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Trade-Offs and Synergies between Plant Species Diversity and Water Retention Capacity of *Pinus massoniana* Plantation Community in Danjiangkou Reservoir Area

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Abstract: In order to quantify the plant species diversity characteristics of *Pinus massoniana* plantations with different stand densities in the Danjiangkou reservoir area of Hubei Province and the relationship of their trade-offs and synergies with the water retention capacity in the reservoir area to give full play to the forest ecosystem services in the reservoir area and improve the level of sustainable management of plantations, we used the typical plot method, selected 35-year-old *Pinus massoniana* with low density (925–1000 plants·ha), medium density (1425–1625 plants·ha), and high density (2375–2525 plants·ha), and its community structure, species composition, and understory plant species diversity were studied, respectively, and the relationship of the trade-offs and synergies between the two services of water retention capacity and plant species diversity in *Pinus massoniana* plantations were calculated. We found that: (1) According to the survey statistics, there were 69 species of plants in the shrub and herb layers under forest including 32 species of shrubs and 37 species of herbs, belonging to 33 families and 62 genera. (2) The species richness of the shrub layer increased with the increase in the stand density, which was opposite in the herb layer. The Shannon–Wiener diversity index and Simpson dominance index of the shrub layer showed the regularity of high density > low density > medium density, while the herb layer decreased gradually with the increase in density. The Pielou evenness index of the shrub layer and herb layer was the highest in the high-density and medium-density stands, respectively. (3) Trunk flow, soil layer water storage and plant species diversity under medium and high density conditions, litter layer water storage and plant species diversity under low-medium density conditions showed synergistic relationships in the shrub layer and herb layer, everything else were trade-off relationships. As far as the Danjiangkou reservoir area is concerned, the low-density *Pinus massoniana* plantations have higher understory plant species diversity and more stable community structure, and there is a trade-off relationship between the water retention capacity and understory plant species diversity.

Keywords: *Pinus massoniana* plantation; plant species diversity; trade-off; synergistic; ecosystem service; Danjiangkou reservoir area

Citation: Li, S.; Tang, Z.; Zhang, A.; Wang, A.; Qi, L. Trade-Offs and Synergies between Plant Species Diversity and Water Retention Capacity of *Pinus massoniana* Plantation Community in Danjiangkou Reservoir Area. *Forests* **2022**, *13*, 2081. https://doi.org/10.3390/f13122081

Received: 18 September 2022
Accepted: 6 December 2022
Published: 7 December 2022

1. Introduction

The concept of ecosystem services was first proposed by Wilson [1], and several other researchers have since further developed the study of ecosystem services [2,3]. Ecosystem services are benefits that are directly or indirectly derived through the structure, process, and function of the ecosystem, which are divided into provisioning, regulating, supporting, and cultural services, and include economic, ecological, and social values related to the ecosystem [4]

More and more attention has been paid to the study of ecosystem services of plantations [5,6]. Understory vegetation, as an indispensable part of the plantation ecosystem, is not only conducive to maintaining forest plant species diversity and optimizing community structure, but also plays an irreplaceable role in promoting the health of the soil–vegetation system and accelerating community succession [7], which is an important aspect of plantation ecosystem research. Species diversity can reflect the competition and coordination mechanism of each species in the community in terms of the resource space and living environment, and plays an important role in measuring the stability of the forest community structure and ecosystem function [8]. *Pinus massoniana*, as a suitable tree species and main cultivated tree species of water retention forest in most areas, has also been deeply studied by many scholars [9]. Cheng Changjin et al. [10] studied the interception effect of *Pinus massoniana* and other vegetation on nitrogen and phosphorus by simulating the surface runoff. Ding Xia et al. [11] analyzed the soil, litter and forest canopy from vertical level to discuss the water retention service function of *Pinus massoniana* forest. Among them, the maximum water holding capacity, effective water holding capacity, and soil effective water holding capacity of the litter layer were the highest in the medium density stand. Therefore, the results showed that the water retention capacity of the forest under medium density was the best. At present, most of the research on *Pinus massoniana* plantations have focused on the impact on carbon storage, soil quality, and nutrient cycling of the plantation [12–14], but there are relatively few studies on the community structure characteristics and diversity of the understory vegetation.

