

Article

Changes in Soil Arthropod Abundance and Community Structure across a Poplar Plantation Chronosequence in Reclaimed Coastal Saline Soil

Yuanyuan Li ^{1,2}, Han Y. H. Chen ³ , Qianyun Song ¹, Jiahui Liao ¹, Ziqian Xu ¹, Shide Huang ¹ 
and Honghua Ruan ^{1,*}

¹ College of Biology and the Environment, Joint Center for Sustainable Forestry in Southern China, Nanjing Forestry University, Nanjing 210037, China; lyy_njfu@163.com (Y.L.); 18705190508@163.com (Q.S.); liaojiahui@njfu.edu.cn (J.L.); zqxu@njfu.edu.cn (Z.X.); hsd9876@126.com (S.H.)

² School of Food Science, Nanjing Xiaozhuang University, Nanjing 211171, China

³ Faculty of Natural Resources Management, Lakehead University, 955 Oliver Road, Thunder Bay, ON P7B 5E1, Canada; hchen1@lakeheadu.ca

* Correspondence: hhruan@njfu.edu.cn; Tel.: +86-25-854-27-312

Received: 9 September 2018; Accepted: 13 October 2018; Published: 15 October 2018



Abstract: Poplar plantations have the capacity to improve the properties of soils in muddy coastal areas; however, our understanding of the impacts of plantation development on soil arthropods remains limited. For this study, we determined the community dynamics of soil dwelling arthropods across poplar plantations of different ages (5-, 10-, and 21-years) over the course of one year in Eastern Coastal China. The total abundance of soil arthropods differed with stand development. Further, there were some interactions that involved the sampling date. On average, total abundance was highest in the 10-year-old stands and lowest in the 5-year-old stands. Total abundance exhibited strong age-dependent trends in June and September, but not in March or December. The abundance of Prostigmata and Oribatida increased in the 5- to 21-year-old stands, with the highest levels being in the 10-year-old stands. The abundance of Collembola increased with stand development; however, the stand age had no significant impact on the abundance of epedapic, hemiedaphic, and euedaphic Collembola. Order richness (Hill number $q = 0$) curve confidence intervals overlapped among three stand ages. Shannon and Simpson diversity (Hill numbers $q = 1$ and $q = 2$) differed between 10- and 21-year-old stand age. They showed almost similar trends, and the highest and lowest values were recorded in the 21- and 10-year-old stand ages, respectively. Permutational multivariate analysis of variance demonstrated that composition also varied significantly with the sampling date and stand age, and the 10-year-old stands that were sampled in June stood well-separated from the others. Indicator analysis revealed that Scolopendromorpha and Prostigmata were indicators in June for the 10-year-old stands, while Collembola were indicators for the 21-year-old stands sampled in September. Our results highlight that both stand development and climate seasonality can significantly impact soil arthropod community dynamics in the reclaimed coastal saline soils of managed poplar plantations.

Keywords: microarthropod; diversity; seasonal variations; stand development

1. Introduction

Soil arthropods are critical to many forest ecosystem processes, and may be employed as bioindicators of ecosystem soil conditions and changes, such as soil fertility, levels of pollutants, and stand development phases [1–3]. They play an essential role in multiple soil functions, including organic matter decomposition, nutrient mineralization and redistribution, and the stimulation of the

growth of mycorrhizal and other fungi [4–7]. Plant diversity and productivity may exert positive effects on soil arthropod abundance and diversity [8–10]; in turn, soil arthropods facilitate plant community succession while enhancing local plant diversity [11].

In 2014, it was estimated that the saline soil area in China was about 34.5 Mha [12], primarily distributed on the eastern coast between the Yellow and Yangzi Rivers. These soils are often restored for agricultural use through the construction of dikes to ensure a steady and reliable food supply. However, these newly reclaimed coastal alkali soils are not suitable for immediate agricultural use [13]. Stand development following afforestation can reduce the soil pH through the accumulation of biomass [14,15]. There are wide variations in condition during different stand development phases, such as canopy closure, humidity, and other abiotic and biotic factors [16–18], which directly or indirectly impact soil arthropod activity [19–22].

Soil arthropod communities are highly dynamic in forests [23], and following their establishment, they are modified by stand development. In European subalpine spruce forests, the abundance of Collembola was higher in young fertile stands, while that of Oribatida was more abundant in mature stands with increased litter input [24,25]. The abundance of Oribatida in spruce forests was observed to increase from young (25-year-old) to mature (170-year-old) stands [24], while the highest abundance was observed in 25-year-old stands along a 5- to 95-year chronosequence [26]. These studies suggest that the effects of forest stand development on the abundance of arthropods are regulated through changes in soil nutrients [9,27,28]. Most previous studies have focused on one taxon, such as collembola, mites, beetles, centipedes, or millipedes [17,24,25,29,30], each of which contributes in various ways to soil functionality [31–33]. Our understanding of overall soil arthropod communities in response to forest stand development, however, remains elusive.

Soil arthropod communities undergo seasonal changes [34]. In tropical forests, soil arthropods are more abundant during the rainy season than the dry season [35]. In high latitude forests, drought reduces the abundance of soil arthropods [36,37]. Changing seasonal precipitation and temperature influences the composition of soil arthropod communities not only directly, but also indirectly, through the influence of understory shrub communities [36]. Studies that have examined the effects of plant communities and seasonality found that changes in resident arthropod populations are often more influenced by seasonality than changes in plant communities [19,21,37], while others have reported more pronounced influences from shifts in tree species composition over seasonality [1]. Nevertheless, knowledge of the seasonal dynamics of soil arthropods in plantations with diverse stand ages remains limited.

Poplar plantations are an important contributor to bioenergy resources and carbon sequestration [38]. In China, poplar trees are widely cultivated not only due to their rapid growth and wood supplies, but also for improving soil properties in muddy coastal areas [39]. For this study, we sampled soil arthropods across three poplar plantation ages (5-, 10-, and 21-years) on four sampling dates (in March, June, September, and December) in Eastern Coastal China. We sought to determine the structures of soil arthropod assemblages as relating to stand development in terms of total abundance, major group abundance, diversity, and composition. We hypothesized that (1) the abundance, diversity, and composition of soil arthropods would change with stand development, as aboveground and belowground conditions in forests are altered with stand aging processes [28,39]; and (2) if changes occurred, the patterns would not be consistent across seasons in these subtropical plantations as a result of variable seasonal rainfall and temperatures.

2. Materials and Methods

2.1. Site Description

This study was conducted at the Yellow Sea State Forest Park in Eastern Coastal China (32°33′–32°57′ N, 102°07′–102°53′ E), which is located in a warm temperate subtropical transition zone influenced by a monsoon climate. Seasonal changes in precipitation and temperature were recorded at

the local Dongtai meteorological station (Figure S1). The average annual temperature and rainfall in this area over the past ten years (2005–2015) were 15.4 °C and 1494.0 mm, respectively, with an annual mean relative humidity of 76.0%. The terrain includes the middle and lower reaches of the alluvial Yangtze River plain, with desalted sandy loam meadow soil. The Forest Park consists of an area of approximately 3000 ha of pure poplar (*Populus deltoides* Marsh) plantations, with stand ages that range from three to 23 years.

