and physical zonation, with the exception of parts of southwest China (National Committee of Atlas Compilations 1999). From region to region, the floristic composition and geographical elements are readily observable due to different geological history and ecological environments. The mean annual temperature in the tropics of China is usually between 20 and 22 °C with no frost year round. The mean annual precipitation is more than 1500 mm, most of which falls between April and November (Zhang 2007).

The vegetation in the tropics of China is tropical monsoon rain forest and rain forest (Zhang 2007). In detail, Xishuangbanna Dai Autonomous Prefecture, Yunnan, is located in the area of the Xishuangbanna mountains and basins seasonal rain forest and monsoon rain forest. Xinglong County, Hainan, is located in the area of the Southern Hainan hills and mountain monsoon rainforest. Here, primary rainforest has been destroyed to make way for large areas of rubber plantations. Only the strip of

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Published online 28 Jan 2019

Tongtieling still preserves a remnant of secondary forest. Finally, Luojingpan vegetation in Haikou belongs to the Hainan-Leizhou platform semi-evergreen monsoon rain forest, tropical scrub and grass-forb communities (Zhang 2007).

3. Material and methods

3.1. Sampling strategy

We collected three nest samples of weaver ants (*Oecophylla smaragdina*) on tree branches at the edge of a tropical rainforest at the Xishuangbanna Tropical Botanical Garden (BN), Chinese Academy of Sciences (Figure 1; Plate 1). This rainforest is a little disturbed due to anthropogenic activities such as horticulture and plant reintroduction. Ferns are rich in the understory of the rainforest. Six nest samples of weaver ants (*Oecophylla smaragdina*) on tree branches were collected near an experimental field of pepper vines inside the Xinglong Tropical Botanical Garden (XL). Then, three nest samples of an ant (*Camponotus* sp.) on the branches of lacquer trees (*Rhus chinensis*) were collected close to a road at Luojingpan in Shishan Volcanic Cluster National Geopark, Haikou (HK).

In total, 12 ants' nests were sampled in 2010–2011 at the three sites mentioned above (Table 1). At the same time, one surface sample (top 2 cm soil, ca. 100 g) was collected near each nest at each site for comparison.

3.2. Laboratory work

Bagged samples of ant nests and surface soil were opened under sterile conditions in the laboratory. The ant nests were immersed in a beaker of hot water for about 4 hours. Then the water was poured into another clean beaker and prepared to obtain the pollen and spores. Each 30 g sample of surface soil was processed using improved heavy liquid separation (Li and Du 1999). Extractions from the nests and surface soils were both treated with an acetolysis solution consisting of a 9:1 mixture of acetic anhydride and sulfuric acid (Erdtman 1960). Fifty percent glycerol solution was used for storage and preparation of microscopic slides. The spores and pollen were examined under a Leica DM 2500