Danjiangkou Reservoir is located at the junction of Hubei, Henan, and Shaanxi Provinces. It is located in the middle and upper reaches of Hanjiang River, the largest tributary of the Yangtze River, connecting the Hanjiang River and its tributary Danjiang River. As the water source of the Middle Route Project of South-to-North Water Transfer, it is also an important local wetland and water source protection area. Since its official storage, the Danjiangkou Reservoir has continuously delivered high-quality, abundant drinking water to Northern China, benefiting 53 million residents in the provinces (cities) of Beijing, Tianjin, and Hebei, and effectively solving the water shortage problem of people along the route (https://www.ndrc.gov.cn/ accessed on 17 September 2022). Its ecological construction has largely determined the success or failure of the South–North Water Transfer Project [15]. Some scholars have studied the water and soil conservation capacity and water retention function of vegetation types such as conifer and cypress mixed forest [16] and oak and broadleaf mixed forest [17] in the Danjiangkou reservoir area. The representative plantations are *Cunninghamia lanceolata*, *Larix gmelinii*, and *Pinus massoniana*. *Pinus massoniana* is a typical coniferous tree species in the subtropical region of China. It has the characteristics of a large area, wide distribution, strong adaptability to climate and soil, rapid growth, and is easy to grow into forests. It is one of the afforestation species widely distributed in the Danjiangkou reservoir area. Taking the *Pinus massoniana* plantation in the Danjiangkou reservoir area as an example, this paper aimed to: (1) Discuss the impact of stand density change on the community structure and species diversity of *Pinus massoniana* plantation; (2) analyze the stand density most suitable for the local community environment; (3) investigate the trade-offs and synergies between the two ecosystem service functions of water content function and species diversity in the study area, with a view to providing theoretical references for the management and improvement of the comprehensive benefits of plantation forests in the reservoir area to further optimize the forest community structure, protect species diversity, and promote ecosystem health.

2. Materials and Methods

2.1. Study Area

The research area (Figure 1) is located in the Longkou Forestry Station (110°11′E–111°12′E, 32°40′N–32°41′N), Danjiangkou City, Hubei Province, covering an area of 5045.66 ha. Located in the source area of the middle line of the South-to-North Water Diversion Project, it belongs to the subtropical monsoon climate zone, with a warm climate, abundant precipitation, the same period of rain and heat, sufficient sunlight, and four distinct seasons. The average annual temperature is 15.9 °C, the average annual sunshine is 2009.5–2059.7 h, the average relative humidity is 71%, the frost-free period is 180–250 days, and the average annual precipitation is 750–900 mm, with the least rainfall in January and the most from July to September. The soil is mainly composed of yellow soil and yellow brown soil, the soil layer is thin and barren, and the erosion is serious. The forests in the reservoir area are mainly plantation forests and secondary forests. Tree layers include *Pinus massoniana*, *Quercus variabilis*, *Cupressus funebris*; the understory shrub layer includes *Rhus chinensis*, *Zanthoxylum bungeanum*, *Ziziphus jujuba*, *Sophora davidii*, etc. Herb layers include *Ophiopogon bodinieri*, *Imperata cylindrica*, *Trachelospermum jasminoides*, *Oxalis corniculata*, etc.