2.2. Experimental and Sampling Design

For this study, three stands (5-, 10-, and 21-years) of pure poplar plantations under similar site conditions were sampled in triplicate, with a spatial interspersion of ~500–600 m for stands of the same age. All stands contained the same basalt parent material, similar elevations (less than 5 m difference), and original field management with the same initial plant community composition prior to the establishment of the plantations (based on the management records provided by the State Forest Park). We established experimental plots (20 m × 30 m) in each stand, for a total of nine plots.

In September, within each plot, tree trunks were measured at the height of 1.3 m above ground and diameters at breast height (DBH) of >5 cm were recorded. Understory vegetation richness surveys were conducted by counting all species found in the 1 m² of each plot. Coverage of individual layers of shrub and herb species was visually estimated as the percentage cover of the plot area [40].

During September 2014, ten 2.5-cm diameter soil cores were extracted from random locations at a 0–20 cm depth (10 cm intervals) in each plot. Five random soil cores from the ten locations were combined to represent a specific soil depth (0–10 cm or 10–20 cm) for the determination of soil moisture, while the other five cores were employed to quantify its chemical properties. Each of the samples was sieved through a mesh (2 mm) to remove coarse fragments prior to analysis. Soil moisture was calculated as:

$$\text{Soil moisture} = [(\text{wet} - \text{dry mass}) \times 100] / \text{dry mass} \quad (1)$$

The dry mass of the soil was determined following oven drying at 105 °C for 24 h. The soil samples for chemical analyses were air dried and the pH was determined using a glass electrode in a 1:2.5 soil/water solution (w/v). Soil carbon and nitrogen were measured using an element analyzer (Elementar, Vario ELIII, Elementar Analysen Systeme GmbH, Hanau, Germany).

2.3. Soil Arthropod Sampling and Extraction

Soil arthropod sampling was conducted seasonally, i.e., in December 2013 and in March, June, and September 2014. On each sampling date, three random replicate soil samples, excluding the litter layer, were extracted from each plot. Three random replicate soil samples were extracted from a 0–20 cm soil depth with soil cores (4 cm in diameter) and averaged to sample soil arthropods using Tullgren extractors (Tullgren Funnel Unit, Burkard, UK) over 24 h [17]. All core samples were immediately placed in plastic bags, sealed, and transferred to the laboratory for further processing. On each sampling date, we also dug one pit that measured 25 cm × 25 cm × 20 cm to sample macroarthropods (Polydesmida, Scolopendromorpha, Coleoptera, Diptera (larvae), Araneida, Lepidoptera, Siphonaptera, Thysanoptera, and Hymenoptera (Formicidae)) in each plot [41]. All extracted arthropods were preserved in 75% ethanol and subsequently sorted under a dissecting microscope (Eclipse E200, Nikon, Tokyo, Japan).

The soil arthropods were identified to an ordinal level [42], which is often used for the rapid assessment of arthropod diversity [43,44]. In particular, it can be a useful method in the early stages of investigation for assessments of biodiversity [45]. The habitat preference structure of Collembola was organized into epedaphic, hemiedaphic, and euedaphic types [46,47]. The biodiversity of the soil arthropod communities was estimated through the abundance of soil arthropods (ind. m⁻²), and diversity was computed with Hill numbers ($q = 0, 1, 2$) using the 'iNEXT' package [48–50].

2.4. Statistical Analysis

We tested the effects of stand age (A , years) and sampling date (D) on soil arthropod abundance, using the following model:

$$Y_{ijkl} = A_i + D_{j(k)} + A_i \times D_{j(k)} + \pi_k + \varepsilon_{l(ijk)} \quad (2)$$

where Y_{ijkl} is the total abundance of soil arthropods, the abundance of each major group (i.e., Prostigmata, Oribatida, Hymenoptera, Collembola, or Diptera); A_i ($i = 1, 2, 3$) is the stand age; $D_{j(k)}$ ($j = 1, 2, 3, 4$) is the sampling date (March, June, September, and December); π_k is the random plot effect ($k = 1, 2, \dots, 9$) to account for temporal autocorrelation among sampling dates within each plot; and $\varepsilon_{l(ijk)}$ ($l = 1, 2, 3$) is the random sampling error. We conducted mixed effect analysis using maximum likelihood with the *lme4* package in R 3.4.1 [51]. Shapiro-Wilk's tests of model residuals indicated that the assumption of normality was not met at $\alpha = 0.05$ for most models. Hence, we bootstrapped parameter estimates by 1000 iterations using the 'boot' [52] and 'ggplot2' packages [53].

To examine the effects of stand age and sampling date on arthropod composition, we used permutational multivariate analysis of variance (PerMANOVA) [54]. When analyzing counts of abundances (which are often overdispersed), we calculated $\lg(x + 1)$ -transformed data prior to the perMANOVA [55]. The perMANOVA was implemented using the *Adonis* function of the 'vegan' package in R with the Bray–Curtis dissimilarity measure and 999 permutations for the compositional data [56]. Subsequently, we visualized the compositional data using non-metric multidimensional scaling of the Bray–Curtis dissimilarity measure. Moreover, we used indicator analyses to identify the arthropod orders that were associated with particular stand ages and sampling date combinations [57], computing the specificity (i.e., the positive predictive value of species as an indicator of a group) and sensitivity (i.e., the probability of identifying an arthropod belonging to the group) associated with each indicator value [57]. Spearman correlation analysis was used to examine the relationships between community or major group-level variables for soil arthropods, and environmental variables for the samples extracted in September.

3. Results

Stand age had a significant impact on soil arthropod total abundance, which was significantly higher in the 10-year-old stand (Table 1). Furthermore, stand age had an interaction with sampling date (Table S1). In June, the total abundance was highest in the 10-year-old stands and lowest in the 5-year-old stands. In September, the total abundance increased in the 5- to 21-year-old stands; however, the stand-age-dependent trends were less apparent in March and December (Figure 1a).

Dominant soil arthropod orders included Prostigmata mites (40%) and Oribatida mites (26.4%), followed by Hymenoptera (11.8%), Collembola (9.6%), and Diptera (7.2%). The others were Mesostigmata, Coleoptera, Araneae, Scolopendromorpha, Polydesmida, Thysanoptera, Siphonaptera, and Lepidoptera. The abundance of Prostigmata, Oribatida, and Diptera increased from the 5- to 21-year-old stands, with the highest level being in the 10-year-old stands, while the abundance of Collembola increased with stand development (Table 2). In addition, there were some interactions with the sampling dates. The abundance of Prostigmata revealed similar stand age and sampling date trends to those for total abundance. The abundance of Oribatida was higher in the 10-year-old stands than in the other stands for the March, June, and September sampling dates; however, this was not the case in December. The abundance of Hymenoptera (Formicidae) was highest in the 10-year-old stands in June; however, in September, it peaked in the 21-year-old stands. The abundance of Collembola increased with stand age in September and December; however, the effect of stand age was less apparent in March or June. The stand age and sampling date interaction had weak effects on the abundance of epedaphic Collembola (Table S1). The stand age or sampling date had no impact on the abundance of euedaphic and hemiedaphic Collembola. The abundance of Diptera (larvae) did not differ significantly with stand age.

