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Short communication

Sentinel soil invertebrate taxa as bioindicators for forest management practices

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ABSTRACT

The objectives of the present study were to explore the potential of soil invertebrate taxa (families or genera) to evaluate forest management practices. An experiment with four treatments: control, understory removal, *Cassia alata* (a legume shrub) addition, and both understory removal and *C. alata* addition, was conducted at Heshan Hilly Land Interdisciplinary Experimental Station, Guangdong, China. Redundancy analysis showed that some bacterivores and fungivores of soil invertebrates (nematodes, mites, collembolans) were correlated positively, but some predators and omnivores were correlated negatively with forest management practices. *C. alata* addition increased the abundance of the high trophic-level nematodes and mites, which indicated *C. alata* addition was a good forest management practice in terms of improved soil food web structure. In contrast, removal of forest understory plants appeared to disturb the ecosystem by suppressing high-trophic groups of soil invertebrates, demonstrating that understory removal was not a good forest management practice. Redundancy analysis also showed that soil fauna at the genus or family level can be used as biological indicators for forest management practices. Specifically, some high trophic-level nematode genera such as *Eudorylaimus*, *Chrysonema*, *Iotonchus* and *Thornia* were suppressed significantly by understory removal and some nematode genera such as *Prismatolaimus*, *Eudorylaimus*, *Chrysonema*, and *Thornia* and one common mite genus *Rhodacarus* in high trophic-level were enriched significantly by legume addition.

1. Introduction

In the past decades, it is well documented that soil invertebrates (i.e. nematodes, mites and collembolans) can be served as useful bioindicators for environmental changes and agricultural managements (Aspetti et al., 2010; Bongers and Ferris, 1999; Neher, 2001; Ponge et al., 2003; Ruf, 1998). However, whether sentinel invertebrate taxa can indicate specific forest management practice has not been studied.

Forest plantations have exceeded 264 million hectares globally and they are under intensive management (FAO, 2010). Nevertheless, sustainable forest management (SFM) has caught wide public attention in recent years. Understory plants can compete for nutrients and water with the overstory species (Nambiar and Sands, 1993). Therefore, understory removal has been a common forest management practice in southern China and elsewhere (Liu et al., 2012; Wu et al., 2011; Zhao et al., 2011, 2012). Due to the nitrogen-fixing trait, legumes have been used as green manure plants intercropped with crops for a long time, but only recently they were used in forest ecosystems to improve soil fertility (Li et al., 2011; Wang et al., 2011). In the present study, understory vegetation was either removed or replaced with legumes as forest management practices in order to improve the sustainability of the forest ecosystems. Our objectives were to (1) define the relationship between soil invertebrates and understory management practices using multivariate analysis and (2) explore the potential of soil invertebrate as bioindicators to evaluate forest management practices.

2. Materials and methods

2.1. Experimental design

This study was conducted at the Heshan Hilly Land Interdisciplinary Experimental Station (112°50′E, 22°34′N), Guangdong Province, China. The climate is subtropical monsoon with distinct wet (from April to September) and dry seasons (from October to March). The mean annual temperature and precipitation are 21.7 °C and 1700 mm, respectively. The soil is acrisol. Six mixed plantations of similar age and similar tree species

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Table 1
Sentinel nematode genus that correlated positively or negatively to understory removal (UR) and *C. alata* addition (CA) treatments in wet and dry seasons.

Season	Treatment	Soil nematode genus			
		Positive correlation[a]		Negative correlation	
		Genus	Guild[b]	Genus	Guild
Wet season	UR	*Filenchus*	Fu2	*Chrysonema*	Om5
		Trophurus	Pl2	*Eudorylaimus*	Om4
	CA	*Thornia*	Om4	*Acrobeloides*	Ba2
		Aphelenchiodes	Fu2		
		Acrolobus	Ba2		
		Cephalobus	Ba2		
Dry season	UR	*Ditylenchus*	Fu2	*Chrysonema*	Om5
		Longidorus	Pl5	*Eudorylaimus*	Om4
				Thonia	Om4
				Iotonchus	Pr4
	CA	*Trichodorus*	Pl4	*Acrobeloides*	Ba2
		Eudorylaimus	Om4	*Epidorylaimus*	Om4
		Chrysonema	Om5		
		Prismatolaimus	Ba3		

[a] Positive correlation or negative correlation represent nematode genus that correlated positively or negatively to certain treatment, respectively.
[b] Guild designation is the composite of trophic group and *cp*-value: Pl, herbivore; Ba, bacterivore; Fu, fungivore; Pr, predator; Om, omnivore.

composition were selected for our experiment (details see Zhao et al., 2011).