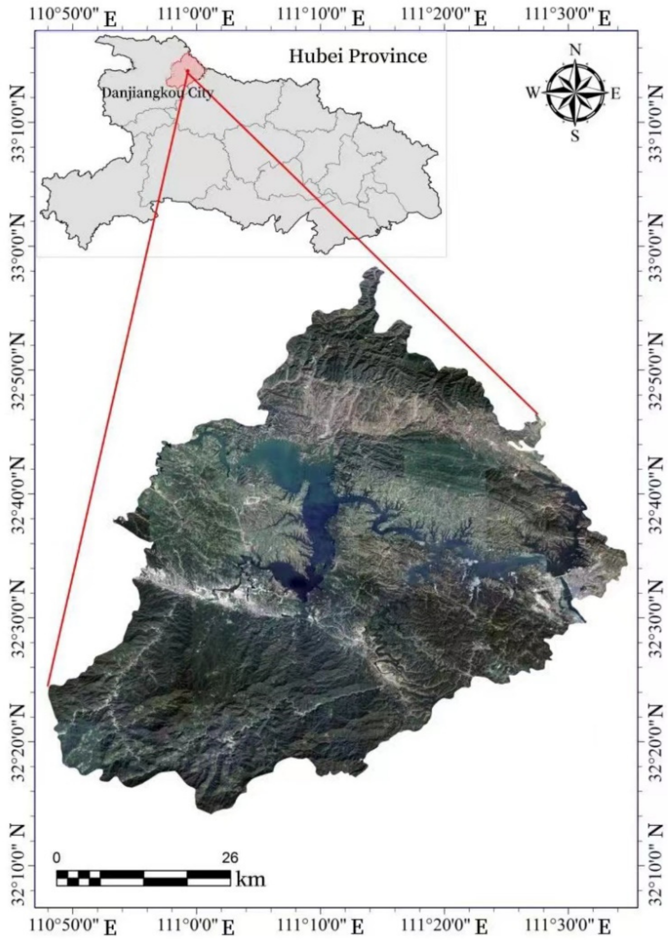

Figure 1. Location of the study area.

2.2. Method

2.2.1. Plot Setup and Investigation

Based on a field survey of plantation forests in the Danjiangkou reservoir area in 2018, sample plots were selected from stands of 35-year old *Pinus massoniana* plantation with basically the same stand conditions and representative of the plantation forests as the study objects. Three representative plots of low density (925–1000 plants·ha), medium density (1425–1625 plants·ha), and high density (2375–2525 plants·ha) were set, and the area of each plot was 20 m × 20 m. A total of 54 shrub quadrants with an area of 5 m × 5 m were set in each plot by the diagonal method. A total of 108 herbaceous quadrats with an area of 1 m × 1 m were set up. In each plot, all individual trees were examined by measuring each wood scale, and the site factors were recorded (Table 1).

Table 1. Basic information of the survey plots.

Geographical Position	Density /Plants·ha	Density Type	Slope/°	Altitude /m	Average Diameter/cm	Average Height/m	Rainfall /mm	Penetrating Rain/mm
111°11′55″ E, 32°40′50″ N	950	low	20	178	18.14 ± 0.59	12.94 ± 0.85	291.4	232.80 ± 32.76
111°11′9″ E, 32°40′1″ N	1000		17	260				
111°11′44″ E, 32°40′23″ N	925		19	207				
111°11′52″ E, 32°40′21″ N	1625	mid	21	190	16.34 ± 0.75	12.72 ± 0.16	291.4	213.87 ± 40.29
111°11′38″ E, 32°40′20″ N	1425		17	202				
111°11′59″ E, 32°40′37″ N	1425		15	198				
111°11′40″ E, 32°41′21″ N	2400	high	27	231	12.79 ± 1.35	13.24 ± 2.19	291.4	209.67 ± 38.02
111°12′23″ E, 32°40′35″ N	2525		19	192				
111°12′12″ E, 32°40′38″ N	2375		21	189				

2.2.2. Methods for Analysis of Understory Plant Species Diversity

In this paper, based on the plant community diversity measure reviewed by Ma et al. [18–20], the totaling species importance value [21] IV, species richness index [22] S, Shannon–Wiener diversity index [23] H, Simpson dominance index [24] D, and Pielou evenness index [25] J were used to evaluate the community species diversity characteristics. The calculation formulae are as follows:

$$\text{IV} = (\text{relative density} + \text{relative frequency} + \text{relative significance})/3 \times 100\% \quad (1)$$

$$\text{Species richness: S} \quad (2)$$

$$\text{Shannon–Wiener diversity index}: \text{ H} = -\sum_{i=a}^{S} P_i \log P_i \quad (3)$$

$$\text{Simpson dominance index}: \text{ D} = 1 - \sum_{i=1}^{S} P_i^2 \quad (4)$$

$$\text{Pielou evenness index}: \text{ J} = \frac{-\sum P_i \log P_i}{\log(S)} \quad (5)$$

In the formulae, $P_i = \frac{n_i}{n}$, i = 1,2,3, . . . , is the proportion of the number of individuals of the ith species in the total number of individuals of the species; n_i is the number of individuals of the ith species and n is the total number of individuals of the survey species; S is the number of species.

