SILVA FENNICA

Guoping Chen[1], Cong Shi[2], Shanshan Cheng[3], Tiejian Zhao[4], Guoquan Liu[4] and Fuchen Shi[1]

The structure and soil characteristics of a *Pinus tabuliformis* planted forest after 60 years of natural development in North China

Highlights

- Increasing proportions of broadleaf tree species was shown to affect nutrient content of the forest floor and soil, and the soil microbial community in the process of natural development of *Pinus tabuliformis* planted forest. In this regard, this study can act as a reference for management of the near-natural transformation of *P. tabuliformis* planted forests and for the choice of the tree species used.

Abstract

This study evaluated the transformation of a *Pinus tabuliformis* Carrière forest into a near-natural forest after 60 years of natural development. The structure and soil characteristics of *P. tabuliformis* planted forest, the near-natural forest (coniferous-broadleaved *P. tabuliformis* mixed forest), and secondary forest (*Quercus mongolica* Fisch. ex Ledeb. forest) were compared. Tree, shrub and herb species diversity of the mixed and *Q. mongolica* forests was higher than that of the planted *P. tabuliformis* forest. Examination of soil characteristics revealed that compared to the pure pine forest, nitrogen (N) and phosphorus (P) concentrations of the mixed and *Q. mongolica* forests increased in the forest floor and soil, but total carbon (C) concentration decreased in the forest floor, countered by increases in the soil. Furthermore, soil cation exchange capacity (CEC) and pH in the *P. tabuliformis* forest increased when deciduous broadleaved species were present. Total microbial biomass and bacterial biomass in the soils were greatest in the *Q. mongolica* forest, followed by the mixed, and then the *P. tabuliformis* forests. However, fungal biomass did not significantly differ among the three forests. Overall, the findings of this study suggest that different forest types can affect soil microbial biomass and community structure. Meanwhile, the natural development is recommended as a potential management alternative to near-natural transformation of a *P. tabuliformis* planted forest.

1 Introduction

In an effort to address current ecological concerns, large-scale national projects have been implemented in China over the decades to restore degraded land, primarily through afforestation and reforestation (Zhang et al. 2000). Currently, 31.8%, or 62 million hectares, of forest area in China is planted forest, which is the most of any country in the world (State Forest Administration 2010). The ecological environment has considerably improved through the afforestation. However, it has been recognized that monocultures and unreasonable stand structure of planted forests have inevitable disadvantages, which include low biodiversity, poor stress-resistance and stability, and forest degradation as compared to natural forests (Zhang et al. 2000; Shi et al. 2013). To overcome these disadvantages and improve ecosystem functioning of planted forests, near-natural transformations of planted forests have been implemented in many regions of the world (Lu 2006). This new silvicultural system transforms planted forests into near-native forests according to natural forest succession processes that are designed specifically to enhance biodiversity, improve forest structure, sustain ecosystem functions (diversity, productivity and nutrient cycling), and identifies sustainable levels of use for a broad range of renewable resources (Nakamura et al. 2005; Zhang et al. 2000).

Current management practices used to implement near-natural transformations of planted forests include selective logging (He et al. 2013; Luo et al. 2013), thereby creating gaps (Rouvinen and Kouki 2011; Wang and Liu 2011), and encouraging the establishment of broad-leaved species in mixtures with conifers. The broadleaved trees used in this process are primarily native species (Lu 2006). The near-natural transformation of conifer planted forests can change the composition and structure of forests and enhance biodiversity as has been shown for *Pinus massoniana* Lamb. (Luo et al. 2013), *Cryptomeria japonica* (Thunb. ex L. f.) D. Don (Taki et al. 2010), *Cunninghamia lanceolata* (Lamb.) Hook. (He et al. 2013), and *Pinus tabuliformis* Carrière (Wang and Liu 2011) plantations.

P. tabuliformis is the main afforestation tree species in large areas north of the Yangtze River basin, and it is also distributed in Japan, Korea, and parts of Russia (Shi et al. 2013). This predominance makes the near-natural transformation of *P. tabuliformis* forest important. Recently, through the management methods of selective logging and gap creation, the composition, structure, and diversity of *P. tabuliformis* forests have been improved significantly (Ning et al. 2009; Wang and Liu 2011). How the composition, structure, and diversity of *P. tabuliformis* planted forests change after 60 years of natural development is not well documented.

Moreover, only a few studies have considered how stand conversion influence soil physical and chemical properties, and microbial communities in these near-natural forests. Soil microorganisms play a key role in the cycling of nutrients and decomposition of soil organic matter in soil ecosystems and are one of the most studied indicators of soil quality (Ritz et al. 2009). One factor that strongly influences soil microbial communities is litter quality (Sayer 2006). A change in litter quality can affect the population dynamics and community structure of soil microorganisms by altering the supply of nutrients, affecting the microclimate and pH at the soil surface, and releasing chemical compounds (Hättenschwiler et al. 2005; Wardle et al. 2006; Sayer 2006; Zhao et al. 2013). Therefore, the effects of changes in litter quality [e.g., carbon (C), nitrogen (N), phosphorus (P), C/N ratio] on soil physicochemical properties, microbial biomass, and community structure were included as part of this investigation.