The experimental design was a two-factor orthogonal design. In March 2007, four 10 m × 10 m plots were established in each of the six replicate plantations. Within each plantation, four treatments were assigned randomly to the four plots: control (CK), understory removal (UR), *C. alata* (a legume species) addition (CA), and both understory removal and *C. alata* addition (UR + CA). In the UR treatment, shoots of all understory plants were removed manually with a machete knife. In CA treatment, *C. alata* was planted at a spacing of 1 m × 1 m with all original understory plants intact. In UR + CA treatment, *C. alata* was planted at a spacing of 1 m × 1 m after all original understory plants were removed.

2.2. Soil sampling and analysis

Soil was sampled twice, both in August 2008 (wet season) and in January 2009 (dry season). Soil cores (5 cm diameter) were taken at 0–5 cm and 5–10 cm depth from six randomly selected locations in each plot within each plantation. Six cores of the same depth from each plot were combined to form one composite sample. In total, there were six composite samples from each depth for each treatment. The litter above each sampling spot was removed before the core was collected. Nematodes were extracted from 50 g of moist soil using the Baermann funnel method. Microarthropods were extracted from three soil cores (5 cm diameter and 5 cm depth) with a Tullgren funnel. Invertebrates were counted with an inverted compound microscope. All the nematodes, mites and collembolans of each sample were identified to genus level when possible.

2.3. Data analysis

Multivariate analysis was performed to account for collinearity. By using the two-factor orthogonal design, UR and CA were the two orthogonal factors. After down-weighting rare genus and/or family, redundancy analysis (RDA) was performed to explore the relationships between factors (i.e. UR and CA) and soil invertebrates (i.e., nematodes, mites and collembolans) by designating factors as nominal (0, 1) environmental variables (Fiscus and Neher, 2002; Lepš and Šmilauer, 2003). In this case, the data from UR treatment were designated as 1 associated to UR factor but as 0 associated to CA factor; the data from CA treatment were designated as 1 associated to CA factor but as 0 associated to UR factor; the data from CK treatment were designated as 0 associated to both UR and CA factors; and the data from UR + CA treatment were designated as 1 associated to both UR and CA factors. Monte Carlo permutation tests were applied to compute statistical significance. Multivariate analysis used CANOCO 4.5 software (ter Braak et al., 1988).

3. Results

3.1. Soil nematodes

Significant effects of managements on soil nematode community were detected in both wet ($p = 0.002$) and dry season ($p = 0.006$). In wet season (Table 1), UR was correlated positively with *Filenchus* and *Trophurus*, and was correlated negatively with *Chrysonema* and *Eudorylaimus*; CA was correlated positively with abundance of *Thornia*, *Aphelenchiodes*, *Acrolobus* and *Cephalobus*, and was correlated negatively with abundance of *Acrobeloids*. In dry season (Table 1), UR was correlated positively with *Ditylenchus* and *Longidorus*, and was negatively correlated with *Chrysonema*, *Eudorylaimus*, *Thonia* and *Iotonchus*; CA was correlated positively with *Trichodorus*, *Eudorylaimus*, *Chrysonema* and *Prismatolaimus*, and was negatively correlated with *Acrobeloides* and *Epidorylaimus*.

3.2. Soil microarthropods

Significant effects of managements on soil mite community were also detected in wet season ($p = 0.028$). UR was positively correlated with *Archolaspulus*, and was negatively correlated with *Scheloribates*, *Allonothrus*, *Platynothrus* and *Archoplophora*; CA was positively correlated with *Tectocepheus*, *Scutacaridae*, *Ceratozetes*, *Parholaspulus*, *Pulaeus*, *Rhodacarus* and *Laelapidae*, and was negatively correlated with *Uropodidae* and *Epilohmannoides* (Table 2). However, significant effects of managements on soil collembolan community were only detected in dry season ($p = 0.004$). UR was positively correlated with *Brachystomella* and *Proisotoma*; CA was negatively correlated with *Folsomides* (Table 2).