2.2.3. Calculation of Water Retention Capacity

In this paper, the comprehensive water storage capacity method [26] was used to measure various water retention indicators of *Pinus massoniana* plantations with different densities from three vertical layers of the forest—canopy, litter, and soil. The specific indicators include canopy interception, trunk runoff, penetration rainfall, litter water holding capacity, and soil water holding capacity.

In the sample plots of *Pinus massoniana* plantations with different densities and in the open areas outside the forest, RG3 automatic rainfall recorders were installed to measure the penetration rain and rainfall in the forest, and then accurately calculate the canopy interception and other data. The calculation formula of the canopy interception rate [27] is as follows:

$$\text{a} = \frac{P - T - F}{P} \times 100\% \quad (6)$$

In the formula, a is the canopy interception rate (%); P is the rainfall (mm); T is the penetration rainfall in the forest (mm); and F is the trunk runoff (mm).

Five litter plots of 1 m × 1 m were evenly arranged along the diagonal in each plot, and the water holding capacity of the litter was determined by the "indoor soaking method" according to the stand density. In order to be closer to the actual interception amount of litter, the formula [28] is used to calculate:

$$W = (0.85 \times R_m - R_0) \times M \quad (7)$$

where W is the effective interception (t·ha); R_m is the maximum water holding rate (%); R_0 is the average natural water content (%); and M is the litter storage volume (t·ha).

Using the S-type sampling method, five sampling points were arranged in the *Pinus massoniana* plots with different densities, and a soil profile was dug for each sampling point to measure the soil water content. In this study, the calculation formula of water storage per unit area of soil layer [29] is:

$$S = \sum_{i=1}^{n} \theta_i H_i A_i \quad (8)$$

where S is the water holding capacity of soil layer per unit area (mm); θ is soil porosity (%). H is the measured soil layer thickness (cm); A is the area (ha); i denotes plots with different stand densities

2.2.4. Calculation of Tradeoffs and Synergies

The ecosystem services trade-offs and synergies degree (ESTSD) can effectively quantify the relationship between various services [30]. Synergy describes a positive state of co-growth or co-decay between different ecosystems under the same driving force [31]. In contrast, trade-off refers to the state of antagonism between two or more ecosystem services under the same driving force [31–33]. According to the improved calculation method of ecosystem services trade-offs and synergies degree by Gong et al. [28], the trade-offs and synergies degree of species diversity and the water retention of the *Pinus massoniana* plantation in the Danjiangkou reservoir area were calculated. The calculation formulae are:

$$ESCI_i = \frac{ES_{ia} - ES_{ib}}{ES_{ib}} \quad (9)$$

$$ESTSD_{ij} = \frac{1}{2}\left(\frac{ESCI_i}{ESCI_j} + \frac{ESCI_j}{ESCI_i}\right) \quad (10)$$

where ES_{ia}, ES_{ib} represent the capacity of i ecosystem services under conditions a and b, respectively; $ESCI_i$ is the change index of i ecosystem services; $ESTSD_{ij}$ is the i and j ecosystem services trade-offs and synergies degree. If $ESTSD_{ij} > 0$, there is a synergistic relationship between two ecosystem services, otherwise it is a trade-off relationship. Density canopy interception, trunk flow, litter interception, and soil interception were included in the calculation. In this paper, the spatial variation replaced the temporal variation under different stand densities to reflect the difference in plant species diversity and water retention ecosystem service capacity of the *Pinus massoniana* plantations in the Danjiangkou reservoir area.

2.3. Data Processing

In this paper, SPSS 26.0 and Origin 2018 software were used for analysis and graphing, and the probability density function was selected to describe the distribution structure of tree height and DBH in the *Pinus massoniana* plantation. One-way ANOVA was performed to test the differences of stand structure and species diversity index under each stand density using the *t*-test and LSD method, and the significance level was $\alpha = 0.05$.