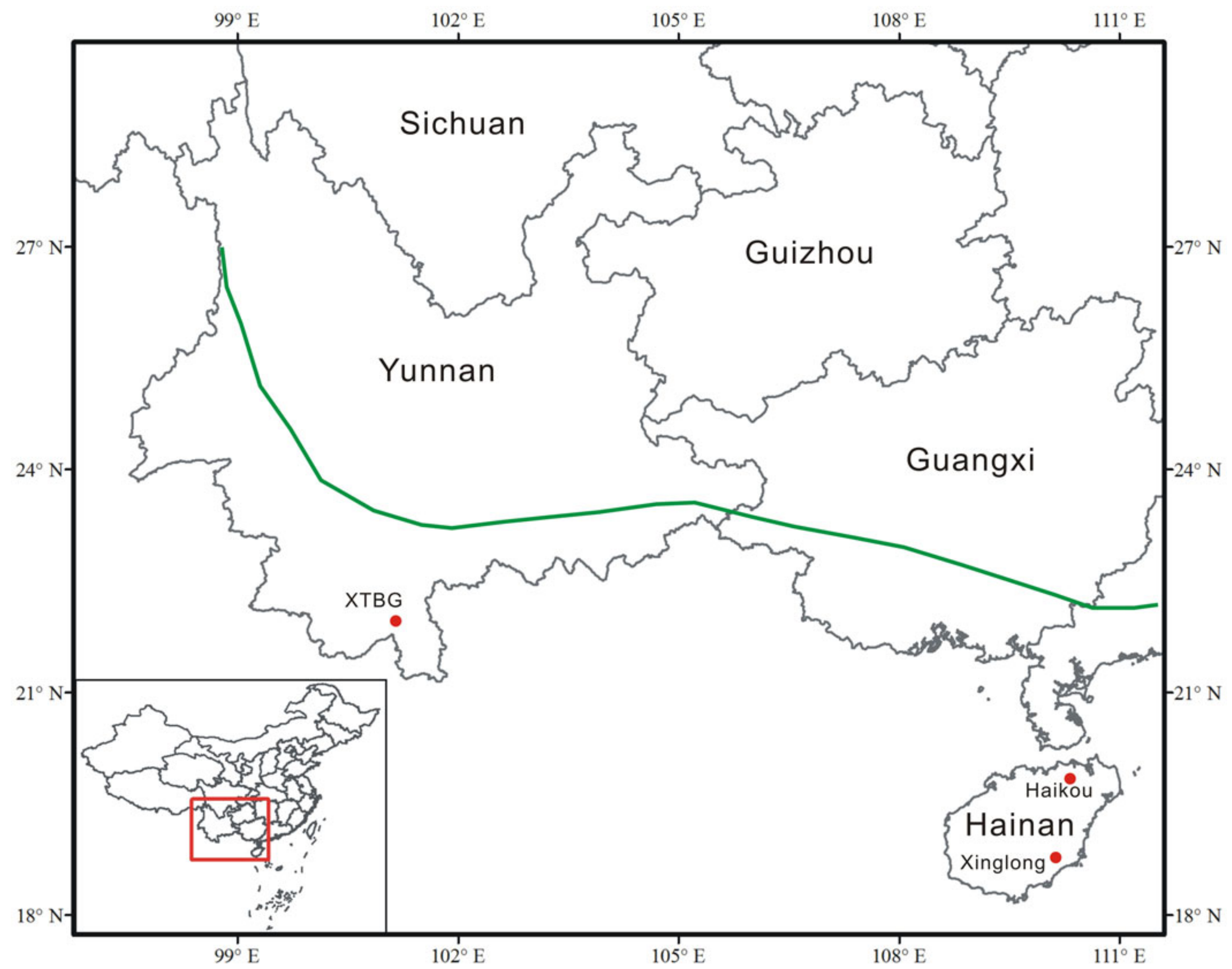


Figure 1. Map of study region and ant nest sampling sites. Dots (red) indicate the sampling sites. The line (green) indicates the approximate northern boundary of the tropical area in China (redrawn from Zhu 2017).