This study was conducted in the Baxian Mountain National Nature Reserve in North China. The predominant tree species in the secondary forest included *Quercus mongolica* Fisch. ex Ledeb., *Quercus variabilis* Blume, *Quercus aliena* Blume, *Juglans mandshurica* Maxim., and *Carpinus turczaninowii* Hance amongst others, whereas *P. tabuliformis* (planted in the 1950s) was the primary

species in the planted forest. After decades of natural development, broadleaved tree species have appeared in the *P. tabuliformis* forest, forming a coniferous-broadleaved mixed forest (near-natural forest). We tested the effect of increasing proportions of broadleaf tree species on species diversity, nutrient content of the forest floor and soil, and the soil microbial community during 60 years of natural development of *P. tabuliformis* planted forests. We hypothesized that species diversity, nutrient contents of the forest floor and soil, and soil microbial biomass in the near-natural forests would be higher than in the planted forests, but still lower than in the secondary forest.

2 Materials and methods

2.1 Site description

The study was carried out at the Baxian Mountain National Nature Reserve (117°30′35″–117°36′24″E, 40°7′24″–40°13′53″N, 270–1052 m a.s.l) in Tianjin, China. The total area covers 5360 ha. The region has a warm, humid continental monsoon climate. The mean annual temperature and precipitation are 8–10 °C and 968.5 mm, respectively. The dominant parent soil material in this area is meso- and neo-proterozoic dolomite and limestone. The typical soils are classified as Eutric Cambisols at the middle mountain area and as Chromic Cambisols at the lower mountain area according to the FAO Taxonomy (FAO-UNESCO 1988). The original forest vegetation in this area was dominated by deciduous broad-leaved forest of a warm temperate zone. However, excessive human activities, such as overgrazing and woodcutting, have caused severe depletions of the original vegetation. According to reserve records and personal communication with retirees, the vegetation in the area was poor, characterized by shrubs (*Vitex negundo* var. *heterophylla* (Franch.) Rehder and *Ziziphus jujuba* var. *spinosa* (Bunge) H.H. Hu ex H.F. Chow) with scattered small trees, before afforestation and protection. Large areas of *P. tabuliformis* forests were planted in the 1950s and subsequently protected. In addition, the government implemented the Natural Forest Conservation Program (NFCP) over the last 20 years (Zhang et al. 2000). Currently, the vegetation has largely been replaced by naturally regenerated secondary forest and planted woodland. In addition, some near-natural forests have formed through native development.

2.2 Investigation and sampling

Three forest types were selected for this study that was conducted in September 2014 (Table 1). We established five, six, and six plots respectively in a random design, in a *P. tabuliformis* forest, a coniferous-broadleaved *P. tabuliformis* mixed forest, and a *Q. mongolica* forest. Each plot covered an area of 0.06 ha (20 m × 30 m). The 20 m × 30 m plot was composed of six quadrants, each

Table 1. General description of communities.

	I	II	III
Elevation (m a.s.l.)	700–800	700–800	700–800
Slope (°)	18	17	17
Aspect	E30°S	E	S
Soil type	Eutric Cambisols	Eutric Cambisols	Eutric Cambisols
Density (Individual/ha)	1900	2033	2183
Standing tree volume (m^3 ha^{-1})	266.32	297.66	285.39

I: *Pinus tabuliformis* forest, II: coniferous-broadleaved *P. tabuliformis* mixed forest, III: *Quercus mongolica* forest

with a 10 m × 10 m area. Trees within plots that had a diameter at breast height (DBH, 1.3 m) of ≥3 cm were recorded. Diagonal two of the established six quadrants were selected for shrub layer measurement, and a subplot (1 m × 1 m) were randomly established for herbaceous layer measurement in each quadrant. Data collected in each plot included plant species, height, diameter at breast height (trees), basal diameter (shrubs), and coverage (herbs).

Here to after, forest floor refers to the litter and unincorporated humus above the mineral soil. Forest floor samples [encompassing the litter (L) and the fermentation and humus (FH) horizons] were collected from six sites within each plot. Each site measured 20 cm × 20 cm and was located at the center of each quadrant. The two horizons (L and FH) were collected separately. Mineral soil samples were collected from beneath the forest floor at depths of 0–10 cm and 10–20 cm using a stainless steel cylinder (100 cm^3). Six forest floor samples and mineral soil from the same horizon for each plot were combined to form one composite sample. Forest floor samples were oven-dried at 65 °C for 72 h, ground, and analyzed for the C, N and P. A portion of the soil samples, from which stones and large plant residues were removed, was frozen at –20 °C prior to phospholipid fatty acid (PLFA) analysis. Another sample was air-dried, sieved through 2 mm mesh, and stored at 4 °C for soil parameter analyses.

2.3 Sample analysis

Carbon and nitrogen concentrations of the forest floor and mineral soil samples were measured using a dry combustion method with a Vario EL elemental analyzer (Vario MAX C/N, Elemental Co., Germany). Phosphorus concentration was measured by molybdate colorimetry after digestion by HNO_3-$HClO_4$; the cation exchange capacity (CEC) was determined by EDTA-CH_3COONH_4 exchange; Soil bulk density was determined using core method following the methods of the Institute of Soil Science (1978). Soil pH was measured with a combination electrode (soil-to-water ratio 1:5). The PLFAs were analyzed with a gas chromatograph (Agilent 7890N GC with an Agilent 5975N mass selective detector) as described by Cao et al. (2014). Concentrations of each PLFA were standardized relative to 19:0 internal reference concentrations. Bacteria biomass was represented by (14:0, 15:0, 16:0, 17:0, 18:0, 20:0, G+, G-), Gram+ bacteria biomass by (i15:0, i16:0, i17:0), Gram- bacteria biomass by (16:1w7c, 18:1w5c, cy17:0, cy19:0), and fungal biomass by (18:1w9c, 18:2w6,9) (Frostegård et al. 1991, 2011; Marshall et al. 2011).