3. Results and Analysis

3.1. Species Composition and Diversity of Understory Vegetation

A total of 69 plant species were recorded in the study plot, belonging to 33 families and 62 genera (Figure 2). There were 20 species of shrub layer plants and 26 species of herb layer plants in the low-density stand, and the vegetation diversity was significantly better than that of the medium- and high-density stands. In the shrub layer of different densities, *Rubus coreanus*, *Rhus chinensis*, *Broussonetia papyifera*, and *Discocleidion rufescens* were the dominant species (Table 2). In the herb layer, *Trachelospermum jasminoides*, *Crepidiastrum lanceolatum*, *Corydalis edulis*, and *Ophiopogon bodinieri* were the dominant species, which to a certain extent indicate that the above plants have good growth and development status and regeneration ability in the community and occupy a wide ecological niche. The important values of *Rubus coreanus* in the shrub layer were higher in each density stand, which were 0.5209, 0.3691, and 0.3441, respectively, and the important r values of *Rhus chinensis* in the low- and medium-density stands were 0.4529 and 0.4705, respectively, but the important value ranked low in the high-density stands, which indicates that the dominant position of *Rhus chinensis* in the *Pinus massoniana* stands was slightly lower than that of *Rubus coreanus*. In the herb layer, the *Crepidiastrum lanceolatum* had a high dominant position in the three densities, and the important values from low-density to high were 0.3520, 0.3386, 0.5403, while in the high-density stands, the most important value of *Trachelospermum jasminoides* was 0.7281, which indicates that *Trachelospermum jasminoides* can still have tenacious vitality and strong competitiveness under low light. In addition, the low-density and high-density stands were the most dominant in *Ophiopogon bodinieri* and *Corydalis edulis*.

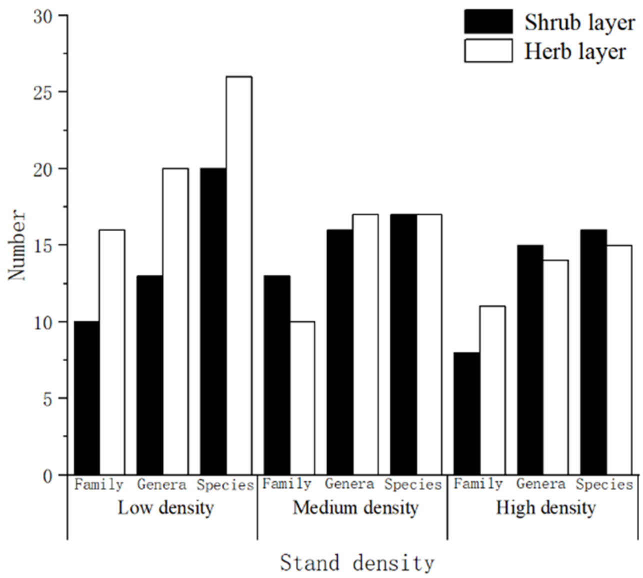

Figure 2. Species composition of the understory plants in *Pinus massoniana* plantations with different stand densities.

Table 2. Important values of the understory vegetation dominant species in *Pinus massoniana* with different densities.

Layer	Density	Dominant Species	Importance Value
Shrub layer	Low	*Rubus coreanus* + *Rhus chinensis* + *Discocleidion rufescens* + *Rubus corchorifolius* + *Pistacia chinensis*	0.5209 + 0.4529 + 0.4214 + 0.3874 + 0.3869
	Mid	*Rhus chinensis* + *Rubus coreanus* + *Sapium sebiferum* + *Broussonetia kazinoki* + *Quercus variabilis*	0.4705 + 0.3691 + 0.3474 + 0.2603 + 0.2096
	High	*Broussonetia papyrifera* + *Melia azedarach* + *Broussonetia kazinoki* + *Rubus coreanus* + *Rubus corchorifolius*	0.4992 + 0.3512 + 0.3512 + 0.3441 + 0.2945

Table 2. *Cont.*

Layer	Density	Dominant Species	Importance Value
Herb layer	Low	*Ophiopogon bodinieri* + *Dendranthema indicum* + *Imperata cylindrica* + *Crepidiastrum lanceolatum* + *Oxalis corniculata*	0.4276 + 0.3809 + 0.3581 + 0.3520 + 0.3030
	Mid	*Corydalis edulis* + *Crepidiastrum lanceolatum* + *Imperata cylindrica* + *Dendranthema indicum* + *Digitaria sanguinalis*	0.4230 + 0.3386 + 0.3220 + 0.2619 + 0.2443
	High	*Trachelospermum jasminoides* + *Crepidiastrum lanceolatum* + *Digitaria sanguinalis* + *Oxalis corniculata* + *Corydalis edulis*	0.7281 + 0.5403 + 0.3816 + 0.3441 + 0.3177