4. Discussion

Nematodes can be readily identified to the generic level, can be classified to trophic groups and can be separated readily into *cp* guilds (colonizer–persister guild). The colonizer–persister (*cp*) value ranges from a colonizer (*cp* value = 1) to a persister (*cp* value = 5) with the index values representing life-history characteristics associated with *r*- and *k*-selection, respectively (Bongers,

Table 2
Sentinel microarthropod family or genus that correlated positively or negatively to understory removal (UR) and *C. alata* addition (CA) treatments in wet season.

Microarthropod group	Treatment	Soil microarthropod family or genus			
		Positive correlation[a]		Negative correlation	
		Taxon	Guild[b]	Taxon	Guild
Mites	UR	*Archolaspulus*	Fu	*Scheloribates*	Fu
				Allonothrus	Fu
				Platynothrus	Fu
				Archoplophora	Fu
	CA	*Tectocepheus*	Fu	*Uropodidae*	Pr
		Scutacaridae	Pr	*Epilohmannoides*	Fu
		Ceratozetes	Fu		
		Parholaspulus	Pr		
		Pulaeus	Pr		
		Rhodacarus	Pr		
		Laelapidae	Pr		
Collembolans	UR	*Brachystomella*	Fu		
		Proisotoma	Fu		
	CA			*Folsomides*	Fu

[a] Positive correlation or negative correlation represent microarthropod taxon that correlated positively or negatively to certain treatment, respectively.
[b] Guild designation is the composite of trophic group: Fu, fungivore; Pr, predator.

1990; Ferris et al., 2001). Theoretically, the bacterivorous and fungivorous nematodes with low *cp*-values are considered as *r*-selected species which can be rapidly responding to soil nutrient enrichment; the predatory and omnivorous nematodes with high *cp*-values are considered as *k*-selected species can be rapidly responding to soil disturbances (Bongers, 1990; Ferris et al., 2001). Understory removal significantly suppressed the high *cp*-value predatory and omnivorous nematodes in wet and dry season in this study, indicating that understory removal caused a serious disturbance to these ecosystems. In fact, understory removal resulted in increased soil temperature and reduced soil moisture and induced a decrease in soil respiration in the same experimental sites as in this study (Li et al., 2010; Wang et al., 2011; Wu et al., 2011; Zhao et al., 2011, 2012). In contrast, the high *cp*-value omnivorous nematodes were correlated positively to *C. alata* addition. Additionally, the abundance of predator mite genera and families increased in *C. alata* addition treatment. Nitrogen fixation by legumes results in large amounts of nitrogen in the soil. The nitrate concentration is usually affected by legumes due to higher-nitrogen litter and root exudation into the soil (Gastine et al., 2003; Rothe et al., 2002). These resources are easily decomposed by soil detrital foodweb (Stephan et al., 2000). The greater proportion of omnivores and predators in the two seasons indicate that the structure of the nematode community was improved (Ferris et al., 2001). In the dry season, a high *cp*-value nematode genus (*Epidorylaimus*) was correlated negatively with *C. alata* addition. The reason might be that *Epidorylaimus* is not a *k*-selected species. In consistence with our finding, Fiscus and Neher (2002) reported that *Epidorylaimus* is not sensitive to disturbance such as direct tillage. Our results suggest that *C. alata* addition is a good forest management practice.

In general, most of collembolans are fungivores (Bilde et al., 2000; Hopkin, 1997). Understory removal had no significant suppressive effects on the collembolan genera. Collembolans are considered to be more *r*-selected and, therefore, more tolerant to disturbance than *k*-selected collembolans (Chauvat et al., 2003; Petersen, 2002).

5. Conclusion

Based on the effects of *C. alata* addition or understory removal on soil fauna, we conclude that addition of *C. alata* might be a good forest management practice, but understory removal was a serious disturbance to the ecosystem. Multivariate analysis results showed that sentinel taxa of soil invertebrates could be used as bioindicators of forest management practices, but the importance of indicator role might vary with different taxa level of soil fauna. Specifically, some high trophic-level nematode genera such as *Eudorylaimus*, *Chrysonema*, *Iotonchus* and *Thornia* were suppressed significantly by understory removal and some nematode genera such as *Prismatolaimus*, *Eudorylaimus*, *Chrysonema*, and *Thornia* and one common mite genus *Rhodacarus* in high trophic-level were enriched significantly by legume addition.

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