2.4 Statistical analysis

Standing tree volume was determined by the experimental form factor according to Wu (1992). The important value (IV) for each tree species was calculated as (relative density + relative dominance + relative frequency) / 3 and the IV for shrub and herb species was determined as (relative height + relative coverage + relative frequency) / 3. The dominant species and important values (IVs) in three forests were presented in Table 2. Calculation of vascular plant diversity index [the Richness index (S): Species in the plots, Shannon-Wiener index (H'): $H' = -\sum_{i=1}^{S} P_i \, ln \, P_i$, Simpson index (E): $E = H'/lnS$, and Pielou index (P): $P = 1 - \sum_{i=1}^{S} P_i^2, P_i$: important value of specie i (i = 1,2,3…)] were carried out as described by Fang et al. (2009). To test the significance of the findings, all data were analyzed with one-way ANOVAs. Microbial community composition were analyzed using principal component analysis (PCA) (Zhao et al. 2011, 2013). Data were transformed (natural log, square root, or rank), when required to meet assumptions of normality and homogeneity of variance. Statistical significance was determined at $p < 0.05$. ANOVAs and PCA were performed with SPSS 19.0 (Chicago, IL, USA). A Duncan's test was used to determine differences among treatment means.

Table 2. Plant individual important value (IV) in different forest types.

Forest types	Trees		Shrubs		Herbs	
	Species	IV	Species	IV	Species	IV
I	*Pinus tabuliformis* Carrière	49.01	*Deutzia parviflora* Bunge	38.54	*Athyrium multidentatum* Ching	20.14
	Evodia daniellii Hemsl.	16.56	*Philadelphus incanus* Koehne	34.86	*Arthraxon hispidus* Makino	12.57
	Carpinus turczaninowii Hance.	9.66	*Spiraea trilobata* L.	7.82	*Diarrhena mandshurica* Maxim.	10.51
	Tilia mandshurica Rupr. et Maxim.	9.23			*Thalictrum aquilegifolium* var. *sibiricum* Regel et Tiling	9.35
					Lithospermum erythrorhizon Sieb. et Zucc.	7.86
					Mentha haplocalyx Briq.	7.54
	Others	15.54	Others	18.76	Others	32.03
II	*Pinus tabuliformis* Carrière	29.94	*Actinidia arguta* Planch. ex Miq.	27.38	*Clematis heracleifolia* DC.	16.35
	Quercus variabilis Blume	27.65	*Deutzia parviflora* Bunge	25.17	*Melica scabrosa* Trin.	10.15
	Evodia daniellii Hemsl.	12.57	*Myripnois dioica* Bunge	8.40	*Solanum japonense* Nakai	10.04
	Acer truncatum Bunge	9.57	*Ampelopsis humulifolia* Bunge	8.16	*Carex callitrichos* V. Krecz.	9.95
	Quercus mongolica Fisch. ex Ledeb.	3.45	*Rubus crataegifolius* Bunge	7.98	*Artemisia brachyloba* Franch.	8.15
					Polygonatum sibiricum Delar. ex Redoute	6.48
					Vicia unijuga A. Braun	5.72
	Others	16.82	Others	22.91	Others	33.16
III	*Quercus mongolica* Fisch. ex Ledeb.	30.21	*Spiraea trilobata* L.	22.22	*Synurus deltoides* Nakai	15.42
	Pinus tabuliformis Carrière	17.51	*Rhamnus davurica* Pall.	18.38	*Melica scabrosa* Trin.	14.02
	Quercus aliena Blume	10.77	*Ampelopsis humulifolia* Bunge	12.33	*Polygonum lapathifolium* L.	12.92
	Betula dahurica Pall.	9.82	*Rhododendron micranthum* Turcz.	9.39	*Phlomis umbrosa* Turcz.	12.89
	Fraxinus chinensis Roxb.	8.96	*Rubus crataegifolius* Bunge	9.31	*Dioscorea nipponica* Makino	9.67
			Deutzia parviflora Bunge	8.89	*Spodiopogon sibiricus* Trin.	8.22
	Others	22.73	Others	19.48	Others	26.86

I: *Pinus tabuliformis* forest, II: coniferous-broadleaved *P. tabuliformis* mixed forest, III: *Quercus mongolica* forest.

3 Results

3.1 Tree, shrub and herb species diversity index

Richness of trees, shrubs, and herbs in the coniferous-broadleaved *P. tabuliformis* mixed forest and the *Q. mongolica* forest was higher than in the *P. tabuliformis* forest (Table 3). The Shannon-Wiener index and Simpson index of trees, shrubs, and herbs showed similar trends with Richness. In contrast to the species diversity indices, the evenness index (Pielou index) for herbs in the *P. tabuliformis* forest was higher than it was in the other two forests, while this was not the case for tree species in this forest.

Table 3. Species diversity in different forest types.