By analysis of the species diversity index of the shrub–herb layer in the *Pinus massoniana* (Table 3), the Shannon diversity index H, Simpson dominance index D, and Pielou evenness index J in the low- and medium-density stands showed that the shrub layer < herb layer, while in the high density stand, the shrub layer > herb layer. The diversity, uniformity, and dominance of the shrub layer were the highest in the high density stand, followed by the low density stand. In the herb layer, the species richness, Shannon–Wiener diversity index, and Simpson dominance index were the largest in low-density stands, and the evenness was slightly lower than that in the medium-density stand. The evenness of the medium-density stands was the largest, and the high density was the smallest, and in the shrub layer and herb layer, the stand uniformity of medium and high density were significantly different ($p < 0.05$).

Table 3. Understory plant species diversity index of the *Pinus massoniana* plantation with different densities.

Level	Density	S	H	D	J
Shrub layer	Low	7.00 ± 2.00 a	0.68 ± 0.13 a	0.74 ± 0.07 a	0.81 ± 0.04 ab
	Mid	9.33 ± 2.51 a	0.64 ± 0.14 a	0.67 ± 0.13 a	0.67 ± 0.16 b
	High	9.33 ± 0.58 a	0.83 ± 0.04 a	0.81 ± 0.03 a	0.86 ± 0.03 a
Herb layer	Low	10.67 ± 3.061 a	0.93 ± 0.09 a	0.86 ± 0.03 a	0.91 ± 0.04 ab
	Mid	8.67 ± 3.51 a	0.84 ± 0.181 ab	0.83 ± 0.06 ab	0.93 ± 0.04 a
	High	6.67 ± 3.51 a	0.60 ± 0.29 b	0.66 ± 0.22 b	0.74 ± 0.17 b

Note: Different lowercase letters indicate significant differences between forests of different density at the same level ($p < 0.05$).

3.2. Water Retention Capacity of Pinus massoniana Plantation

By monitoring the rainfall in the flood season (June–September) in the study area, a total of eight effective rainfalls were recorded, with a total rainfall of 291.4 mm, and the average penetration rainfall in the *Pinus massoniana* plantation forest during the wet season was 218.78 mm. The canopy interception rate of the whole stand was 23.56%, there was no obvious change trend in the rate of runoff, and the average runoff rate of the stand as a whole was 1.83% (Table 4). The thickness of the litter increased with the stand density and the effective interception amount increased correspondingly. Overall, the effective interception rate of the litter layer was 25.39%. In the 0–30 cm soil layer, the soil density was 1.45–1.54 g·cm^{-3}, which was low density > high density > medium density, and the average order of total porosity was medium density > high density > low density, the mean non-capillary porosity was ranked as medium density > low density > high density, and the variation range of the effective water holding capacity of the soil layer was 2.94–4.81 mm. It is comprehensively known that the soil density of the medium-density stand was the smallest, and the total porosity and the non-capillary porosity were the largest, indicating that the *Pinus massoniana* plantation had the best soil water-holding performance under the medium-density, and the effective interception rate of the soil layer on the stand was 2.24%.

Table 4. Water retention capacity at different levels of *Pinus massoniana* plantations with different densities.