Table 1. The abundance (ind m⁻²) of soil arthropod groups in the three stand ages.

Parameters	5 Year Old	10 Year Old	21 Year Old
Total abundance	7433.3 ± 1823.4 a	27,271.8 ± 5837.8 b	18,113.7 ± 2935.7 ab
Prostigmata	2454.9 ± 762.0 a	13,402.3 ± 3569.8 b	5241.5 ± 856.9 a
Oribatida	3118.4 ± 992.0 a	7099.3 ± 810.9 b	3781.8 ± 955.8 a
Mesostigmata	66.3 ± 66.3	530.8 ± 315.0	66.3 ± 66.3
Collembola	597.1 ± 199.0 a	1791.4 ± 450.4 ab	2653.9 ± 816.0 b
Epedaphic	265.4 ± 113.2	663.5 ± 165.0	1194.3 ± 443.7
Hemiedaphic	199.0 ± 142.9	597.1 ± 221.9	729.8 ± 206.9
Euedaphic	133.0 ± 89.5	530.8 ± 149.7	729.8 ± 267.6
Diptera	796.5 ± 240.0	1659.4 ± 494.8	1327.0 ± 436.1
Coleoptera	133.4 ± 89.4	199.0 ± 142.9	531.1 ± 246.8
Hymenoptera	0	2056.8 ± 1071.1	4179.9 ± 2165.2
Araneae	0	0	66.4 ± 66.3
Scolopendromorpha	66.7 ± 66.3	256.7 ± 149.6	0
Polydesmida	0.67 ± 0.45	133.4 ± 89.9	0.33 ± 0.33
Thysanoptera	66.3 ± 66.3	0.33 ± 0.33	66.3 ± 66.3
Siphonaptera	132.7 ± 89.4	0.33 ± 0.33	199.0 ± 199.0
Lepidoptera	0.33 ± 0.33	133.0 ± 89.4	0

Different lowercases letters indicate significant differences between stand ages at $\alpha = 0.05$.

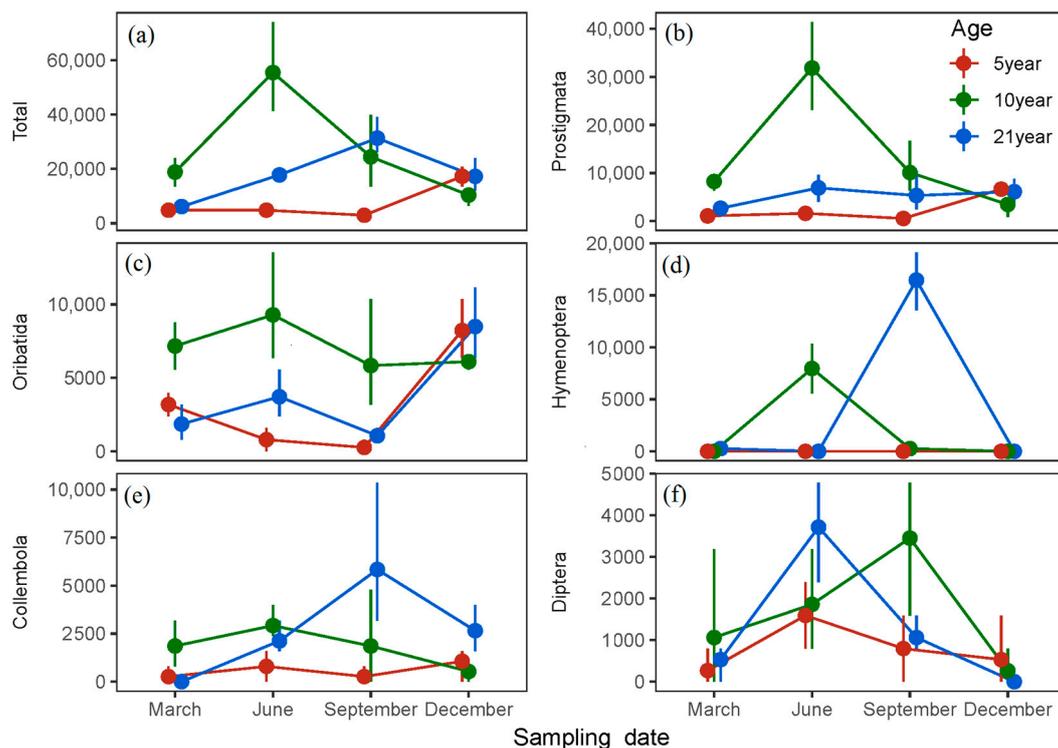


Figure 1. The effects of stand age and sampling date on the abundance (ind. m⁻²) of soil arthropods. Filled circles are bootstrapped means with 95% bootstrapped confidence intervals (error bars). Difference is statistically significant at $\alpha = 0.05$ when 95% bootstrapped confidence intervals do not overlap other means. (a–f) stands for the abundance of Total, Prostigmata, Oribatida, Hymenoptera, Collembola and Diptera, respectively.

In the 5-year-old stands (Figure 2), Oribatida, Prostigmata, and Diptera comprised the most abundant groups, accounting for 85.7% of the total abundance, followed by Collembola, Coleoptera, and Siphonaptera, which together accounted for 11.6% of the total abundance. Less abundant groups included (in a decreasing order of abundance), Scolopendromorpha, Mesostigmata, Thysanoptera, Polydesmida, Lepidoptera, Hymenoptera, and Araneae. In contrast to the 5-year-old stands,

the abundance levels of Prostigmata increased more than fivefold and twofold in the 10- and 21-year-old stands, respectively, and ranked highest among arthropod levels in the 10- and 21-year-old stands. Accordingly, the ranks of Oribatida transitioned to second and third from the top in the 10- and 21-year-old stands, respectively. The rank of Diptera was altered from third position in the 5-year-old stands, to fifth position in the 10- and 21-year-old stands. Hymenoptera emerged and ranked in third and second positions in the 10- and 21-year-old stands, respectively. The rank order of Collembola did not change in the three stand ages.

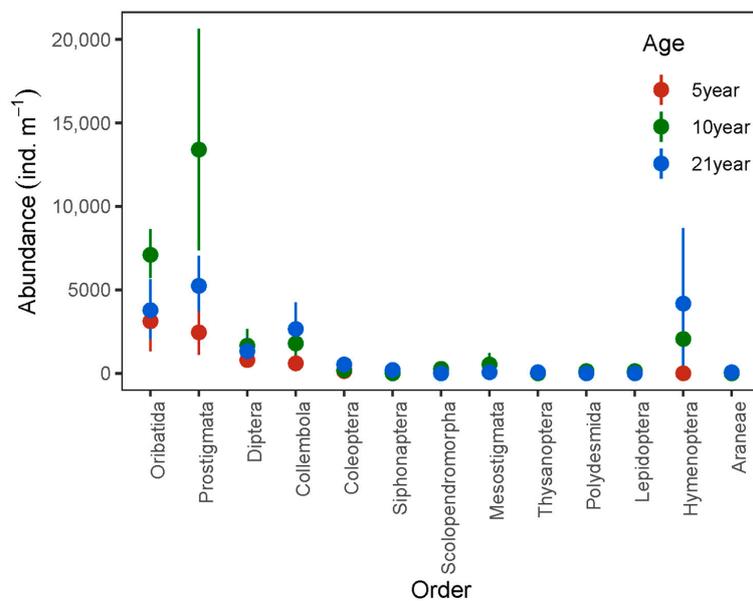


Figure 2. Rank-abundance of different arthropod orders. Filled circles are bootstrapped means, with 95% bootstrapped confidence intervals (error bars).