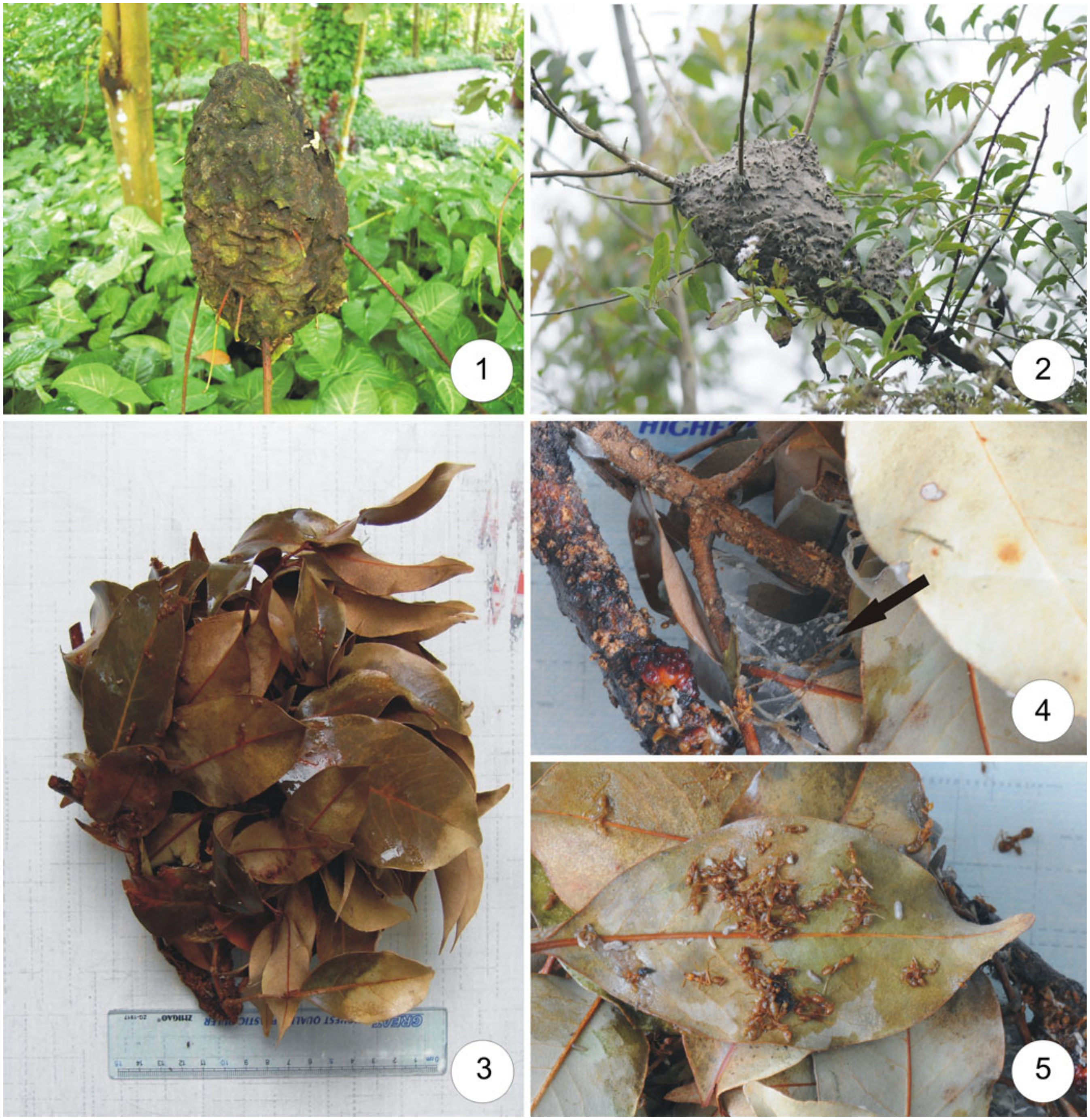


Plate 1. (1) Weaver ant nest (*Oecophylla smaragdina*); (2) nest of *Camponotus* sp.; (3) weaver ant nest cut from a tree of *Litchi chinensis*; (4) black arrow points to the larval silk membrane; (5) weaver ants.

microscope and identified relying chiefly on the *Pollen Flora of China* (Wang et al. 1995) and *Sporae Pteridophytorum Sinicorum* (Zhang et al. 1976). Modern pollen data were plotted using the program Tilia 2.0.41 (Grimm 2015). For dissimilarity analysis between surface samples and ant nests, we use the software program R (v. 3.5.0, R Development Core Team 2018).

4. Results

A total of 49 taxa belonging to 40 families were found in ant nests and surface soil samples (Figure 2; Plate 2). Thirty taxa could be identified at the generic level. There is one kind of spore, which remained unidentified.

Twenty-one taxa belonging to 21 families were recorded in ants' nests from BN and 30 taxa from 27 families were recorded from XL (Figure 2). Ants' nests from HK yielded nine taxa belonging to nine families. Fern spores, at 46.9%, dominate the palynological assemblages of ant nests sampled in BN. Gymnosperm and angiosperm pollen are the subdominants of the assemblages with 31.3% and 20.3%, respectively. While the palynological assemblages from the ants' nests in XL are dominated by angiosperm pollen at 69.1%, fern spores are the subdominant element with a

Table 1. Location of sampling sites and plants around these sites.