Layer	Diversity index	I	II	III
Trees	Richness index	10	14	14
	Shannon-Wiener index	1.639	1.981	2.162
	Simpson index	0.709	0.804	0.842
	Pielou index	0.712	0.751	0.819
Shrubs	Richness index	4	9	11
	Shannon-Wiener index	1.248	1.962	2.189
	Simpson index	0.688	0.827	0.868
	Pielou index	0.900	0.893	0.913
Herbs	Richness index	11	16	12
	Shannon-Wiener index	2.315	2.618	2.349
	Simpson index	0.891	0.916	0.894
	Pielou index	0.965	0.944	0.945

I: *Pinus tabuliformis* forest, II: coniferous-broadleaved *P. tabuliformis* mixed forest, III: *Quercus mongolica* forest

3.2 Concentrations and contents of C, N, and P and C/N ratio of the forest floor and mineral soil

Carbon and nutrient concentrations of the forest floor and mineral soil were presented in Table 4. In the L-horizon, the C, N, and P concentrations and C/N ratio differed between the forests. The C concentration and C/N ratio of the coniferous-broadleaved *P. tabuliformis* mixed forest were significantly lower than those of the P. tabuliformis forest, whereas the N and P concentrations were the highest in the coniferous-broadleaved *P. tabuliformis* mixed forest ($p<0.001$; $p=0.010$). In the FH-horizons, the C concentration did not differ between forests ($p=0.207$). The N concentration in the coniferous-broadleaved *P. tabuliformis* mixed forest was the highest of all the forests ($p=0.007$), resulting in a lower C/N ratio. The P concentration in the *P. tabuliformis* forest was significantly higher than in the other two forests ($p=0.005$). Overall, from the L-horizon to the FH-horizons, the C and P concentrations and C/N ratio decreased between forests, but the N concentration increased. However, the C, N and P content of forest floor decreased in the following order: *P. tabuliformis* forest > coniferous-broadleaved *P. tabuliformis* mixed forest > *Q. mongolica* forest ($p<0.001$; $p=0.003$; $p=0.002$) (Fig. 1).

The C, N, and P concentrations in the upper mineral soil of the coniferous-broadleaved *P. tabuliformis* forest did not differ from the *Q. mongolica* forest (except for the P concentration at a soil depth of 10–20 cm), but they were significantly higher than those of the *P. tabuliformis* forests. The C/N ratio did not differ between forests at a 0–10 cm soil depth ($p=0.921$). At a depth of 10–20 cm, the C/N ratio did not differ between the coniferous-broadleaved *P. tabuliformis* mixed forest and the *P. tabuliformis* forest, but were significantly lower than that of the *Q. mongolica* forest ($p=0.013$). However, the C, N, and P contents of mineral soil increased in the following order: *P. tabuliformis* forest < coniferous-broadleaved *P. tabuliformis* mixed forest < *Q. mongolica* forest ($p<0.001$; $p<0.001$; $p=0.008$) (Fig. 1). The C, N and P contents of mineral soil did not differ between the coniferous-broadleaved *P. tabuliformis* mixed forest and the *Q. mongolica* forest.

Table 4. Forest floor and soil nutrition concentration (mean±SE) in different forest types.

		Carbon (C) (g kg⁻¹)			Nitrogen (N) (g kg⁻¹)			Phosphorus (P) (g kg⁻¹)			Carbon/Nitrogen ratio (C/N ratio)		
		I	II	III	I	II	III	I	II	III	I	II	III
Forest floor	L-horizon	509.05±3.78a	454.25±1.12b	445.58±5.50b	9.05±0.14c	14.23±0.96a	12.00±0.23b	2.16±0.11b	2.95±0.12a	2.54±0.13ab	56.28±0.83a	32.35±2.06c	37.15±0.43b
	FH-horizons	354.70±12.92a	380.52±12.03a	354.08±7.10a	12.50±0.27b	15.20±0.67a	12.75±0.45b	1.56±0.05a	1.25±0.05b	1.33±0.03b	28.36±0.68a	25.10±0.75b	27.85±0.86a
Mineral soil	0–10cm	31.23±1.01b	48.33±1.94a	50.80±3.87a	2.23±0.03b	3.53±0.20a	3.70±0.21a	0.56±0.04b	0.75±0.08a	0.89±0.04a	13.99±0.46a	13.73±0.58a	13.71±0.57a
	10–20cm	10.57±0.75b	19.83±0.64a	20.5±2.14a	0.93±0.03b	1.63±0.07a	1.53±0.17a	0.36±0.02b	0.52±0.02a	0.41±0.02b	11.30±0.49b	12.16±0.29b	13.36±0.10a