The diversity differences among the three stand ages can be seen in rarefaction and extrapolation curves with 95% bootstrapped confidence intervals (Figure 3). The similarities of richness ($q = 0$) among the three ages can be seen in the fact that the 95% confidence intervals all overlapped. The Shannon diversity ($q = 1$) and Simpson diversity ($q = 2$) differed between the 10- and 21-year-old stand ages. They showed an almost similar trend, and the highest and lowest values were recorded in the 21- and 10- year-old stands, respectively.

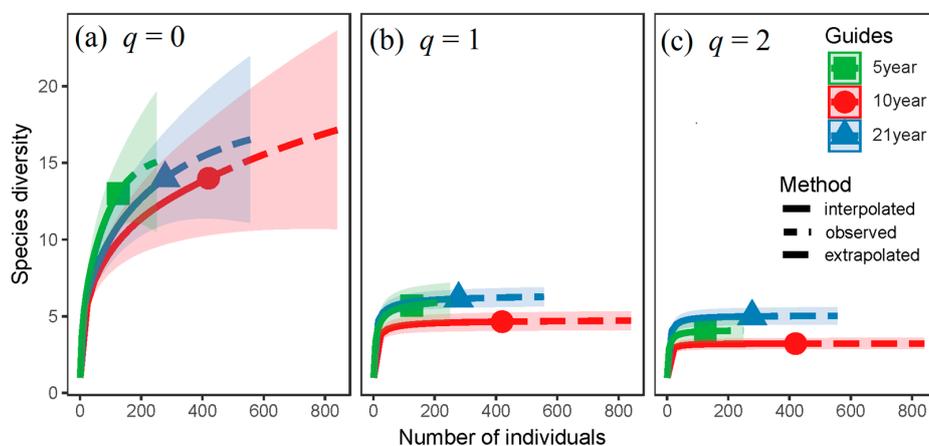


Figure 3. Sample size based rarefaction and extrapolation of soil arthropod diversity for Hill number (a) richness ($q = 0$), (b) Shannon diversity ($q = 1$), and (c) Simpson diversity ($q = 2$) with 95% bootstrapped confidence intervals (shaded areas).

PerMANOVA analysis revealed that the composition of arthropods differed significantly among stand ages, sampling dates, and their interactions, accounting for 56% of the observed variation (Table 2). The nonmetric multidimensional scaling ordination (NMDS) with a stress of 0.105 indicated that the arthropod composition of the 10-year-old stands in June was well-separated from that of the other stands (Figure 4). Among the sampling dates, the arthropod communities found in June and September were distinct from those found in March and December. Indicator analysis revealed that Scolopendromorpha and Prostigmata were indicators in June for the 10-year-old stands, while Collembola were indicators for the 21-year-old stands sampled in September (Table 3).

Table 2. Results of permutation multivariate analysis of variance testing (perMANOVA) for the effects of stand age (A), sampling date (D), and their interactions on soil arthropod Order composition.

Source	df	Sum Squares	F	R ²	p
A	2	0.26	2.05	0.08	0.04
D	3	1.01	5.27	0.29	0.001
A × D	6	0.69	1.79	0.19	0.015
Residuals	24	1.53		0.44	

Table 3. Indicators for stand ages and overstory types.

Stand Age (Years)	Date	Indicator	Indicator Value	Specificity	Sensitivity	p
10	June	Scolopendromorpha	0.800	1.00	0.894	0.005
10	June	Prostigmata	0.377	1.00	0.614	0.001
21	September	Collembola	0.290	1.00	0.538	0.035

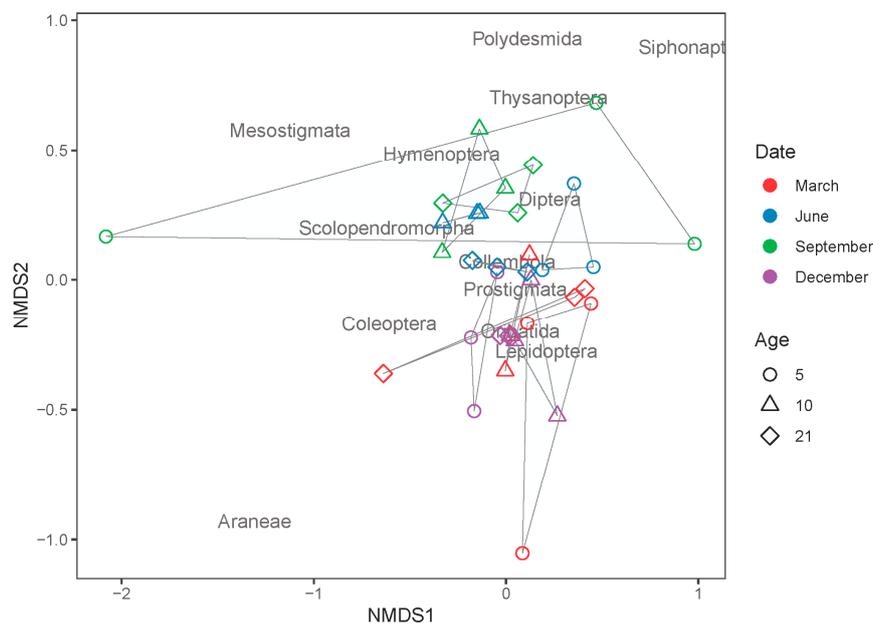


Figure 4. Nonmetric multidimensional scaling ordination (NMDS) showing a two-dimensional representation of the soil arthropod composition. The best NMDS solution was attained at a stress of 0.105. The circles nearest each other in the ordination space have similar assemblages, whereas those located farther apart are less similar.

Environmental variables differed with stand development (Table 4). Significant differences were observed in the top 0–10 cm of soil. Aboveground plant species richness and plant coverage were higher in the 10-year-old stand (Table 4). The Spearman correlation (Table 5) showed that the total abundance of Oribatida was correlated with soil moisture and plant coverage ($p < 0.05$). Prostigmata abundance was significantly correlated with soil moisture and nitrogen, while Collembola was correlated with

nitrogen. Multiple correlation results revealed that the abundance of the soil arthropod community was primarily related to soil variables.

Table 4. Stand characteristics ($n = 3$) along an age chronosequence of poplar plantations in a coastal region of Eastern China.

