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Effects of Forest Conversion on Soil Ecosystem Services in Liuxihe National Forest Park, China

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Abstract: The transition from natural forest to plantations has increased dramatically in the past decades. Forest conversion will affect soil properties and thus soil ecosystem services. Based on soil indicators, we studied the differences of soil ecosystem services among three forest types in Liuxihe National Forest Park and analyzed the effects of conversion from natural forest to artificial forest on soil ecosystem services. The results showed that the soil carbon sequestration of evergreen broadleaf forest (EBF) was stronger, and the soil organic carbon density (36.43 ± 0.97 kg m^{-3}) was significantly higher than that of moso bamboo forest (MBF) (25.46 ± 1.72 kg m^{-3}) and sugar orange forest (SOF) (19.31 ± 2.68 kg m^{-3}) in the 0–10 cm soil layer. The soil water conservation of MBF was higher, and its soil water content was significantly higher than that of EBF in the three soil layers, which was more than 20% higher than that of EBF. There was no significant difference in soil total nitrogen content among the three forest types, while the soil total phosphorus content of MBF and SOF was more than twice that of EBF. It is important to consider soil ecosystem services in forest protection and restoration in forest parks.

Keywords: forest conversion; soil ecosystem services; trade-offs; soil indicators

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1. Introduction

As an important part of forest ecosystem, soil provides a variety of ecosystem services, including soil conservation, water conservation, and carbon sequestration [1]. Soil ecosystem services depend on soil properties and their interaction, and are mostly influenced by its use and management [2]. Studies on the impacts of land use change on soil ecosystem services have focused on the impacts of deforestation and forest conversion to farmland and grassland [3–8]. Forest is the major carbon sink among ecosystem types [9], two-thirds of which is stored in forest soil [10]. Small changes in soil carbon pools can affect the global carbon balance, leading to global climate change, which in turn has a profound impact on the distribution, composition, structure, and function of terrestrial ecosystems. Forests have been converted into plantations for food and industrial materials [11]. Forest degradation significantly reduced soil carbon, total porosity, and water content [12]. Based on the meta-analysis, soil carbon pool changes, caused by land use change, show that the soil organic carbon (SOC) of plantations and farmland, which were converted from natural forest, decreased by 13% and 42%, respectively, while the SOC of plantations and secondary forests which were converted from farmland increased by 18% and 53%, respectively [13].

Forest type conversion is an important way of generating land use change, which can change soil properties and affect soil ecosystem services. The conversion of forests to plantations leads to impacts on soil organic carbon (−24%) and total nitrogen (−29%) [14]. Planting economic trees after deforestation caused significant changes in soil organic carbon [15]. The conversion from natural forest to plantations decreased soil organic carbon [16,17]. The total organic carbon content in surface soil of natural secondary broad-leaved forest decreased by 58.24% after being replaced with *Cunninghamia lanceolata* plantation [18].

While different forest ecosystems exhibit big differences in their water conservation functions, more than 90% of the total water was stored in soil [19]. The hydrological role of forest soil depends on its structure and porosity [20]. The rubber–puzzle complex forest can improve soil porosity so that more water can penetrate the soil during rainfall and enhance soil water conservation. The soil water conservation function index of the rubber–puzzle complex forest was 2.09 times of that of the pure rubber forest [21]. The integrated soil and water conservation capacity of mixed deciduous broadleaf forest was the strongest, followed by Liaodong oak forest, Huabei larch forest, and Chinese pine [22]. Compared with the conversion to secondary broadleaved forests of *Castanopsis carlesii* and plantations of *Cunninghamia lanceolata*, the conversion of natural forests into human-assisted naturally regenerated forests of *Castanopsis carlesii* is more beneficial to the storage and supply of phosphorus in forest soil and to the stability of forest ecosystem in the central subtropical region [23]. For degraded mountains, vegetation restoration significantly changed the storage capacity of soil carbon, nitrogen, and phosphorus, and this effect decreased with the increase in soil depth [24].