Sampling site	Coordinates	Sample no.	Habitat plant
XTBG, BN	21.92°N	1, 2	*Elaeagnus conferta*
	101.27°E	3, 4	*Elaeagnus conferta*
		5, 6	*Litchi chinensis*
Plants around the samples: *Ervatamia flabelliformis*, *Lagerstroemia intermedia*, *Lagerstroemia villosa*, *Woodfordia fruticosa*, *Canarium* sp., *Phyllanthus urinaria*, *Phyllanthus reticulatus*, *Phyllanthus* sp., *Podocarpus fleuryi*, *Podocarpus neriifolius*, *Rauvolfia yunnanensis*, *Rauvolfia vomitoria*, *Selaginella uncinata*, *Arenga* sp., *Sarcandra glabra*, *Toona sinensis*, *Pittosporopsis kerrii*, *Platea parvifolia*, *Nothapodytes obtusifolia*, *Mimosa pudica*, *Acacia delavayi*, *Bauhinia purpurea*, *Bauhinia esquirolii*, *Bauhinia yunnanensis*, *Tectona grandis*, *Micromelum integerrimum*, *Pteracanthus* sp., *Erythrina variegata*, *Cuscuta australis*, *Calamus yunnanensis* var. *yunnanensis*, *Calamus henryanus*, *Myrica nana*, *Pteris* sp., *Cibotium barometz*, *Lygodium yunnanense*, *Citrus* sp.			
Xinglong Tropical Botanical Garden, XL	18.73°N	7, 8	*Kigelia africana*
	110.19°E	9, 10	*Rauvolfia vomitoria*
		11, 12	*Ficus microcarpa*
		13, 14	*Coffea canephora*
		15, 16	*Coffea canephora*
		17, 18	*Calliandra haematocephala*
Plants around the samples: *Acacia confusa*, *Podocarpus nagi*, *Gmelina arborea*, *Artocarpus heterophyllus*, *Alpinia* sp., *Casuarina equisetifolia*, *Cocos nucifera*, *Piper nigrum*, *Cordyline fruticosa*, *Excoecaria cochinchinensis*, *Alocasia macrorrhiza*, *Schefflera octophylla*, *Dracaena cochinchinensis*, *Chaenomeles sinensis*, *Piper sarmentosum*, *Clerodendrum japonicum*, *Uvaria* sp., *Epipremnum aureum*, *Eucalyptus exserta*, *Abrus* sp., *Dianella ensifolia*, *Cibotium barometz*, *Archontophoenix alexandrae*, *Cyclosorus parasiticus*, *Liriope spicata*, *Calathea* sp., *Pterocarpus indicus*, *Bauhinia* sp., *Cananga odorata*, *Ficus pandurata*, *Ixora* sp., *Mesua ferrea*, *Dimocarpus longan*, *Adenanthera pavonina* var. *microsperma*, *Delonix regia*, *Spathodea campanulata*, *Colocasia antiquorum*			
Luojingpan, Haikou, HK	19.84°N	19, 20	*Rhus chinensis*
	110.27°E	21, 22	*Rhus chinensis*
		23, 24	*Rhus chinensis*
Plants around the samples: Asteraceae, *Nephrolepis* sp., *Stenoloma* sp., *Rubus* sp., Moraceae, *Sageretia* sp., *Lantana camara*, Smilacaceae, *Eucalyptus* sp.			

BN = Xishuangbanna, XL = Xinglong, HK = Haikou. Ant nest samples are indicated by odd numbers and surface soil samples are indicated by even numbers.

percentage of 29.2%. Gymnosperm pollen is rare, only 1.7%. The composition of the ant nests from HK is more similar to those in XL than those in BN. Angiosperms, ferns and gymnosperms account for 78.9%, 18.4% and 2.7%, respectively. On the other hand, in the surface soil samples from BN, XL and HK there are 42, 34 and 16 palynomorphs belonging to 32, 29 and 16 families, respectively. Fern spores and angiosperm pollen dominate the assemblages of BN, with 37.9% and 35.0% respectively (Figure 2). Gymnosperm pollen accounts for 22.3% of the assemblage. However, angiosperm pollen dominates the assemblages from XL and HK, 63% and 51.6% respectively. Fern spores and gymnosperm pollen from XL constitute 34.9% and 2.1%. In Haikou, the equivalent figures are 42.7% and 5.8%.

The dissimilarity of pollen assemblages between surface soil and ants' nests from BN is less than 30% (Figure 3). Most pollen assemblages sampled in XL had a dissimilarity of 10–20% between surface soil and ants' nests. Almost all of the samples from HK have a higher dissimilarity of 30–40% between surface soil and ants' nests. In terms both of pollen taxa and percentages, most pollen assemblages from ants' nests in XL have only 10–20% dissimilarity in contrast to pollen assemblages from surface soil from HK. However, the biggest dissimilarity of pollen assemblages also appears between ant nests from HK and surface soil from XL, having a D value of more than 60%. The sum of pollen count increases significantly with the number of taxa identified from the pollen assemblage of surface soil samples, while it has a non-significant increase with the number of taxa identified from the pollen assemblage of ant nest samples (Figure 3).