Data marked with different letters within the same row at each individual nutrition parameter represent significant difference among different forest types at the 0.05 level (Duncan test).
I: *Pinus tabuliformis* forest, II: coniferous-broadleaved *P. tabuliformis* mixed forest, III: *Quercus mongolica* forest
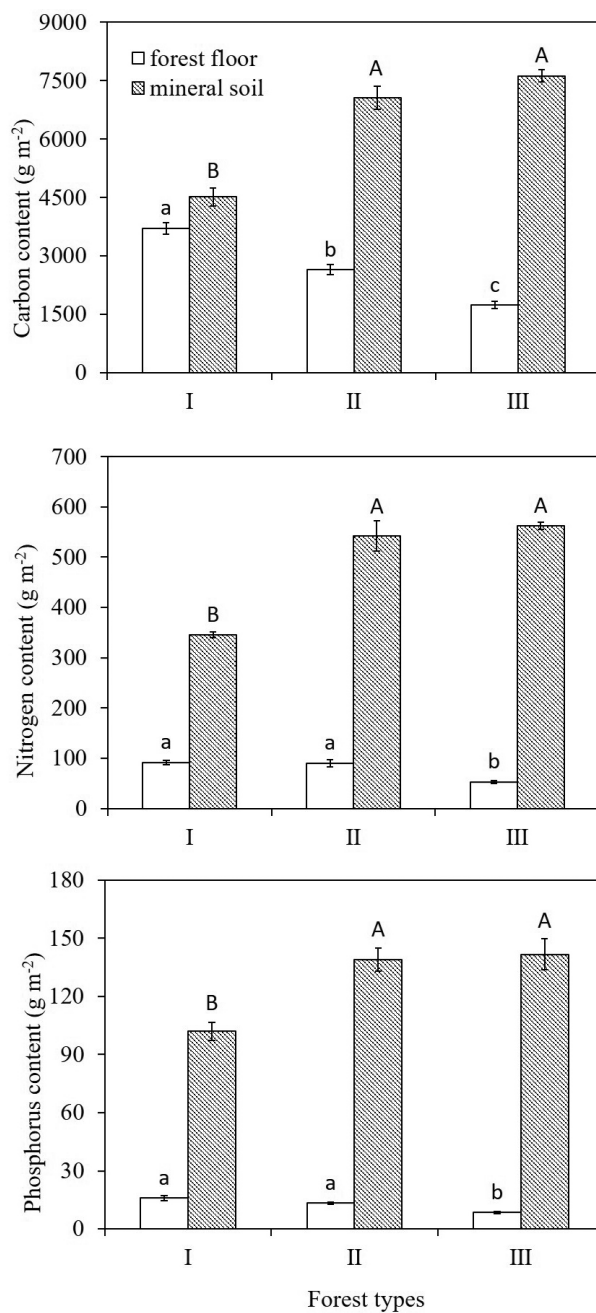L-horizon: litter horizons; FH-horizons: fermentation and humus horizons

Fig. 1. Bars marked with different lowercase letters represent significant difference at the forest floor layer under different forest types at the 0.05 level (Duncan test). Bars marked with different uppercase letters represent significant difference at the mineral soil layer (0–20 cm soil depth) under different forest types at the 0.05 level (Duncan test). **I:** *Pinus tabuliformis* forest, **II:** coniferous-broadleaved *P. tabuliformis* mixed forest, **III:** *Quercus mongolica* forest.

3.3 Soil CEC, pH, and bulk density

In the *Q. mongolica* forest and the coniferous-broadleaved *P. tabuliformis* mixed forest, CEC was the highest in the 0–10 cm and 10–20 cm soil depths, respectively ($p<0.001$) (Fig. 2). CEC was significantly lower in the *P. tabuliformis* forest than in the other two forests at the 0–10 cm soil depth. Soil pH was significantly higher in the coniferous-broadleaved *P. tabuliformis* mixed
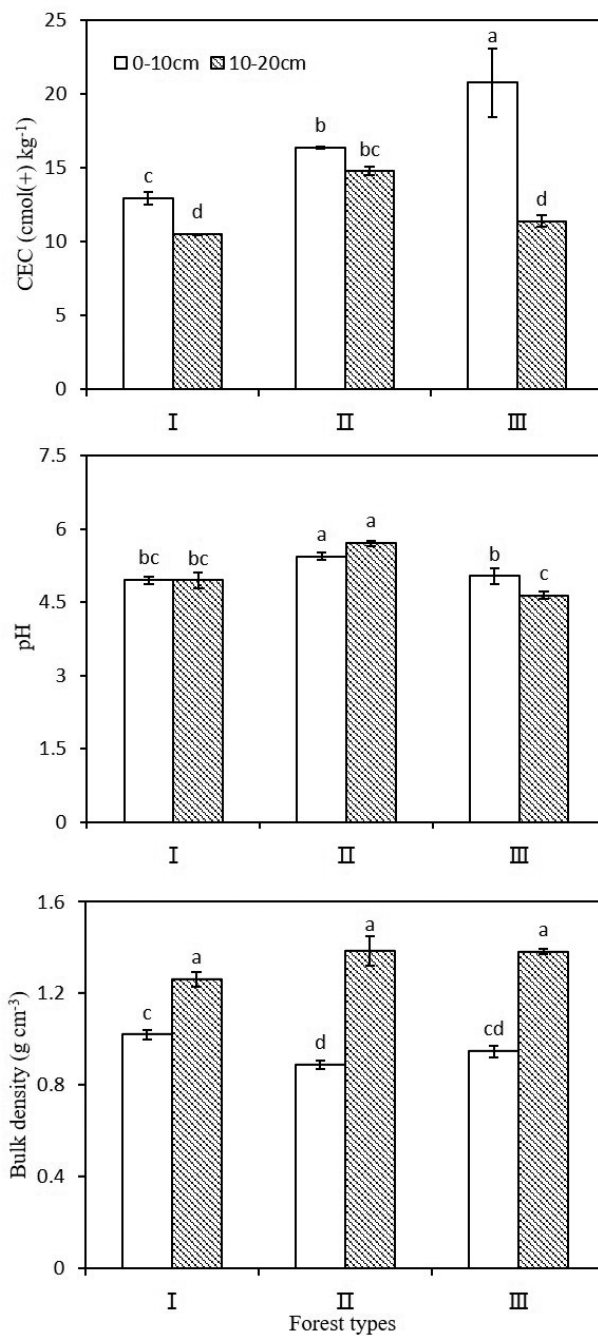
Fig. 2. Cation exchange capacity (CEC), pH, and bulk density in two soil depths under different forest types. Bars marked with the same letters are not significantly different from each other at the 0.05 level (Duncan test). **I:** *Pinus tabuliformis* forest, **II:** coniferous-broadleaved *P. tabuliformis* mixed forest, **III:** *Quercus mongolica* forest.