China has a large area of economic forests and bamboo forests, among which 55.0% of economic forests are fruit trees and 73.8% of bamboo forests are moso bamboo forests. Studying the changes in soil ecosystem services after the conversion of natural forests to economic forests or bamboo forests is of great significance for improving forest soil ecosystem services. Sugar orange forest (SOF) and moso bamboo forest (MBF) were chosen to assess the soil ecosystem services changes due to the conversion of forest types, which are two main plantations in Liuxihe National Forest Park. The purposes of the study were: (1) to assess soil ecosystem services of three forest types based on soil indicators; and (2) to quantify soil ecosystem service changes after the conversion of natural forests into plantations. Using a space-for-time substitution approach [25], we hypothesized that evergreen broadleaf forest (EBF) was the reference as the state at which forest conversion began.

2. Materials and Methods

2.1. Study Region

Liuxihe National Forest Park is located in the northern area of Guangzhou, Guangdong Province, South China, with an area of 88.31 km^2. The mean annual air temperature is 20.3 °C. The mean annual rainfall is 2104.7 mm, and rainfall always occurs in spring and summer. Water flows downstream into the Liuxihe reservoir, which is an important water source of Guangzhou. Forests account for 89.0% of the land area of the national forest park, and evergreen broadleaf forests account for 48.7% of the forest area. The artificial forest was mainly moso bamboo forest and orchard, and they account for 15.0% of the forest area. The main soil type is red soil.

We selected the Nanshanwan watershed, located on the southeast of Liuxihe National Forest Park (23°42′–23°46′ N, 113°46′–113°51′ E) (Figure 1), as a sampling site to analyze the effects of forest conversion on soil ecosystem services. Forests account for 98.8% of the land area of the watershed. Evergreen broadleaf forest, moso bamboo forest, and orchard account for 67.1%, 20.7% and, 11.5% of the forest area, respectively. The main soil type of the watershed is red soil. Evergreen broadleaf forest in the forest park is protected as an ecological forest, while moso bamboo forest and orchard are operated by the surrounding villagers. However, the cutting of moso bamboo forest was restricted by the government and it is in a relatively stable state.