Dimension	Characteristics	5 Year Old	10 Year Old	21 Year Old
Aboveground	DBH (cm)	16.50 ± 1.63 c	26.04 ± 0.46 b	32.77 ± 1.48 a
	Plant species richness	19.0 ± 0.58 ab	23.0 ± 1.52 a	17.3 ± 3.79 b
	Plant coverage (%)	75.37 ± 3.87 a	91.1 ± 2.74 b	77.5 ± 4.22 a
0–10 cm soil	Moisture (%)	19.74 ± 0.79 b	24.88 ± 0.36 a	23.61 ± 1.43 a
	pH	8.25 ± 0.12	8.09 ± 0.11	8.03 ± 0.09
	N (g kg ⁻¹)	1.69 ± 0.04 b	2.10 ± 0.06 a	2.24 ± 0.02 a
	C (g kg ⁻¹)	17.05 ± 0.23	17.25 ± 0.30	18.26 ± 0.35
10–20 cm soil	Moisture (%)	19.25 ± 0.2 b	24.6 ± 0.27 a	23.59 ± 1.11 a
	pH	8.35 ± 0.06	8.31 ± 0.13	8.29 ± 0.13
	N (g kg ⁻¹)	1.66 ± 0.02 b	1.93 ± 0.05 a	1.97 ± 0.07 a
	C (g kg ⁻¹)	16.07 ± 0.23	16.27 ± 0.30	16.09 ± 0.35

Different lowercase letters indicate significant differences between stand ages at $\alpha = 0.05$. DBH: Diameters at breast height.

Table 5. Correlation between abundance of soil arthropods and soil characteristics. Values are Spearman correlation coefficients.

Parameters	Plant Species Richness	Plant Coverage	Moisture	pH	C	N
Total abundance	0.11	0.10	0.55 *	−0.37	0.51 *	0.75 ***
Prostigmata	0.24	0.31	0.59 **	−0.18	0.08	0.47 *
Oribatida	0.39	0.54 *	0.52 *	−0.02	0.04	0.33
Hymenoptera	−0.38	−0.15	0.22	−0.38	0.71 **	0.63 **
Collembola	−0.39	−0.29	0.28	−0.40	0.41	0.56 *
Diptera	0.29	0.33	0.34	0.23	−0.53 *	−0.1

Statistical significance: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

4. Discussion

We found that the abundance and composition of soil arthropod communities were strongly affected by stand age and sampling date in the poplar plantations. On average, the total abundance increased from the 5-year-old to the 10-year-old stands, while remaining similar, or declining, in the 21-year-old stands. The soil arthropod assemblage composition in the 10-year-old stands was well-separated from that of the other two stand ages. The sampling dates explained a similar or greater variation in the abundance and composition of the soil arthropods with their interactions, which accounted for more than the sum of the primary effects and revealed that stand age-associated trends were strongly dependent on the sampling date. These findings supported our expectations that soil arthropod abundance and composition were altered with stand development.

Our findings partially supported previous results on the abundance and diversity of soil arthropods that were associated with forest stand development [20,25–27]. For our study, only Shannon and Simpson diversity of soil arthropods changed across the plantation chronosequence. The distribution of mites, particularly Oribatida, was also in contrast with that recorded in a spruce plantation in northern Germany [58], where no differences in Oribatida abundance between development phases were observed, while [26] found that the Oribatida density increased from that in 5- to that in 25-year-old stands in Tharandter Wald, Germany. However, a direct comparison of stand-age-associated trends, between our study and those published earlier, was rather difficult due to the available stand ages for sampling and the role of vegetation types in soil resources. The physical conditions and quality of soil and organic matter are known to impact soil faunal communities [33]. Soil fauna populations

appeared to be lower when the uptake of water and nutrients were greatest during the stem exclusion stage, leaving fewer resources available for soil fauna [28,59].

In our study system, the available nitrogen tended to be higher in the 10-year-old stands than in the other stands (Table 1), and published data have demonstrated that microbial biomass carbon exhibited the same trend [16]. There was also a strong relationship between the total abundance and soil properties [17], but we lacked the litter data required to analyze the correlation between the litter quantity and soil arthropod activities. Their abundance may have been more strongly impacted by soil properties than by the plant community [22,60]. For this study, plant species richness and plant coverage were higher in the 10-year-old stands (Table 4), which not only prevented UV damage to soil arthropods, but also supplied them with improved living conditions. Thus, the soil properties and habitat conditions may have contributed to the higher total abundance of soil arthropods observed in the 10-year-old stands than in the 5- and 21-year-old stands. Formicidae were only captured in the 10- and 21-year-old stands in June and September, respectively. Ants are not only herbivores and predominant in older fragments [20,61], but are also predators [62]. Our finding of peak total abundance in the 10-year-old stands suggested that arthropod abundance could peak at an intermediate stage of stand development in these poplar plantations. The peak of abundance in an intermediate stand age may be the result of compositional shifts, from pioneer to mature species, or in conjunction with stand development [63]. Indeed, our compositional analysis supported the premise that the composition of soil arthropods shifted along the chronosequence.

Supporting our second hypothesis, the responses of soil arthropod assemblages to stand development varied widely by sampling date. The effects of stand age were more pronounced during the warm and wet seasons than in the cold and dry seasons. These findings are consistent with the results from desertified steppes [20] and dry tropical forests [64]. As poplar forests are deciduous, there was little difference in the canopy cover among the three age groups of stands in winter; thus, the microclimatic conditions were likely to be similar during this period. However, favorable climatic conditions in summer, combined with differences in soil moisture and nutrient availabilities [22,65,66], contributed to the higher abundance and distinct community composition in the 10-year-old stands.

The compositions of arthropod communities in June and September were distinct from those surveyed in March and December. Previous studies reported that soil arthropod abundance was directly or indirectly influenced by changing climate factors, such as solar radiation [24], temperature [67,68], precipitation [69], and moisture [70,71], among which soil moisture was found to be the most important factor in the control of soil arthropod communities [64]. In our study area, the precipitation and temperature both increased from December to June, and attained their highest levels in September (Figure S1). This observation suggests that June or September provides the most suitable climate conditions for soil arthropods in the study area. However, we could not attribute the observed seasonal dynamics of soil arthropods to strong climate seasonality due to a lack of sufficient field data for testing in our study.

The increase in total abundance with stand development largely resulted from the higher number of Collembola in September. This result is similar to previous findings in beech and spruce forests [72]. Collembola feed predominantly on plant detritus and fungi, with a preference for fungi [73,74], whose biomass increases with stand development [24]. In this study, the increased abundance of euedaphic Collembola with stand age in September may be attributable to the N content, as high N availability might increase the availability of potential food sources (e.g., fungal biomass) for euedaphic Collembola [46]. Further, the population of centipedes increased with the higher accumulation of litter and prey [75]. Since centipedes prey on Collembola [76,77], they were an indicator for the 10-year-old stands sampled in June for this study. It appeared that predation by centipedes was responsible for the fewer Collembola in the 10-year-old stands compared with in the 21-year-old stands by the next sampling date (September).

5. Conclusions

In summary, the total abundance was higher, on average, in the 10-year-old stands during the summer months, with potent interactive effects between the stand age and sampling date. Further, the soil arthropod community composition differed strongly with changing sampling date and stand age, with the 10-year-old stands sampled in June being well-separated from the others. The responses of soil arthropod assemblages to stand development were most pronounced during the warm and wet summer seasons. Indicator analysis revealed that Scolopendromorpha and Prostigmata were indicators for the 10-year-old stands sampled in June, while Collembola were indicators for the 21-year-old stands sampled in September. To elucidate the mechanisms that initiated these changes, more detailed work should be done in the next phases of study, particularly on individual taxonomic soil arthropod groups or functional groups; however, these findings will provide valuable guidelines for plantation managers, considering the conservation of biodiversity in reclaimed coastal saline soil hosting managed poplar plantations.