5. Discussion

We analyzed the palynological characteristics of ant nest samples from tropical regions of China, and then compared these pollen assemblages with assemblages from surface soil in terms of pollen taxa and dissimilarity of pollen assemblages. Most of the ants' nests (65%) are found on branches in tropical rainforest, although soil nests are also frequent (24%) in southeastern Brazil (Soares and Schoereder 2001). Our fieldwork also indicates that branching nests are frequently encountered at BN in Yunnan, and XL and HK in Hainan. Theoretically, these nests should normally trap the pollen produced by the habitat plant and the surrounding plants. However, our results show that none of the ant nest samples contain pollen of the habitat plant. This surprising result indicates that the ant nests were probably built when the habitat plant was not blossoming. On the other hand, wingless ants are poor pollinators because of their inability to move pollen over great enough distances to achieve gene flow among plants (Proctor and Yeo 1972), or because the toxicity of ant cuticular secretions to pollen grains leads to the rarity of ant pollination (Dutton and Frederickson 2012). Studies on ant–plant mutualisms further indicate that the wet or seasonally rainy tropics do not support many plant species exhibiting the characters of the ant-pollination syndrome (Hickman 1974). Thus, the transport of pollen grains by the

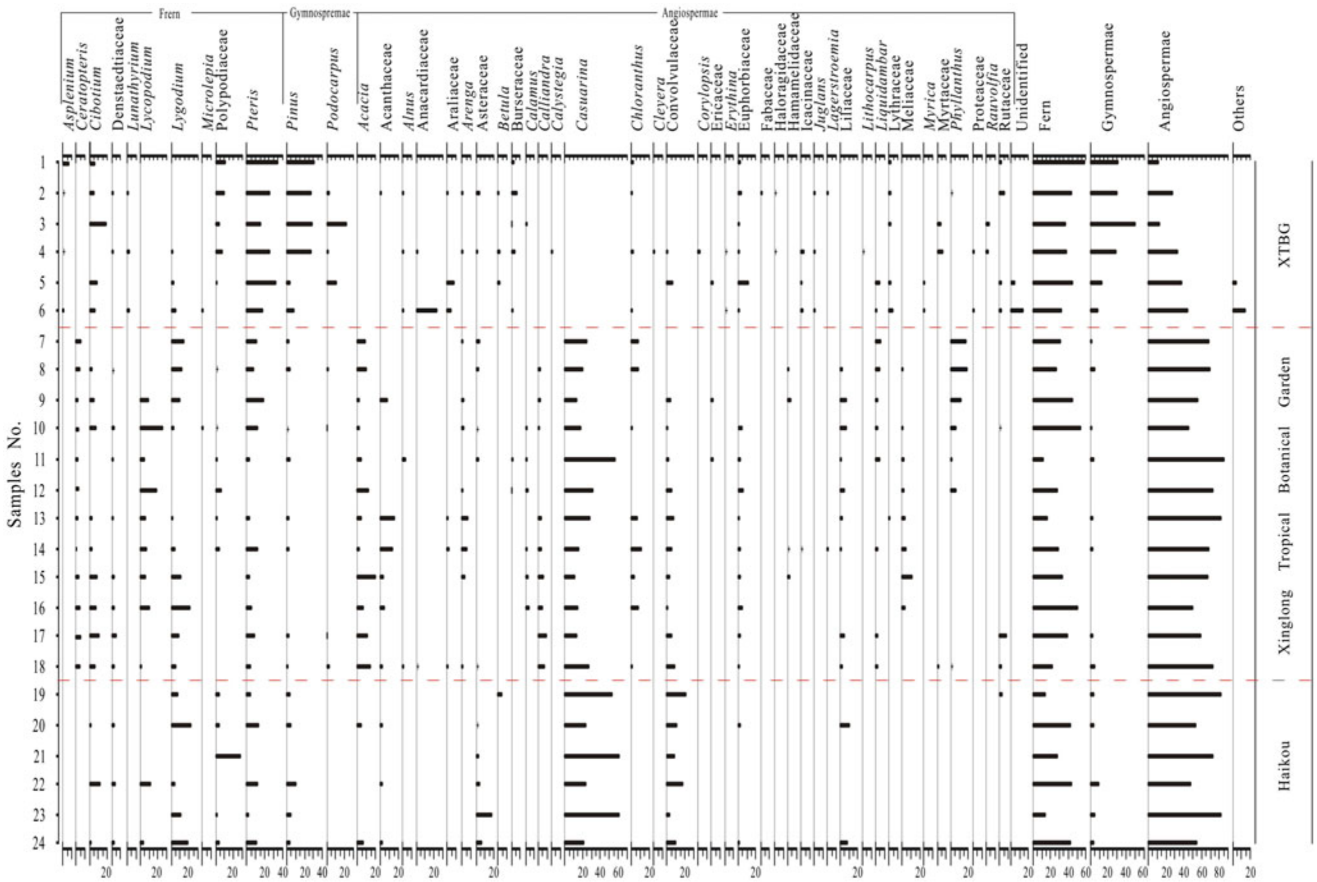


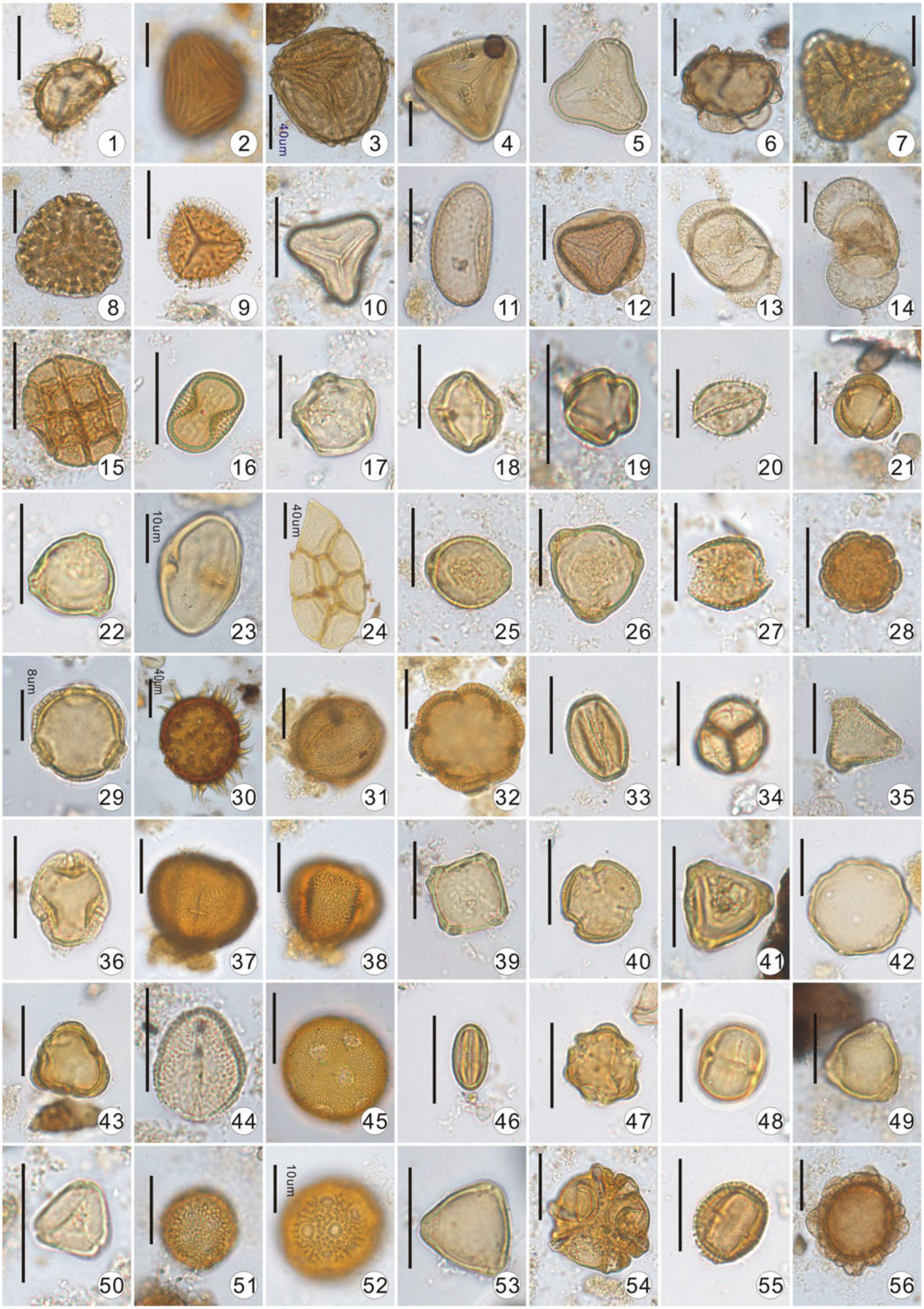
Figure 2. Palynological spectra of the ants' nests and corresponding surface soil samples. Ant nest samples are indicated by odd numbers and surface soil samples are indicated by even numbers.

ants themselves, whether from the host plant or surrounding plants, to the ants' nests may seldom happen.