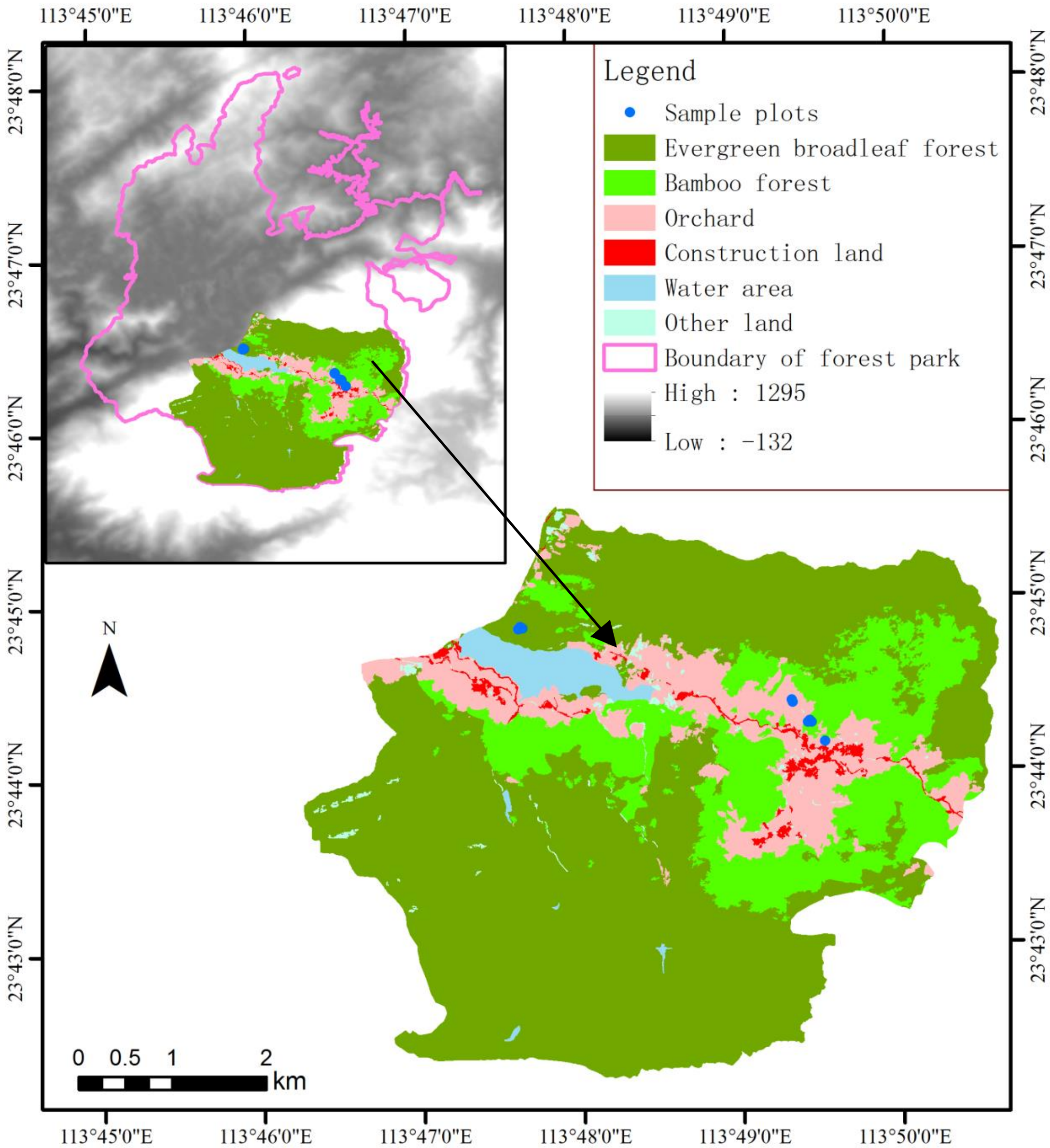


Figure 1. Location of the study site and sampling plots in Liuxihe National Forest Park.

2.2. Soil Sampling and Laboratory Analysis

Three types of forest, including evergreen broadleaf forest, moso bamboo forest, and sugar orange forest, were selected for investigation and sampling in August 2018 (Table 1). Evergreen broadleaf forest is the secondary forest of the subtropical monsoon evergreen broadleaf forest. Moso bamboo forest is an artificial forest composed of *Phyllostachys edulis* as the main species, while the sugar orange forest is an orchard composed of *Citrus reticulata* as the main species, both of which are converted from the subtropical monsoon evergreen broadleaf forests. The difference in soil carbon content among different forest types was mainly in the soil surface layer [4], and the organic carbon content in 0–40 cm soil layer accounted for more than 50% of the whole profile [26,27]. In most subtropical soils, short-term changes in organic carbon occur in the upper layer [28]. A horizon of the soil in this study site is about 10 cm [29]. To facilitate the comparison of vertical differences, the sampling depths are designed to be 0–10 cm, 10–20 cm, and 20–40 cm.

Table 1. Stand information of different forests.

Type	Main Tree Species	Main Undergrowth Vegetation	Location	Elevation(m)	Slope(°)
EBF	*Schima superba* *Castanopsis fabri* *Abarema clypearia*	*Psychotria rubra* *Castanopsis faberi* *Abarema clypearia* *Adiantum flabellulatum* *Rourea microphylla* *Carex chinensis*	23.747617° N, 113.794080° E	228	40
			23.747380° N, 113.793913° E	240	34
			23.747467° N, 113.794323° E	253	38
MBF	*Phyllostachys edulis*	*Ficus hirta* *Rhaphiolepis indica* *Glochidion eriocarpum* *Lophatherum gracile* *Adiantum flabellulatum* *Dicranopteris pedata*	23.737959° N, 113.823933° E	339	29
			23.738152° N, 113.824166° E	340	36
			23.737956° N, 113.824332° E	343	37
SOF	*Citrus reticulata*	*Ageratum conyzoides* *Oxalis corniculata* *Spermacoce alata*	23.736124° N, 113.825680° E	289	40
			23.740152° N, 113.822283° E	350	28
			23.739930° N, 113.822395° E	342	31

EBF: evergreen broadleaf forest; SOF: sugar orange forest; MBF: moso bamboo forest.