forest than in the other two forests ($p < 0.001$). The bulk density increased in the following order: coniferous-broadleaved *P. tabuliformis* mixed forest < *Q. mongolica* forest < *P. tabuliformis* forest at the 0–10 cm soil depth ($p < 0.001$), and were not significantly different between forests at the 10–20 cm soil depth.
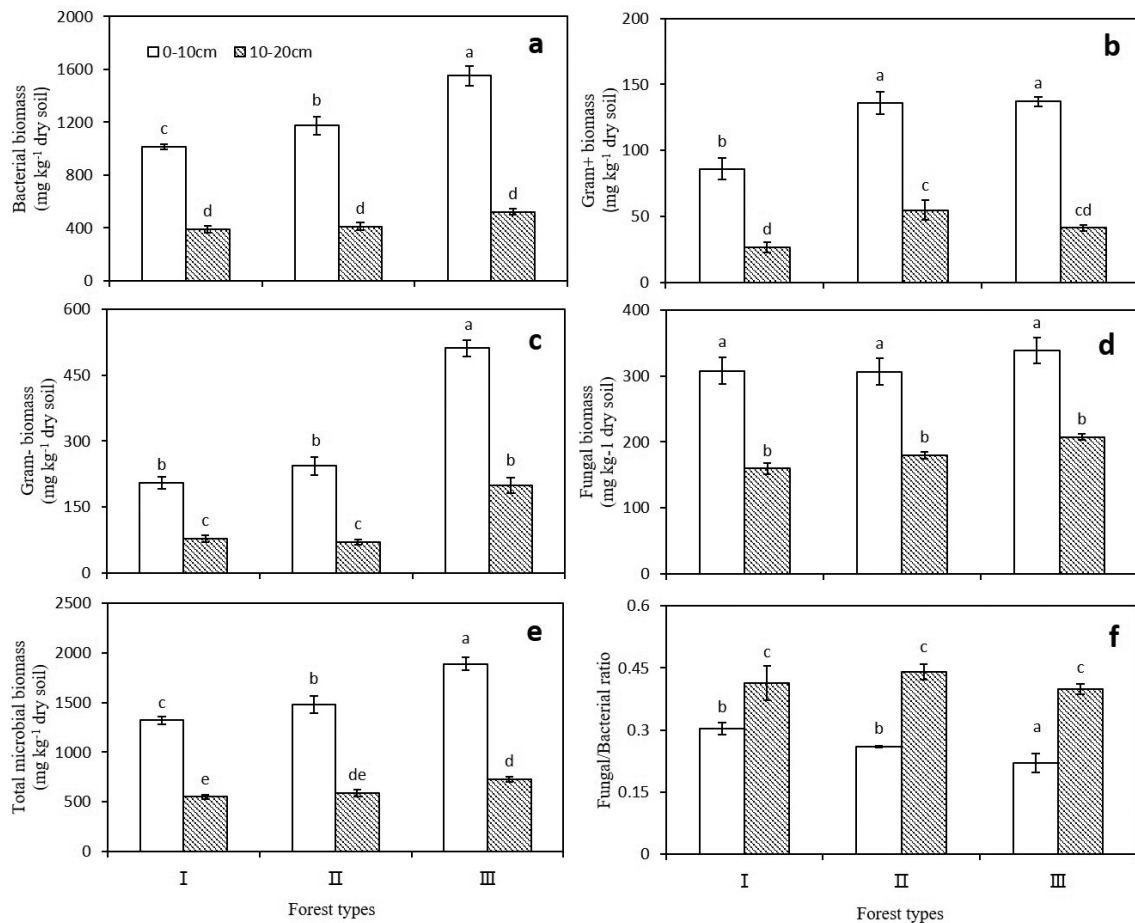
Fig. 3. Bacterial biomass (a), Gram+ biomass (b), Gram- biomass (c), fungal biomass (d), total microbial biomass (e), and fungi/bacterial ratio (f) in two soil depths under different forest types. Bars marked with the same letters are not significantly different from each other at the 0.05 level (Duncan test).
I: *Pinus tabuliformis* forest, **II:** coniferous-broadleaved *P. tabuliformis* mixed forest, **III:** *Quercus mongolica* forest.