The main characteristic of a botanical garden is the high diversity of plants, up to 10,000 species amassed in Xishuangbanna Tropical Botanical Garden and 1200 species in Xinglong Tropical Botanical Garden, which may explain why ants' nests from these botanical gardens contain more pollen taxa than the nests in Haikou. At BN, the habitat at the edge of the rainforest supports a rich fern flora. Gardeners have introduced many plant species such as *Lagerstroemia intermedia*, *Lagerstroemia villosa*, *Woodfordia fruticosa*, and *Canarium* sp. Thus, ants' nests contain pollen of Lythraceae and Burseraceae. *Phyllanthus* pollen may be produced by *Phyllanthus urinaria*, *Phyllanthus reticulatus*, and/or *Phyllanthus* sp. Pollen of *Podocarpus* is probably derived from *Podocarpus fleuryi* and *Podocarpus neriifolius*. The record of pollen deposition is consistent with the plants' flowering periods (Lu et al. 2010). In our study, *Casuarina* pollen accounts for a large percentage of the pollen assemblage in the Xinglong and Haikou samples, which suggests that the *Casuarina* flowering period varying from April to May coincided with the phase of ant nest building. No doubt *Casuarina*'s high pollen production also played a role. The *Casuarina* pollen was probably produced by *Casuarina equisetifolia* that was introduced into Xinglong Tropical Botanical Garden and planted along the road of the Geopark in Haikou.

The palynoassemblage extracted from ants' nests is, to some extent, representative of local pollen rain. Ants' nests are comparatively small, and thus they record a relatively limited number of pollen grains representative of few taxa. In general, ants' nests trap less pollen than surface soil does, although exceptions exist in two samples from XL. Almost all taxa trapped by ants' nests are also encountered in surface soil samples. The pollen sum displays a significant increase as the number of taxa found in the assemblages from surface soil samples increases, whereas it increases insignificantly for ants' nests. This indicates that the surface soil is more effective at collecting pollen than ants' nests are.

The threads of larval silk probably trap some of the pollen as spiders' webs do (Bera et al. 2002; Song et al. 2007). Some pollen probably comes from small pieces of soil and vegetable matter such as bark, which are used to strengthen the nests (Hölldobler and Wilson 1983) and have been identified as good pollen traps (Faegri and Iversen 1989; Groenman-vanWaateringe 1998). Pollen grains and spores captured by raindrops (McDonald 1962) also constitute a minor contribution to the whole palynoassemblage of ants' nests. However, rainfall not only has a positive influence in carrying pollen to ants' nests, but also has a negative influence in washing out pollen originally trapped within the nests. Abundant precipitation during rainy seasons in Yunnan and Hainan sporadically washes both ants' nests on branches and the surface soil. Due to leaching, it is understandable that pollen spectra in these two kinds of samples are not identical. Even so, the average similarity of pollen taxa tested between ants' nests and surface soil samples reaches approximately 70%.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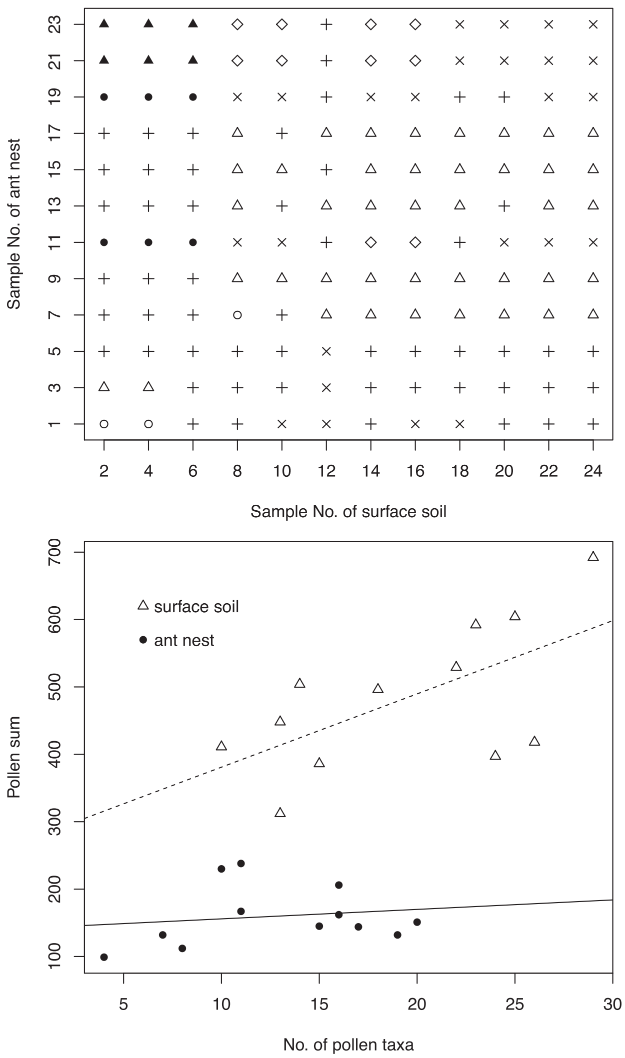