Areas with similar elevation (228–350 m), slope (28–40°), and southward orientation were selected for sampling, and the sampling locations were located in the middle or lower slope. The parent material of the soil in the study site is granite. Three 20 m × 20 m plots were randomly selected for each forest type, and three soil profiles in each plot were dug to a depth of 40 cm. The samples were taken from three depths (0–10 cm, 10–20 cm, 20–40 cm), and soil samples from the same depth in the same plot were pooled into one composite sample. Soil samples were sealed in plastic bags and transported to the laboratory. The soils were air-dried and sieved through a 0.15 mm sieve before chemical analysis. Soil organic carbon concentrations were determined using the $K_2Cr_2O_7$-H_2SO_4 titration method. The soil total nitrogen content was analyzed by using Vario EL III elemental analyzer (Elementar, Langenselbold, Germany). Soil total P was determined by acid digestion with an H_2SO_4 + $HClO_4$ solution. The soil bulk density for each soil layer was determined by volumetric rings (5 cm in diameter) obtained during the digging of soil subsamples. The drying of volumetric rings subsamples occurred at 105 °C to a constant mass for the determination of bulk density and water moisture content. Total soil porosity, soil capillary porosity, and soil non-capillary porosity were also obtained using the cutting ring method.

2.3. Data Analysis

Data analysis is an effective method to evaluate soil ecosystem services based on indicators [30]. Soil ecosystem services of three forest types were assessed using several indicators. The content and density of soil organic carbon, soil water content, total nitrogen, and total phosphorus were used to evaluate carbon sequestration, water conservation, and nutrient accumulation functions of different forest soils.

SOC in each layer were calculated as follow:

$$SOC_i = 0.1 \times C_i \times B_i \times H_i, \quad (1)$$

where C_i is the SOC concentration (g kg^{-1}), B_i is the bulk density (g cm^{-3}), and H_i is the thickness (cm).

The data on soil ecosystem services were statistically analyzed by the one-way analysis of variance (ANOVA) technique using the software SPSS 20.0 (SPSS Inc., Chicago, IL, USA). The least significant difference (LSD) test was used to compare soil ecosystem services among forests and different depths at the 95% confidence level. According to the results of homogeneity test of variance (Table 2), the soil organic carbon content (10–20 cm), soil capillary porosity (0–10 cm), and soil total phosphorus content (0–10 cm and 10–20 cm) failed the homogeneity test, so Welch's ANOVA, following the Games–Howell test, was used to analyze the difference among different forest types.

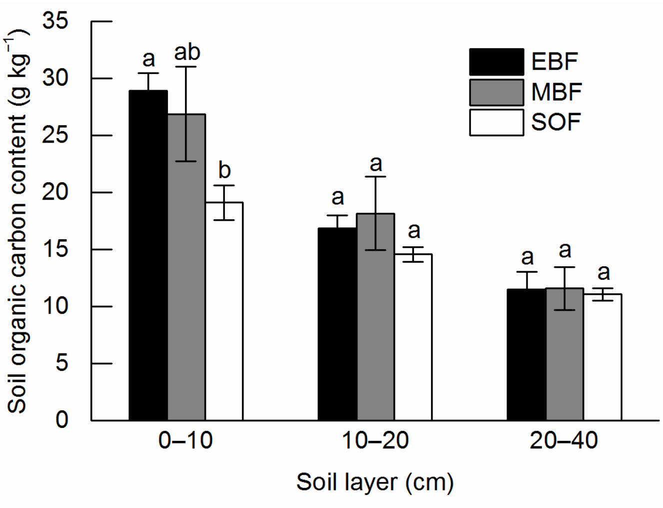
Table 2. Homogeneity test for variances.

	Significance		
	0–10 cm	**10–20 cm**	**20–40 cm**
soil organic carbon content	0.268	0.028	0.227
soil organic carbon density	0.303	0.198	0.498
soil water content	0.109	0.902	0.203
total soil porosity	0.145	0.588	0.325
soil capillary porosity	0.050	0.265	0.142
soil non-capillary porosity	0.152	0.178	0.203
soil total nitrogen	0.071	0.601	0.470
soil total phosphorus	0.007	0.017	0.117