3.4 Soil microbial community

Total microbial biomass and bacterial biomass were significantly different between forests at the 0–10 cm soil depth. In decreasing order, bacterial and total microbial biomass of the three forests were *Q. mongolica forest* > coniferous-broadleaved *P. tabuliformis* mixed forest > *P. tabuliformis* forest (Fig. 3a,e), respectively ($p < 0.001$; $p < 0.001$). Gram+ biomass and Gram- biomass in the *P. tabuliformis* forest were significantly lower than in the *Q. mongolica* forest at the 0–10 cm soil depth (Fig. 3b,c). At the 10–20 cm soil depth, total microbial biomass and Gram- biomass in the *Q. mongolica* forest were significantly higher than in the *P. tabuliformis* forest, and Gram+ biomass in the coniferous-broadleaved *P. tabuliformis* mixed forest was significantly higher than in the *P. tabuliformis* forest and not significantly different with the *Q. mongolica* forest (Fig. 3b,c,e). Additionally, the fungal/bacterial ratio (F/B ratio) did not differ at the 10–20 cm soil depth between forests, but the ratio of the *Q. mongolica* forest was significantly lower than that of the other two forests at the 0–10 cm soil depth ($p < 0.001$) (Fig. 3f). Overall, bacterial biomass, Gram+ biomass, Gram- biomass, fungal biomass, and total microbial biomass decreased with increasing soil depth in contrast to the F/B ratio. The composition of the microbial community in the 0–10 cm soil depth did not vary between the *P. tabuliformis* and coniferous-broadleaved *P. tabuliformis* mixed forests, but it did differ at the 10–20 cm depth among forest types ($p < 0.001$) (Fig. 4).
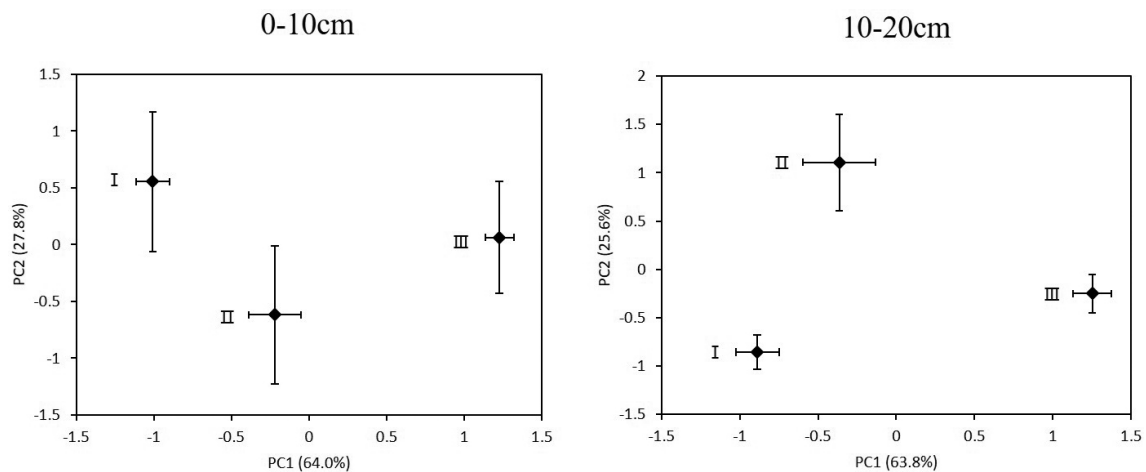
Fig. 4. Principal component analysis (PCA) of microbial species at 0–10 cm and 10–20 cm soil depths under different forest types. Bars indicate the standard errors of means.
I: *Pinus tabuliformis* forest, **II:** coniferous-broadleaved *P. tabuliformis* mixed forest, **III:** *Quercus mongolica* forest.

4 Discussion

Certain regions have experienced moderate success in the near-natural transformation of planted forest through selective logging and creating gaps (Luo et al. 2013; Taki et al. 2010; He et al. 2013; Wang and Liu 2011). Although these methods have resulted in positive changes to some forests, in other cases, simply allowing the course of natural development to take place can also result in comparable transitions. The current study focused on near-natural and secondary forests that have existed with *P. tabuliformis* planted forest that has undergone natural development for 60 years. This transition in forest type has resulted in changes to species diversity, forest floor and soil properties, and microbial community characteristics.

4.1 Influence of forest type on litter and soil properties

The present study revealed that the C concentration in the L-horizon in the *P. tabuliformis* forest was significantly higher than in the *Q. mongolica* forest, whereas the N and P concentrations in the *P. tabuliformis* forest were lower than in the *Q. mongolica* forest. Only the litter quality (N and P) of the *P. tabuliformis* forest was significantly higher when deciduous broadleaved species were present and thus formed the coniferous-broadleaved mixed forest. Polyakova and Billor (2007) also indicated that mixed pine-deciduous litter had a higher nutrient concentration than pure pine litter. In the current study, from the L-horizon to the FH-horizons, C and P concentrations exhibited a decreasing trend, whereas the N concentration increased. During litter decomposition, a large amount of C is released to the atmosphere in the form of carbon dioxide through microbial respiration, and N acts as an immobilizer due to microorganisms colonization of decaying litter (Chapin et al. 2002; Fioretto et al. 2005). Plant litter quality is an important influence on soil nutrient cycling, particularly because the C/N ratio, which is the most common index of litter quality, modifies the decomposition rate (Cao et al. 2014; Szanser et al. 2011; Polyakova and Billor 2007). In the current study, the C, N, and P concentrations of soil in the *P. tabuliformis* forest were significantly lower than in the *Q. mongolica* forest likely because the lower C/N ratio in the *Q. mongolica* forest litter coupled with a higher nutrient concentration improved soil fertility. Furthermore, changes in litter composition due to the distinct effects of diverse plant species have direct (or indirect)

consequences on further decomposition by altering microhabitat structure and food availability for litter-feeding animals (Hättenschwiler et al. 2005). Klemmedson (1987) reported that mixed pine (*Pinus ponderosa* P. Lawson & C. Lawson)-oak (*Quercus gambelii* Nutt.) litter accelerated rates of litter decay and nutrient release and improved soil fertility compared to a pure pine forest. Our research showed that the C, N, and P concentrations of soil in a coniferous-broadleaved *P. tabuliformis* mixed forest were significantly higher than those in the *P. tabuliformis* forest. This was why the N and P contents of forest floor in the *P. tabuliformis* forest were significantly higher those of the coniferous-broadleaved *P. tabuliformis* mixed forest, but those of mineral soil showed the opposite tendency. Although the C content in the soil increased from the pure pine forest to the near-natural forest, further studies will be needed to determine the stability of the soil C pool (Wang et al. 2015) in the *P. tabuliformis* planted forest after 60 years of natural development.