Density	Canopy Interception	Trunk Flow	Litter Interception	Soil Interception
Low	19.26%	1.06%	20.32%	2.36%
Mid	24.77%	2.50%	27.27%	2.68%
High	26.66%	1.93%	28.59%	1.69%
Average	23.56%	1.83%	25.39%	2.24%

3.3. Trade-Offs and Synergies Analysis of Plant Species Diversity and Water Retention Capacity

Under the conditions of changing from low- to medium-density and from medium- to high-density, the plant species diversity change index all showed negative values. The understory plant species diversity of the *Pinus massoniana* plantation and its water retention capacity generally showed a trade-off relationship (Table 5). In accordance with the actual situation in the study area and the needs of the research objectives, the water retention capacity of this paper consisted of canopy interception, trunk flow, litter interception, and soil interception. The diversity of plant species in the understory was calculated separately for the shrub layer and the herb layer. On this basis, their trade-offs and synergistic relationships were calculated (Table 6). It shows that the plant species diversity and water retention capacity were mostly in a trade-off relationship. In the shrub layer, the trade-off relationship between trunk flow and plant species diversity under low-medium density conditions was the most prominent, and a synergistic relationship between the soil water storage and plant species diversity under medium-high density conditions was the most prominent; in the herb layer, a trade-off relationship between soil water storage and plant species diversity under low-medium density conditions was the most prominent, and a synergistic relationship with plant species diversity under medium–high density conditions was the most prominent. Among them, the trunk flow and soil water storage and plant species diversity under medium–high density conditions and litter layer water storage and plant species diversity under low–medium density conditions showed a synergistic relationship in the shrub layer and herb layer. Everything else showed a trade-off relationship. Among the calculated indices, the trade-off rate of forest canopy interception, trunk flow, litter layer water storage, and soil water storage with the shrub layer and herb layer was 61.54% and synergy rate was 38.46% under different density changes.

Table 5. Trade-off and synergistic relationship between the water retention capacity and biodiversity change index.

Density Change	ESCI of Biodiversity	ESCI of Water Retention	ESTSD
Low–mid	−0.26	0.14	−1.18
Mid–high	−0.09	0.03	−1.53

Table 6. Trade-offs and synergies between plant species diversity and water retention capacity in the shrub layer and herb layer.

	Layer	Density Change	Canopy Interception	Trunk Flow	Litter Layer Water Storage	Soil Water Storage
Cor.	Shrub		−0.999	−0.760	0.837	0.612
	Herb		−0.997	−0.804	0.874	0.554
Trade-offs and synergies	Shrub	Low–mid	−1.2156	−3.938	1.036	−1.725
		Mid–high	−1.033	2.175	−1.046	3.380
	Herb	Low–mid	−1.018	−1.827	1.674	−3.680
		Mid–high	−1.097	1.270	−1.538	1.804

This paper further explained the trade-offs and synergies between plant species diversity and water retention capacity in the understory by conducting a Pearson correlation analysis between the plant species diversity under the shrub and herb layers and the retention capacity of the canopy layer, trunk stem flow, litter layer, and soil layer. The results showed that the understory plant species diversity was negatively correlated with interception in the upper layers of the *Pinus massoniana* plantation, but positively correlated with the litter layer interception and soil layer interception. Among them, the canopy interception showed a significant negative correlation with biodiversity ($p < 0.05$), in other words, the higher the density of the *Pinus massoniana* plantation forest, which means more interception, the lower the diversity of plant species in the understory. Trunk flow was negatively correlated with the plant species diversity, but the correlation was relatively weak because the trunk flow rate was relatively less affected by rainfall (Table 4), and therefore the trunk flow had less impact on the understory organisms. The water retention capacity of the litter layer and soil layer had a positive correlation with the understory plant species diversity. The understory could store more water, which means that it can reserve more material conditions for understory plant species diversity. This result further verified that there is a trade-off between plant species diversity and water retention capacity, that is, the richness of the understory plant species diversity in forests with a high canopy density is lower than that in stands with medium- and low-density.

4. Discussion

In this study, with the increase in the stand density, the species diversity decreased gradually, and the species richness and Shannon–Wiener diversity index of the shrub layer also decreased with the increase in the stand density. The diversity of shrub vegetation was also different among the three densities, indicating that the understory vegetation composition is sensitive to the change in the canopy density and microenvironment, which is consistent with the research results of many scholars [34]. The research results of Lu et al. [35] showed that the stand density will limit the species and quantity of undergrowth plants by changing the soil, temperature, and light intensity in the forest and the distribution of soil nutrient elements in the forest. With the increase in stand density, the amount of light penetrating through the forest decreases, which affects the decomposition of litter [35] and there is insufficient light in the forest, which directly leads to the decrease in soil fertility, thus resulting in the decrease in the species diversity of the understory plants. Unlike herb plants, the species richness of shrubs increased slightly with the increase in stand density, indicating that the survival ability of shrubs in high-density stands is obviously better than that of dwarf grasses, indicating that with the increase in the stand density, the canopy density increased, and the competition for resource space of the tree layer species intensified, which inhibited the survival of the understory vegetation species. In the long succession process, some species without competitive advantage are gradually eliminated.