3. Results

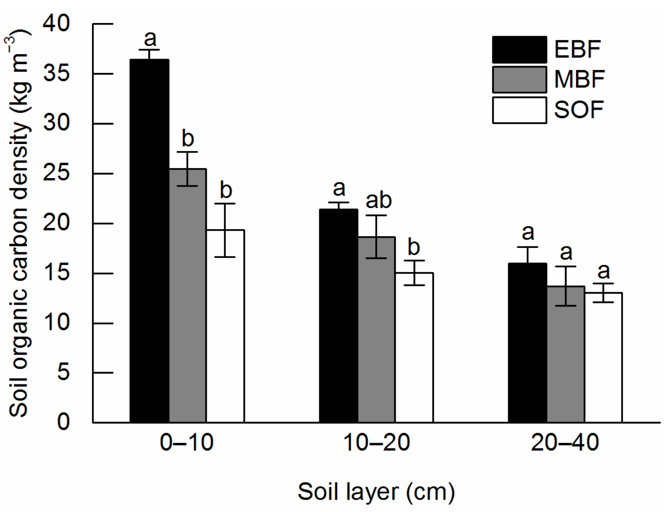
3.1. Carbon Sequestration

The content and density of soil organic carbon in evergreen broadleaf forest, moso bamboo forest, and sugar orange forest decreased with the increase in soil depth. The forest types significantly affected the soil organic carbon density. In the 0–10 cm soil layer, the soil organic carbon content of evergreen broadleaf forest was the highest (28.92 $\pm$ 1.54 g kg^{-1}), and significantly higher than that of sugar orange forest (19.12 $\pm$ 1.53 g kg^{-1}) (Figure 2a). As for the soil organic carbon density, in three different soil layers, the soil organic carbon density of evergreen broadleaf forest was the highest. In the 0–10 cm soil layer, the soil organic carbon density of EBF was significantly higher (36.43 $\pm$ 0.97 kg m^{-3}) than that of MBF (25.46 $\pm$ 1.72 kg m^{-3}) and SOF (19.31 $\pm$ 2.68 kg m^{-3}) (Figure 2b). In the 10–20 cm soil layer, the soil organic carbon density of EBF (21.40 $\pm$ 0.73 kg m^{-3}) was significantly higher than that of SOF (15.05 $\pm$ 1.22 kg m^{-3}). In the 20–40 cm soil layer, however, the soil organic carbon density of three forest types was not significantly different.



(**a**)

Figure 2. *Cont.*



(**b**)

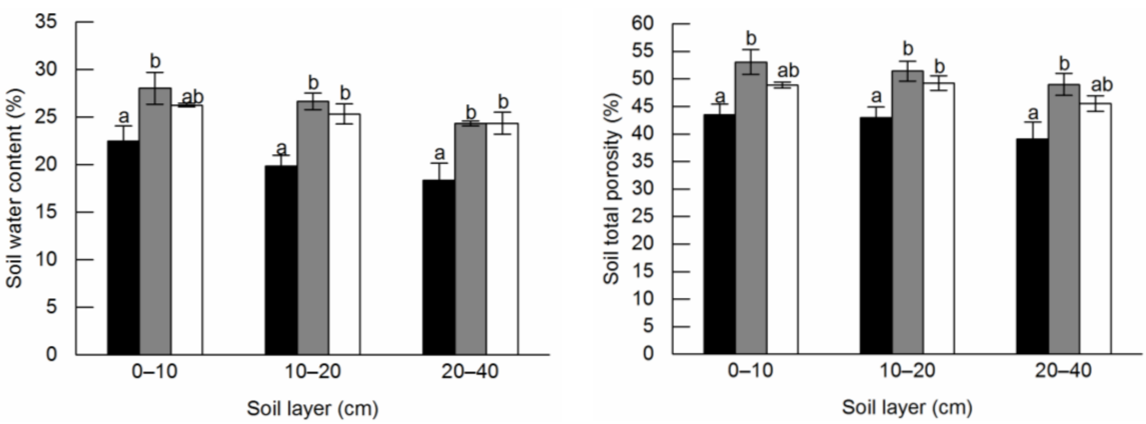
Figure 2. Soil carbon sequestration in three forest types at different depths. (**a**) Soil organic carbon content; (**b**) Soil organic carbon density. Different lowercase letters (a, b) above each bar indicate significant differences among different forest types ($p < 0.05$), the same letters indicate no significant differences between each other, and two repeated letters (ab) indicate that the forest type is not significantly different from the other two types. Vertical bars show ± S.E.

3.2. Water Conservation

The soil water content of EBF, SOF, and MBF decreased with the increase in depth, but there was no significant difference among different soil layers. In the 0–10 cm soil depth, the soil water content of MBF was significantly higher (28.03 ± 1.67%) than that of EBF (22.48 ± 1.62%) (Figure 3a). The soil water content of MBF and SOF was significantly higher than that of EBF at 10–20 cm and 20–40 cm soil layers.