Figure 3. Comparisons between the characteristics of pollen assemblages of surface soil and of ants' nests. Upper: dissimilarity comparisons, the percentages of dissimilarity (D) are as follows: circle ($D \leq 10\%$), triangle ($10\% < D \leq 20\%$), plus ($20\% < D \leq 30\%$), cross ($30\% < D \leq 40\%$), solid triangle ($40\% < D \leq 50\%$), solid circle ($50\% < D \leq 60\%$), diamond ($60\% < D$). Samples 1-6 collected from BN, samples 7-18 collected from XL, and samples 19-24 collected from HK. Below: Linear regression of surface soil samples (triangle) and ant nests' samples (solid circle).

6. Conclusion

There is a close relationship between pollen assemblages from ant nests and from surface soil. More pollen taxa are trapped by ants' nests in the botanical gardens than from the Geopark, a phenomenon attributed to the high species diversity of botanical gardens. Pollen found with high percentages in ants' nests and surface soil samples may indicate that the flowering time of the particular plant coincided with the construction of the ants' nests, e.g. *Casuarina* pollen. Unfortunately, we did not detect any pollen from host plants of ant nests. Finally, surface soil proves to be a more effective pollen trap than ants' nests. However, in the future more attention should be paid to the potential of ant nests as a natural pollen trap.

Acknowledgements

We are thankful to Engineers Wen-Xiang Xiao and Zi-Yun Huang, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Yunnan, China, for their help during the sampling campaign, and also grateful to Senior Engineer Nai–Qiu Du, Institute of Botany, CAS, Beijing, China, for her help during pollen identification. We thank Prof. Nilamber Awasthi from the Birbal Sahni Institute of Palaeobotany, India, for his comments on the first version of the manuscript, as well as Prof. Dr Jean-Pierre Suc and two anonymous reviewers for their review of the manuscript.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was supported by the following grants: National Natural Science Foundation of China [grant number 41861003]; Chinese Academy of Sciences Visiting Professorship for Senior International Scientists [grant number 90004F1005]; State Key Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, CAS [grant number SKLLQG1333].

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Plate 2. Pollen plate (×400, scale bars = 20 µm unless otherwise stated): 1. *Asplenium*, 2. *Ceratopteris*, 3. *Ceratopteris* (×200), 4. *Cibotium*, 5. Dennstaedtiaceae, 6. *Lunathyrium*, 7, 8. *Lycopodium*, 9. *Lygodium*, 10, *Microlepia*, 11. Polypodiaceae, 12. *Pteris*, 13. *Pinus*, 14. *Podocarpus*, 15. *Acacia*, 16. Acanthaceae, 17. *Alnus*, 18. Anacardiaceae, 19. Araliaceae, 20. *Arenga*, 21. Asteraceae, 22. *Betula*, 23. Burseraceae (×1000), 24. *Calliandra* (×200), 25, 26. *Casuarina*, 27. *Calamus*, 28. *Chloranthus*, 29. *Cleyera* (×1000), 30. Convolvulaceae (×200), 31, 32. Convolvulaceae, 33. *Corylopsis*, 34. Ericaceae, 35. *Erythrina*, 36. Euphorbiaceae, 37, 38. Fabaceae, 39. Haloragidaceae, 40. Hamamelidaceae, 41. Icacinaceae, 42. *Juglans*, 43. *Lagerstroemia*, 44. Liliaceae, 45. *Liquidambar*, 46. *Lithocarpus*, 47. Lythraceae, 48. Meliaceae, 49. *Myrica*, 50. Myrtaceae, 51. *Phyllanthus*, 52. *Phyllanthus* (×1000), 53. Proteaceae, 54. *Rauvolfia*, 55. Rutaceae, 56. Unidentified.

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