Supplementary Materials: The following are available online at <http://www.mdpi.com/1999-4907/9/10/644/s1>, Figure S1: Total precipitation (mm) and mean temperature (°C) three months prior to sampling dates in the study area, during 2013–2014. The data are from the local meteorological station, Table S1: The effects of stand age (A) and sampling date (D) on the abundance of total groups and major groups.

Author Contributions: H.R. and Y.L. conceived and designed the experiments; Y.L., Q.S., J.L., Z.X., and S.H. performed the experiments; H.Y.H.C., Y.L., and J.L. analyzed the data; Y.L. and H.Y.H.C. wrote the manuscript; and all co-authors edited numerous drafts.

Funding: This study was supported by the National Key Research and Development Program of China (No. 2016YFD0600204) and Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD).

Acknowledgments: We gratefully acknowledge and thank David C. Coleman for his review and revision of this paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Grgič, T.; Kos, I. Influence of forest development phase on centipede diversity in managed beech forests in Slovenia. *Biodivers. Conserv.* **2005**, *14*, 1841–1862. [[CrossRef](#)]
2. Cakir, M.; Makineci, E. Humus characteristics and seasonal changes of soil arthropod communities in a natural sessile oak (*Quercus petraea* L.) stand and adjacent Austrian pine (*Pinus nigra* Arnold) plantation. *Environ. Monit. Assess.* **2013**, *185*, 8943–8955. [[CrossRef](#)] [[PubMed](#)]
3. Cortet, J.; Vauflery, A.G.; Poinsothalaguer, N.; Gomot, L.; Texier, C.; Cluzeau, D. The use of invertebrate soil fauna in monitoring pollutant effects. *Eur. J. Soil Biol.* **1999**, *35*, 115–134. [[CrossRef](#)]
4. 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. [[CrossRef](#)] [[PubMed](#)]
5. Mace, G.M.; Norris, K.; Fitter, A.H. Biodiversity and ecosystem services: A multilayered relationship. *Trends Ecol. Evol.* **2012**, *27*, 19–26. [[CrossRef](#)] [[PubMed](#)]
6. De Deyn, G.B.; Van der Putten, W.H. Linking aboveground and belowground diversity. *Trends Ecol. Evol.* **2005**, *20*, 625–633. [[CrossRef](#)] [[PubMed](#)]
7. Fu, S.; Coleman, D.C.; Hendrix, P.F.; Crossley, D.A. Responses of trophic groups of soil nematodes to residue application under conventional tillage and no-till regimes. *Soil Biol. Biochem.* **2000**, *32*, 1731–1741. [[CrossRef](#)]
8. Siemann, E. Experimental tests of effects of plant productivity and diversity on grassland arthropod diversity. *Ecology* **1998**, *79*, 2057–2070. [[CrossRef](#)]
9. Hansen, R.A. Effect of habitat complexity and composition on a diverse litter microarthropod assemblage. *Ecology* **2000**, *81*, 1120–1132. [[CrossRef](#)]
10. Callahan, M.A.; Richter, D.D.; Coleman, D.C.; Hofmockel, M. Long-term land-use effects on soil invertebrate communities in Southern Piedmont soils, USA. *Eur. J. Soil Biol.* **2006**, *42*, S150–S156. [[CrossRef](#)]
11. 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**, *422*, 711–713. [[CrossRef](#)] [[PubMed](#)]

12. Li, J.; Pu, L.; Zhu, M.; Zhang, J.; Li, P.; Dai, X.; Xu, Y.; Liu, L. Evolution of soil properties following reclamation in coastal areas: A review. *Geoderma* **2014**, *226–227*, 130–139. [[CrossRef](#)]
13. Sun, Y.; Li, X.; Mander, Ü.; He, Y.; Jia, Y.; Ma, Z.; Guo, W.; Xin, Z. Effect of reclamation time and land use on soil properties in Changjiang River Estuary, China. *Chin. Geogr. Sci.* **2011**, *21*, 403–416. [[CrossRef](#)]
14. Brais, S.; Camiré, C.; Bergeron, Y.; Paré, D. Changes in nutrient availability and forest floor characteristics in relation to stand age and forest composition in the southern part of the boreal forest of northwestern Quebec. *For. Ecol. Manag.* **1995**, *76*, 181–189. [[CrossRef](#)]
15. Binkley, D.; Valentine, D.W.; Wells, C.G.; Valentine, U. An empirical analysis of the factors contributing to 20-year decrease in soil pH in an old-field plantation of loblolly pine. *Biogeochemistry* **1989**, *8*, 39–54. [[CrossRef](#)]
16. Ge, Z.; Fang, S.; Chen, H.; Zhu, R.; Peng, S.; Ruan, H. Soil aggregation and organic carbon dynamics in poplar plantations. *Forests* **2018**, *9*, 508. [[CrossRef](#)]
17. Wang, S.; Chen, H.Y.H.; Tan, Y.; Fan, H.; Ruan, H. Fertilizer regime impacts on abundance and diversity of soil fauna across a poplar plantation chronosequence in coastal Eastern China. *Sci. Rep.* **2016**, *6*, 20816. [[CrossRef](#)] [[PubMed](#)]
18. Chen, H.Y.H.; Biswas, S.R.; Sobey, T.M.; Brassard, B.W.; Bartels, S.F.; Mori, A. Reclamation strategies for mined forest soils and overstorey drive understorey vegetation. *J. Appl. Ecol.* **2018**, *55*, 926–936. [[CrossRef](#)]
19. Jucevica, E.; Melecis, V. Global warming affect Collembola community: A long-term study. *Pedobiologia* **2006**, *50*, 177–184. [[CrossRef](#)]
20. Liu, R.; Zhu, F.; Song, N.; Yang, X.; Chai, Y. Seasonal distribution and diversity of ground arthropods in microhabitats following a shrub plantation age sequence in desertified steppe. *PLoS ONE* **2013**, *8*, e77962. [[CrossRef](#)]
21. Basset, Y.; Cizek, L.; Cuenoud, P.; Didham, R.K.; Novotny, V.; Odegaard, F.; Roslin, T.; Tishechkin, A.K.; Schmidl, J.; Winchester, N.N.; et al. Arthropod distribution in a tropical rainforest: Tackling a four dimensional puzzle. *PLoS ONE* **2015**, *10*, e0144110. [[CrossRef](#)] [[PubMed](#)]
22. Wu, P.; Liu, X.; Liu, S.; Wang, J.; Wang, Y. Composition and spatio-temporal variation of soil microarthropods in the biodiversity hotspot of northern Hengduan Mountains, China. *Eur. J. Soil Biol.* **2014**, *62*, 30–38. [[CrossRef](#)]
23. Eisenbeis, G.; Wichard, W. *Atlas on the Biology of Soil Arthropods*; Springer Science & Business Media: New York, NY, USA, 2012.
24. Salmon, S.; Artuso, N.; Frizzera, L.; Zampedri, R. Relationships between soil fauna communities and humus forms: Response to forest dynamics and solar radiation. *Soil Biol. Biochem.* **2008**, *40*, 1707–1715. [[CrossRef](#)]
25. Salmon, S.; Mantel, J.; Frizzera, L.; Zanella, A. Changes in humus forms and soil animal communities in two developmental phases of Norway spruce on an acidic substrate. *For. Ecol. Manag.* **2006**, *237*, 47–56. [[CrossRef](#)]
26. Zaitsev, A. Oribatid mite diversity and community dynamics in a spruce chronosequence. *Soil Biol. Biochem.* **2002**, *34*, 1919–1927. [[CrossRef](#)]
27. Bokhorst, S.; Wardle, D.A.; Nilsson, M.-C.; Gundale, M.J. Impact of understory mosses and dwarf shrubs on soil micro-arthropods in a boreal forest chronosequence. *Plant Soil* **2014**, *379*, 121–133. [[CrossRef](#)]
28. Miller, H.G. Forest fertilization: Some guiding concepts. *Forestry* **1981**, *54*, 157–167. [[CrossRef](#)]
29. Scheu, S.; Albers, D.; Alpehi, J.; Buryan, R.; Klages, U.; Migge, S.; Platner, C.; Salamon, J.-A. The soil fauna community in pure and mixed stands of beech and spruce of different age: Trophic structure and structuring forces. *Oikos* **2003**, *101*, 225–238. [[CrossRef](#)]
30. Magura, T.; Bogyó, D.; Mizser, S.; Nagy, D.D.; Tóthmérész, B. Recovery of ground-dwelling assemblages during reforestation with native oak depends on the mobility and feeding habits of the species. *For. Ecol. Manag.* **2015**, *339*, 117–126. [[CrossRef](#)]
31. Scheu, S. Plants and generalist predators as links between the below-ground and above-ground system. *Basic Appl. Ecol.* **2001**, *2*, 3–13. [[CrossRef](#)]
32. Seastedt, T.R. The role of microarthropods in decomposition and mineralization processes. *Ann. Rev. Entomol.* **1984**, *29*, 25–46. [[CrossRef](#)]
33. Vasconcellos, R.L.F.; Segat, J.C.; Bonfima, J.A.; Baretta, D.; Cardoso, E.J.B.N. Soil macrofauna as an indicator of soil quality in an undisturbed riparian forest and recovering sites of different ages. *Eur. J. Soil Biol.* **2013**, *58*, 105–112. [[CrossRef](#)]