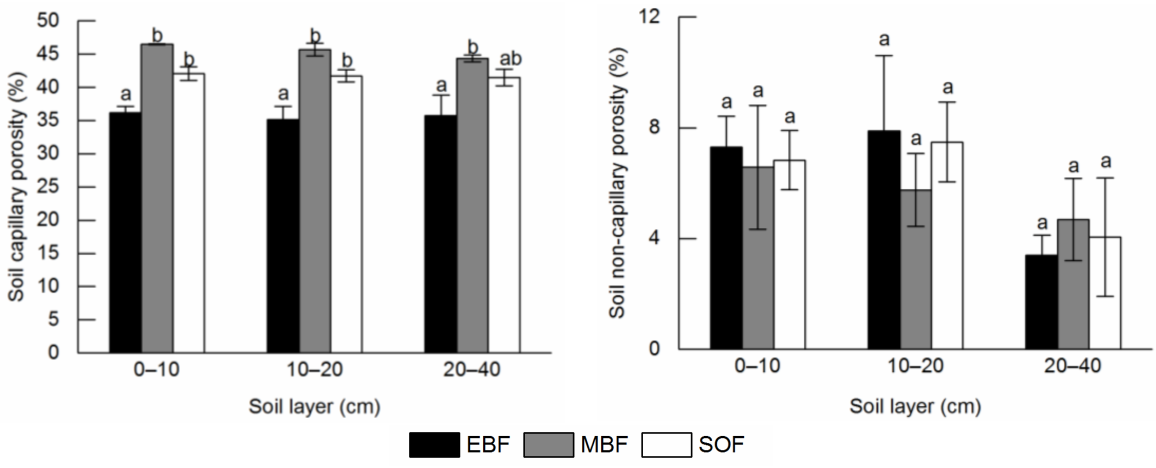
The total soil porosity of MBF was significantly higher (53.05 ± 2.25%) than that of EBF (43.49 ± 1.91%) at the 0–10 cm soil layer (Figure 3b). In the 10–20 cm soil depth, the total soil porosity of SOF (49.21 ± 1.34%) and MBF (51.41 ± 1.82%) was significantly higher than that of EBF (42.99 ± 1.96%). The total soil porosity of MBF (49.01 ± 1.99%) was significantly higher than that of EBF (39.10 ± 3.08%) in the 20–40 cm soil layer.

The soil capillary porosity of MBF and SOF was significantly higher than that of EBF in the 0–10 cm and 10–20 cm soil layers (Figure 3c), and MBF (44.32 ± 0.52%) was significantly higher than that of EBF (35.71 ± 3.09%) in 20–40 cm soil layer. There was no significant difference in the soil non-capillary porosity among EBF, SOF, and MBF in the three soil layers (Figure 3d).



(a) **(b)**

Figure 3. *Cont.*



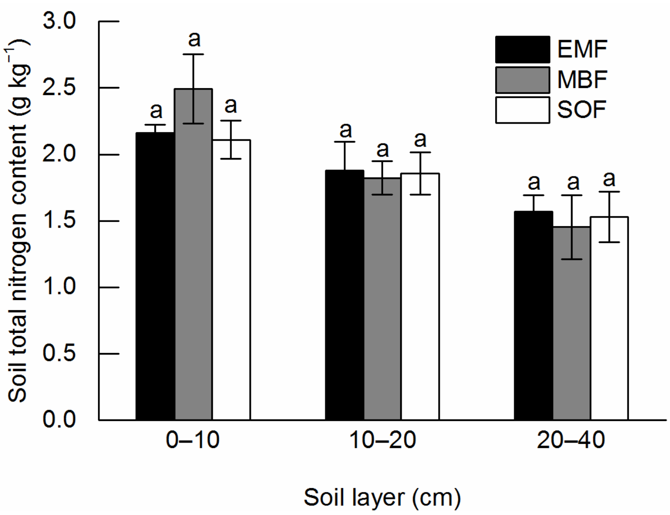
(c) **(d)**

Figure 3. Soil water conservation in three forest types at different depths. (**a**) Soil water content; (**b**) soil total porosity; (**c**) soil capillary porosity; (**d**) soil non-capillary porosity. Different lowercase letters (a, b) above each bar indicate significant differences among different forest types ($p < 0.05$), the same letters indicate no significant differences between each other, and two repeated letters (ab) indicate that the forest type is not significantly different from the other two types. Vertical bars show ± S.E.