CEC is an important indicator of soil nutrient content, pH-related buffer ability (the capacity to control the input and release of nutrients), and quality assessment (Troeh and Thompson 1993). Research has shown that CEC improves with restoration time in a degraded landscape (Negash and Kagnew 2013). The CEC of the 0–10 cm soil depth in the coniferous-broadleaved *P. tabuliformis* mixed forest was significantly higher than that of the *P. tabuliformis* forest. However, the CEC of the 0–10 cm soil depth in the *Q. mongolica* forest was the highest among all forests. Soil organic matter may provide the bulk of exchange sites in soils, and therefore strongly influence CEC (Sayer 2006; Jiang et al. 2012), whereas the nutrient contents at the 0–10 cm soil depth in the *Q. mongolica* forest were the highest among the three forest types. Our research was consistent with that of a previous study (Van Nevel et al. 2014) in that the topsoil in the oak stands had significantly higher CEC than in that of the pine stands.

The acidification of forest soils remains an important concern because this process leads to numerous adverse effects on forest ecosystems, such as the depletion of essential base cations (Mg^{2+}, Ca^{2+}, K^+, Na^+) and increased availability of potentially toxic elements (Al^{3+}) (Marlow and Peart 2014; Van Nevel et al. 2014). Atmospheric deposition of acidifying emissions of N and sulfur (S) and other potentially acidifying compounds (e.g., NH_x) unequivocally drives forest soils towards more acidic conditions, but the rate of soil acidification is also modified by litter quality and litter decomposition rates (De Schrijver et al. 2012). Lower C/N ratios potentially facilitate litter decomposition and base cation release to soils, which in turn increases soil buffering capacity (Cornelissen and Thompson 1997; Clarholm and Skyllberg 2013). In the present study, soil pH in the coniferous-broadleaved *P. tabuliformis* mixed forest stand was significantly higher than in the *P. tabuliformis* forest stand. However, soil pH in the *Q. mongolica* forest stand was not significantly different with the *P. tabuliformis* forest stand. It might be due to the difference of sort and percentage composition of litter between the coniferous-broadleaved *P. tabuliformis* mixed forest stand and the *Q. mongolica* forest stand. This finding suggested that the presence of deciduous broadleaved species improved the buffering capacity of pine forest soil via a change in litter quality and ameliorated soil pH to some extent.

4.2 Influence of forest type on soil microbial biomass and community structure

Litter quality is often a strong determinant of soil microbial communities. Changes in litter quality can affect the population dynamics and community structure of soil microorganisms by supplying nutrients, changing the microclimate at the soil surface, and releasing chemical compounds (Zhao et al. 2013; Wardle et al. 2006; Sayer 2006; Hättenschwiler et al. 2005). Our research showed that total microbial biomass in the *Q. mongolica* forest was significantly higher than in the other two forests, but when deciduous tree species were added to the *P. tabuliformis* forest, total microbial biomass was significantly improved in the coniferous-broadleaved *P. tabuliformis* mixed forest.

Lower C/N ratios and higher litter nutrients not only improve the decomposition rate and increase soil nutrients, but also enhance the total microbial biomass and influence the composition of soil microbial community (Tu et al. 2012; Chen et al. 2011). Bacteria and fungi are the most important functional communities in soil (Coleman 2008; Holtkamp et al. 2008; Fierer et al. 2009), and high nutrient contents may be favorable to bacterial communities (Bardgett and Cook 1998; Fioretto et al. 2005). In the present study, bacterial biomass significantly differed among the three forests, and decreased in the following order: *Q. mongolica* forest > coniferous-broadleaved *P. tabuliformis* mixed forest > *P. tabuliformis* forest. In order to enlarge the absorbing area of fine roots and increase nutrient uptake efficiency, *Pinus* and *Quercus* commonly form a symbiotic relationship with ectomycorrhizal fungi (Wang et al. 2012; Makoto et al. 2010). This was likely the main reason why fungal biomass did not differ among the forests in the 0–10 cm soil depth in our study. However, the F/B ratio (Fungal/Bacterial ratio) in the *Q. mongolica* forest soil was lower than in the other two forests, and the ratio in the 0–10 cm soil depth reached significant levels. Our data showed that the composition of the soil microbial community in the 0–10 cm soil depth did not differ between the *P. tabuliformis* forest and coniferous-broadleaved *P. tabuliformis* mixed forest, but it did vary significantly in the 10–20 cm soil depth among the three forests.

5 Conclusion

Overall, our results suggest that a change in forest type influenced soil microbial biomass and community structure. However, previous research indicated that belowground communities (microorganisms and animals) actually play a major role in shaping aboveground biodiversity (Bardgett and van der Putten 2014), which can include varieties of tree species. Therefore, the contribution of soil microorganisms to the process of a near-natural transformation of planted forest merits further study. Meanwhile, this study can act as a reference for management of the near-natural transformation of *P. tabuliformis* planted forests and for the choice of the tree species used.

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