34. Kardol, P.; Reynolds, W.N.; Norby, R.J.; Classen, A.T. Climate change effects on soil microarthropod abundance and community structure. *Appl. Soil Ecol.* **2011**, *47*, 37–44. [[CrossRef](#)]
35. Wiwatwitaya, D.; Takeda, H. Seasonal changes in soil arthropod abundance in the dry evergreen forest of north-east Thailand, with special reference to collembolan communities. *Ecol. Res.* **2004**, *20*, 59–70. [[CrossRef](#)]
36. Lindberg, N.; Bengtsson, J. Population responses of oribatid mites and collembolans after drought. *Appl. Soil Ecol.* **2005**, *28*, 163–174. [[CrossRef](#)]
37. Pflug, A.; Wolters, V. Influence of drought and litter age on Collembola communities. *Eur. J. Soil Biol.* **2001**, *37*, 305–308. [[CrossRef](#)]
38. Sartori, F.; Lal, R.; Ebinger, M.H.; Eaton, J.A. Changes in soil carbon and nutrient pools along a chronosequence of poplar plantations in the Columbia Plateau, Oregon, USA. *Agric. Ecosyst. Environ.* **2007**, *122*, 325–339. [[CrossRef](#)]
39. Wang, H.; Xu, Y.; Zhang, J.; Zhang, Y.; Yang, X. Study on soil improvement effect of the *Populus tomentosa* pure forest of saline land on the muddy sea-coast in northern Jiangsu Province. *Sci. Soil Water Conserv.* **2013**, *11*, 65–68. (In Chinese)
40. Mueller-Dombois, D.; Ellenberg, H. *Aims and Methods of Vegetation Ecology*; John Wiley & Sons: Toronto, ON, Canada, 1974.
41. Decaëns, T.; Dutoit, T.; Alard, D.; Lavelle, P. Factors influencing soil macrofaunal communities in post-pastoral successions of western France. *Appl. Soil Ecol.* **1998**, *9*, 361–367. [[CrossRef](#)]
42. Yin, W.Y. *Pictorial Keys to Soil Animals of China*; Science Press: Beijing, China, 1998. (In Chinese)
43. Gkisakis, V.D.; Kollaros, D.; Barberi, P.; Livieratos, I.C.; Kabourakis, E.M. Soil arthropod diversity in organic, integrated, and conventional olive orchards and different agroecological zones in Crete, Greece. *Agroecol. Sustain. Food Syst.* **2015**, *39*, 276–294. [[CrossRef](#)]
44. Cotes, B.; Campos, M.; Pascual, F.; García, P.A.; Ruano, F. Comparing taxonomic levels of epigeal insects under different farming systems in Andalusian olive agroecosystems. *Appl. Soil Ecol.* **2010**, *44*, 228–236. [[CrossRef](#)]
45. Biaggini, M.; Consorti, R.; Dapporto, L.; Dellacasa, M.; Paggetti, E.; Corti, C. The taxonomic level order as a possible tool for rapid assessment of arthropod diversity in agricultural landscapes. *Agric. Ecosyst. Environ.* **2007**, *122*, 183–191. [[CrossRef](#)]
46. Salamon, J.-A.; Wissuwa, J.; Moder, K.; Frank, T. Effects of *Medicago sativa*, *Taraxacum officinale* and *Bromus sterilis* on the density and diversity of Collembola in grassy arable fallows of different ages. *Pedobiologia* **2011**, *54*, 63–70. [[CrossRef](#)]
47. Chauvat, M.; Zaitsev, A.S.; Wolters, V. Successional changes of Collembola and soil microbiota during forest rotation. *Oecologia* **2003**, *137*, 269–276. [[CrossRef](#)] [[PubMed](#)]
48. Chao, A.; Gotelli, N.J.; Hsieh, T.C.; Sander, E.L.; Ma, K.H.; Colwell, R.K.; Ellison, A.M. Rarefaction and extrapolation with Hill numbers: A framework for sampling and estimation in species diversity studies. *Ecol. Monogr.* **2014**, *84*, 45–67. [[CrossRef](#)]
49. Colwell, R.K.; Chao, A.; Gotelli, N.J.; Lin, S.Y.; Mao, C.X.; Chazdon, R.L.; Longino, J.T. Models and estimators linking individual-based and sample-based rarefaction, extrapolation and comparison of assemblages. *J. Plant Ecol.* **2012**, *5*, 3–21. [[CrossRef](#)]
50. Hsieh, T.C.; Ma, K.H.; Chao, A.; McInerny, G. iNEXT: An R package for rarefaction and extrapolation of species diversity (Hill numbers). *Methods Ecol. Evol.* **2016**, *7*, 1451–1456. [[CrossRef](#)]
51. Bates, D.; Bolker, B.; Walker, S.; Christensen, R.H.B.; Singmann, H.; Dai, B.; Grothendieck, G. lme4: Linear Mixed-Effects Models Using Eigen and S4. R Package; Version 1.1-13. Available online: <https://cran.r-project.org/web/packages/lme4/index.html> (accessed on 1 September 2016).
52. Canty, A.; Ripley, B. Package 'boot', Version 1.3-19; Available online: <https://cran.r-project.org/web/packages/boot/index.html> (accessed on 11 February 2017).
53. Wickham, H.; Chang, W. *ggplot2: Create Elegant Data Visualisations Using the Grammar of Graphics*; Version 2.2.1; Springer: New York, NY, USA, 2016.
54. Anderson, M.J. A new method for non-parametric multivariate analysis of variance. *Austral Ecol.* **2001**, *26*, 32–46.
55. Anderson, M.J.; Crist, T.O.; Chase, J.M.; Vellend, M.; Inouye, B.D.; Freestone, A.L.; Sanders, N.J.; Cornell, H.V.; Comita, L.S.; Davies, K.F.; et al. Navigating the multiple meanings of beta diversity: A roadmap for the practicing ecologist. *Ecol. Lett.* **2011**, *14*, 19–28. [[CrossRef](#)] [[PubMed](#)]