3.3. Nutrient Accumulation

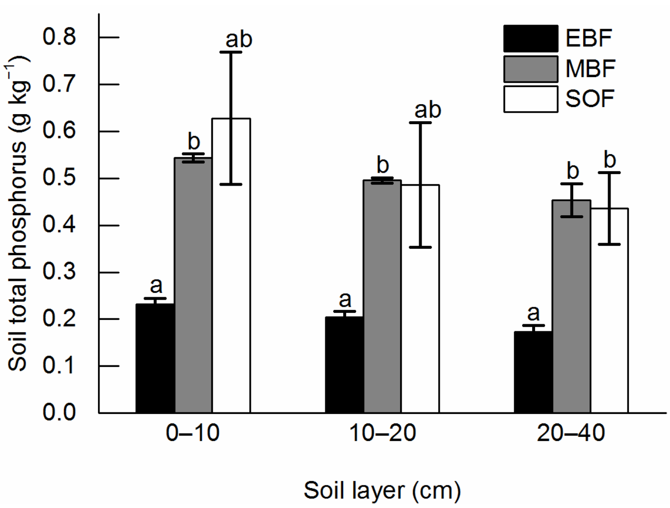
The soil total nitrogen content of the three forest types was higher in the upper layer than in the lower layer. There were no significant differences in the soil total nitrogen content among different forest types (Figure 4a). The content of total phosphorus in soil decreased with the increase in soil depth in the three forest types. The total phosphorus content of EBF was significantly lower than that of MBF in the three soil layers (Figure 4b). Meanwhile, the soil total phosphorus content in EBF was significantly lower than that in SOF in the 20–40 cm soil layer.

On the whole, the soil carbon sequestration capacity of evergreen broadleaf forest was the strongest, and the soil water conservation capacity of moso bamboo forest was the strongest. Nutrient accumulation in the moso bamboo forest and sugar orange forest was higher than that in evergreen broadleaf forest.



(**a**)

Figure 4. *Cont.*



(**b**)

Figure 4. Contents of soil total nitrogen (**a**) and total phosphorus (**b**) in three forest types at different depths. Different lowercase letters (a, b) above each bar indicate significant differences among different forest types ($p < 0.05$), the same letters indicate no significant differences between each other, and two repeated letters (ab) indicate that the forest type is not significantly different from the other two types. Vertical bars show ± S.E.

4. Discussion

4.1. Effects of Forest Conversion on Soil Ecosystem Services

Forest conversion is an important factor causing changes in soil ecosystem services. The present study shows that soil carbon sequestration decreased with the transition from EBF to MBF and SOF. In the 0–10 cm soil layer, the soil carbon density of evergreen broadleaf forest was 43.14% and 88.66% higher than that of moso bamboo forest and sugar orange forest, respectively. Our results are consistent with previous studies on soil carbon changes caused by forest conversion [31–34]. The soil water conservation function of EBF was significantly lower than that of MBF [35], but higher than other plantations such as *Pinus massoniana* forest [19]. However, soil total nitrogen did not change significantly after evergreen broadleaf forest was converted to plantation, while soil total phosphorus increased significantly, which was different from previous studies [14].

Forest degradation will change the site structure, microclimate, soil physical, and biochemical properties, thereby affecting the carbon sequestration capacity [15,36–38]. The decrease in soil carbon could be attributed to plantations having lower net primary production than natural forests [39]. Additionally, the removal of vegetation in plantations may result in reduced carbon input into the soil, leading to a decrease in soil carbon [11]. The water storage capacity of forest soil is closely related to soil porosity [19], and the soil porosity of MBF and SOF is higher than that of EBF, so their water conservation function is stronger than that of EBF. After the conversion of EBF to MBF and SOF, the soil total phosphorus content increased significantly, which may be related to soil moisture [23] and fertilization.

4.2. Trade-Offs of Soil Ecosystem Services

The evaluation of soil ecosystem services, as well as tradeoffs or synergies among these services, are current research hotspots [40–43]. After the natural forest was converted into artificial forest, soil organic carbon decreased significantly [32–34]). Through reasonable forest management, including the selection of afforestation tree species, forest rearing, and cutting measures, maximizing the carbon sequestration potential of artificial forests has become a global focus [4]. However, there are significant differences in ecosystem services such as soil carbon sequestration, water conservation, and nutrient accumulation in different plantations [44]. In addition, the tradeoffs between forest ecosystem services are not constant and vary greatly in different regions and at different scales [45].