The calculated results of the ecosystem service relationship between the water retention capacity and understory plant species diversity of the *Pinus massoniana* plantation in the Danjiangkou reservoir area showed that there is a trade-off relationship between the two services, and the higher the stand density, the greater the trade-off. As far as the study area is concerned, the larger the stand density, the higher the canopy density, and the larger the canopy interception. With the increase in the stand density, the living environment under the canopy deteriorates, and the species number of understory plants decreases due to the lack of sufficient water and light. Therefore, water retention and biodiversity services present a trade-off relationship.

In contrast, China's plantation structure is a single tree-layer, plant species diversity is low, ecological stability and stress resistance are poor, and productivity and pollution resistance are low. In forestry management, intensive afforestation technical measures are not fully implemented, and soil erosion and soil fertility degradation are common [36]. Research on trade-offs and synergies among ecosystem services is an important means to clarify the relationships among various services, and is also the premise for managers to put forward targeted strategies. Plant species diversity is the basis of maintaining ecosystem health and stability, and indirectly reflects the quality and sustainable management level of the plantation. The species diversity of the understory vegetation plays an important role in improving forest productivity, maintaining forest community stability, and exerting ecosystem functions [37]. Appropriate stand density is beneficial to improving the stand structure, maintaining higher species diversity of each community, and promoting the natural regeneration of stands. Therefore, it is very necessary to control reasonable stand density in the process of watershed ecological environment management. Therefore, it is suggested that the medium-density forest should be taken as a reference, the over-dense forest should be tended and selectively cut, and the over-sparse forest should be replanted with fast-growing, shade-tolerant and stress-resistant broad-leaved species. In the investigation of the study area, it was found that there are many natural regeneration broadleaf seedlings under the forest, which can be considered to protect them, increase the mixing ratio, and improve soil fertility and ecological function.

5. Conclusions

In this study, a total of 69 species of shrubs and herbs were investigated and counted including 32 species of shrubs and 37 species of herbs, belonging to 33 families and 62 genera. The data in Table 3 show that the species richness of the shrub layer increased with increasing stand density, while the opposite was true for the herbaceous layer. The Shannon–Wiener diversity index and Simpson dominance index of the shrub layer showed a pattern of high density > low density > medium density, while the herbaceous layer gradually decreased with increasing density. The Pielou evenness index was the highest in the high-density and medium-density stands for the shrub and herbaceous layers, respectively. The trunk stem flow and soil layer interception are synergistic with biodiversity at medium–high densities. Except for trade-offs, litter layer interception with biodiversity at low–medium densities in the shrub and herb layers also showed a synergistic relationship.

Sustainable development particularly emphasizes the importance of forests in social and economic development in China [38]. In order to better maintain the plant species diversity of *Pinus massoniana* plantations, give full play to the ecological benefits of the plantation, and promote the healthy development of habitat quality in the reservoir area, comprehensive analysis of the plant species diversity of understory vegetation and its water retention capacity was carried out. Among the ecosystem services of *Pinus massoniana* plantations in the Danjiangkou reservoir area, there was a trade-off relationship between the water retention capacity and community plant species diversity. Comprehensive consideration of the relationship between multiple ecosystem services, combined with site conditions, focusing on selecting key ecosystem services for governance and improvement, is a necessary condition to promote the value of ecosystem services in the basin.

Author Contributions: S.L. and Z.T. analyzed the data and wrote the paper, A.Z. and A.W. conducted the field investigation and sample analyses, L.Q. contributed to the draft manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Key R&D program of China, grant number 2022YFF1303001.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: This work was jointly funded by the National Key R&D program of China (2022YFF1303001.). Thanks to Jian Zhang, Changjin Cheng, and Xia Ding for their help in the process of conducting experiments and writing the manuscript.

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

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