56. Oksanen, J.; Blanchet, F.G.; Friendly, M.; Kindt, R.; Legendre, P.; McGlinn, D.; Minchin, P.R.; O'Hara, R.B.; Simpson, G.L.; Solymos, P.; et al. vegan: Community Ecology Package. Available online: <https://cran.r-project.org/web/packages/vegan/index.html> (accessed on 7 April 2017).
57. De Caceres, M.; Jansen, F. Package 'Indicspecies'. Available online: <https://cran.r-project.org/web/packages/indicspecies/indicspecies.pdf> (accessed on 30 August 2016).
58. Miggea, S.; Maraun, M.; Scheu, S.; Schaefer, M. The oribatid mite community (Acarina) of pure and mixed stands of beech (*Fagus sylvatica*) and spruce (*Picea abies*) of different age. *Appl. Soil Ecol.* **1998**, *9*, 115–121. [[CrossRef](#)]
59. Berg, M.P.; Hemerik, L. Secondary succession of terrestrial isopod, centipede, and millipede communities in grasslands under restoration. *Biol. Fertil. Soils* **2004**, *40*, 163–170. [[CrossRef](#)]
60. Wu, P.; Liu, S.; Liu, X. Composition and spatio-temporal changes of soil macroinvertebrates in the biodiversity hotspot of northern Hengduanshan Mountains, China. *Plant Soil* **2012**, *357*, 321–338. [[CrossRef](#)]
61. Sanders, N.J.; Gotelli, N.J.; Wittman, S.E.; Ratchford, J.S.; Ellison, A.M.; Jules, E.S. Assembly rules of ground-foraging ant assemblages are contingent on disturbance, habitat and spatial scale. *J. Biogeogr.* **2007**, *34*, 1632–1641. [[CrossRef](#)]
62. Letourneau, D.K.; Dyer, L.A.; Burslem, D.; Pinard, M.; Hartley, S. Multi-trophic interactions and biodiversity: Beetles, ants, caterpillars, and plants. In *Biotic Interactions in the Tropics: Their Role in the Maintenance of Species Diversity*; Cambridge University Press: Cambridge, UK, 2005; pp. 366–385.
63. Connell, J.H. Diversity in tropical rain forests and coral reefs—High diversity of trees and corals is maintained only in a non-equilibrium state. *Science* **1978**, *199*, 1302–1310. [[CrossRef](#)] [[PubMed](#)]
64. Peña-Peña, K.; Irmeler, U. Moisture seasonality, soil fauna, litter quality and land use as drivers of decomposition in Cerrado soils in SE-Mato Grosso, Brazil. *Appl. Soil Ecol.* **2016**, *107*, 124–133. [[CrossRef](#)]
65. González, G.; Seastedt, T.R. Comparison of the abundance and composition of litter fauna in tropical and subalpine forests. *Pedobiologia* **2000**, *44*, 545–555. [[CrossRef](#)]
66. Wang, S.; Tan, Y.; Fan, H.; Ruan, H.; Zheng, A. Responses of soil microarthropods to inorganic and organic fertilizers in a poplar plantation in a coastal area of eastern China. *Appl. Soil Ecol.* **2015**, *89*, 69–75. [[CrossRef](#)]
67. Berthe, S.C.F.; Derocles, S.A.P.; Lunt, D.H.; Kimball, B.A.; Evans, D.M. Simulated climate-warming increases Coleoptera activity-densities and reduces community diversity in a cereal crop. *Agric. Ecosyst. Environ.* **2015**, *210*, 11–14. [[CrossRef](#)]
68. Bokhorst, S.; Huiskes, A.H.; Convey, P.; Van Bodegom, P.M.; Aerts, R. Climate change effects on soil arthropod communities from the Falkland Islands and the Maritime Antarctic. *Soil Biol. Biochem.* **2008**, *40*, 1547–1556. [[CrossRef](#)]
69. Frampton, G.K.; Brink, P.J.V.D.; Gould, P.J.L. Effects of spring drought and irrigation on farmland and arthropods in southern Britain. *J. Appl. Ecol.* **2000**, *37*, 865–883. [[CrossRef](#)]
70. Kaneda, S.; Kaneko, N. Influence of Collembola on nitrogen mineralization varies with soil moisture content. *Soil Sci. Plant Nutr.* **2011**, *57*, 40–49. [[CrossRef](#)]
71. Chikoski, J.M.; Ferguson, S.H.; Meyer, L. Effects of water addition on soil arthropods and soil characteristics in a precipitation-limited environment. *Acta Oecol.* **2006**, *30*, 203–211. [[CrossRef](#)]
72. Salamon, J.-A.; Scheu, S.; Schaefer, M. The Collembola community of pure and mixed stands of beech (*Fagus sylvatica*) and spruce (*Picea abies*) of different age. *Pedobiologia* **2008**, *51*, 385–396. [[CrossRef](#)]
73. Rotheray, T.D.; Boddy, L.; Jones, T.H. Collembola foraging responses to interacting fungi. *Ecol. Entomol.* **2009**, *34*, 125–132. [[CrossRef](#)]
74. Jonas, J.L.; Wilson, G.W.T.; White, P.M.; Joern, A. Consumption of mycorrhizal and saprophytic fungi by Collembola in grassland soils. *Soil Biol. Biochem.* **2007**, *39*, 2594–2602. [[CrossRef](#)]
75. Chen, B.R.; Wise, D.H. Bottom-up limitation of predaceous arthropods in a detritus-based terrestrial food web. *Ecology* **1999**, *80*, 761–772. [[CrossRef](#)]
76. Lewis, J.G.E. *The Biology of Centipedes*; Cambridge University Press: Cambridge, UK, 1981.
77. Gao, M.; Taylor, M.K.; Callahan, M.A. Trophic dynamics in a simple experimental ecosystem: Interactions among centipedes, Collembola and introduced earthworms. *Soil Biol. Biochem.* **2017**, *115*, 66–72. [[CrossRef](#)]