There were trade-offs and synergies between carbon sequestration, water conservation, and nutrient maintenance in different forest types. The water conservation capacity of moso bamboo forest is better than that of evergreen broadleaf forest [35]. Soil water retention positively promoted soil bacterial diversity, which could increase available P content in the surface soil layer [46]. However, the density of soil organic carbon in evergreen broadleaf forest was higher than that in moso bamboo forest [47]. Plantation is considered to be one of the effective measures to reduce soil erosion and achieve rapid vegetation restoration. However, scientific planting should be carried out in combination with ecosystem services of different plantations during the plantation transformation or restoration of degraded ecosystems [43].

4.3. Implications for Forest Management

Moso bamboo forest and sugar orange forest are two main plantations in Liuxihe National Forest Park. Different from other areas, strict forest protection policies are adopted in Liuxihe National Forest Park, and strict approval procedures are required for deforestation. Liuxihe National Forest Park is located in the upper reaches of the Liuxihe River basin, which is an important water conservation area. In view of moso bamboo forest having a good soil water conservation function, it should be protected from damage, which is conducive to the stability of regional water conservation capacity. Forest operations in forest parks should be avoided, since this could lead to negative effects on soil quality and contribute to an increase in the risk of soil degradation [48]. As for fruit forests such as sugar orange forest, it can be restored to evergreen broadleaf forest or moso bamboo forest in the future. Integrating soil ecosystem services into management decisions is an important direction when formulating forest protection and restoration policies [49,50].

4.4. Limitations

In this study, only three soil ecosystem services including carbon sequestration, water conservation, and nutrient accumulation were selected to compare the differences among different forest ecosystems, which had certain limitations. In the future, ecosystem services such as biodiversity conservation and pollutant purification can be included [1], so as to better analyze the trade-off and synergistic relationship of soil ecosystem services. We used a space-for-time substitution approach instead of sampling the soil before and after forest conversion and analyzing its changes. Although this is an effective method [25], it is difficult to ensure complete consistency of environmental characteristics. The main difference in soil carbon storage is in the surface layer [51], so we collected soil samples from a 0–40 cm depth for analysis. However, the dynamic of ecosystem services in the deep soil may be different from those in the surface layer. In addition, spatial analysis can be carried out from the perspective of landscape to evaluate the spatio-temporal changes in different forest types and the evolution of ecosystem services [52,53], thus providing support for forest management.

5. Conclusions

We analyzed the changes in soil ecosystem services after the conversion of evergreen broadleaf forest to moso bamboo forest and sugar orange forest. The conversion of EBF to MBF and SOF will reduce its carbon sequestration function. When evergreen broadleaf forest is converted to moso bamboo forest, soil water conservation function will be enhanced. Forest conversion did not cause significant changes in soil total nitrogen, but caused a significant increase in soil total phosphorus. The use of soil indicators to assess soil ecosystem services is helpful for a rapid assessment of forest soil ecosystem services. Evaluating the changes in forest soil ecosystem services caused by forest conversion can be used to evaluate ecological effects caused by forest degradation or ecological restoration. The trade-offs or synergies of soil ecosystem services brought about by forest conversion should be evaluated, which can provide reference for forest restoration. Evergreen broadleaf forest in the study site has a good carbon sequestration function, which needs to be further protected. Moso bamboo forest has good water conservation and nutrient accumulation function, and it also has good ornamental value and can be properly reserved. Sugar orange forest can be gradually restored to evergreen broadleaf forest or partially transformed to moso bamboo forest in the future. The study on changes in forest soil ecosystem services will contribute to the formulation of forest management policies, improve the value of ecological products in national forest parks, and promote the win–win situation of stakeholders.

Author Contributions: Conceptualization, methodology, software, resources, writing—original draft preparation, funding acquisition, C.Z.; investigation, validation, formal analysis, data curation, C.Z. and W.C.; writing—review and editing, C.Z. and X.Z.; visualization, Y.H.; supervision, M.D. All authors have read and agreed to the published version of the manuscript.

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