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Comparing the Water-holding Characteristics of Broadleaved, Coniferous, and Mixed Forest Litter Layers in a Karst Region

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Karst forests are often located in mountainous regions, and because of various geological factors both soil and water loss are major conservation concerns. We investigated the water-holding characteristics of 3 typical karst forest types through field sampling and laboratory experiments. The results showed that (1) the total litter mass of the coniferous forest was significantly higher than that of either the mixed forest or the broadleaved forest; (2) the mass of semidecomposed litter was significantly higher than that of undecomposed litter; (3) the litter layers of the mixed and coniferous forests had similar maximum water-holding capacity, whereas the maximum water-holding capacity of the broadleaved forest was significantly lower; (4) the maximum water-retention capacity of both the mixed and coniferous forests was significantly higher than that of the broadleaved forest; and (5) water-absorption rate and maximum water-holding capacity varied significantly across forest and litter types, with the mixed forest and undecomposed litter layers tending both to hold more water and to absorb water more quickly than the other forest types or the semidecomposed litter layer. Because of the elevated water-holding capacity and absorption rate of the mixed forest in karst regions, special emphasis on the conservation of this complex forest ecosystem is critical from both hydrological and ecological perspectives.

Keywords: Forests; leaf litter; water-holding capacity; water absorption; karst; China.

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Introduction

Forests are usually located in mountain regions, which have significant ecological benefits such as climate regulation, rainfall interception, and improvement of ecological balance (Chang 2006; Serrano-Muela et al 2008; Pinos et al 2017; Wangdi et al 2017). Precipitation is intercepted by the canopy layer, interrupted by litter, and infiltrated into the soil to complete the water cycle. This process deeply influences a forest ecosystem's water budget (Llorens and Domingo 2007; Fan et al 2015). The litter layer, an interface between the atmosphere and the mineral soil, mainly comprises decomposing plant material and plays a significant role in hydrological processes (Keith et al 2010a). The litter layer is a mixture of undecomposed and semidecomposed litter (Keith et al 2010b). It redistributes rainfall by covering the mineral soil and modifying the amount of rainwater available for infiltration and runoff, and consequently alters the forest

hydrological process (Sato et al 2004; Guevara-Escobar et al 2007; Keith et al 2010a). It also has great significance for water conservation and soil erosion prevention (Deguchi et al 2006; Staelens et al 2008).

Karst landscapes are widely distributed around the world, accounting for about 15% of the Earth's land surface (Larson 2011); the largest continuous karst area exists in mainly mountainous southwest China (He et al 2008; Huang and Cai 2009; Zhao et al 2014, 2015). In the mountainous karst regions of southwest China, soil formation is extremely slow because of the underlying highly porous limestone and highly heterogeneous microhabitats (Liu et al 2011; Deng et al 2018). Because of long-term development by humans, karst forest areas have been greatly reduced, currently covering 3% of the of karst ecosystem (Wang and Xu 2013). Although a large area of karst forest has disappeared, the small remaining amount still plays an indispensable role in biodiversity and mountainous karst ecosystem functions like water

FIGURE 1 Location of the study site. The dotted line is the borderline of China in the South China Sea. (Map by Qiuwen Zhou)
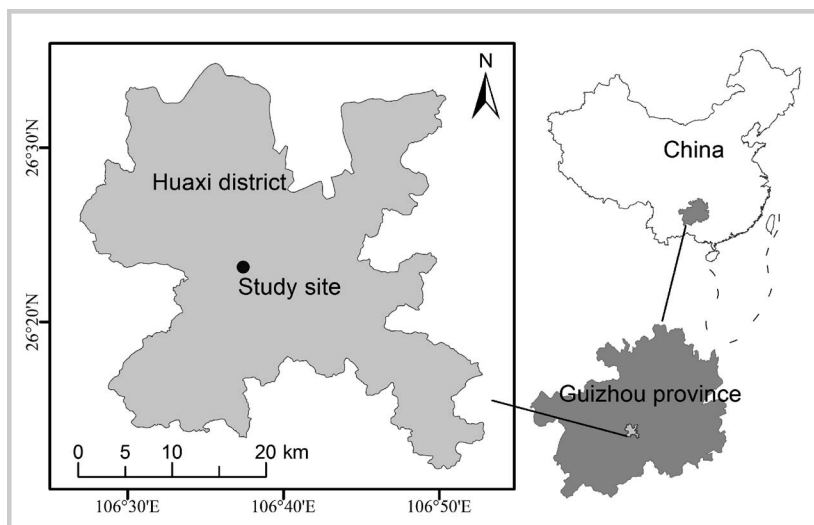
conservation and soil erosion prevention. Especially in mountainous karst regions with thin soil layers, the water storage and soil conservation function of the litter layer is very important.

Differences in the water-holding characteristics of the litter layer in different areas, under different forest types and other physical conditions, have been the focus of a great deal of research (Sato et al 2004). For example, Neris et al (2013) studied forest floor characteristics and their effects on hydrological processes in Andisols on Tenerife in Spain's Canary Islands. Keith et al (2010a) used a 3-dimensional coupled heat and water budget model driven by empirical data to investigate the water budget of a hill slope forest litter layer. Studying water conservation in karst areas, researchers have investigated litter fall dynamics, water-holding characteristics of litter for different broadleaved tree species, litter dynamics during vegetation restoration and succession, and the water-holding characteristics of soil and litter in secondary forest (Wei et al 2009). Most of these studies focused on a single forest type or tree species; few investigated the water-holding characteristics of litter layers in different forest types in the same area in a karst region. However, it is important to understand the water-holding characteristics of litter layers in different forest types under similar physical conditions. This information will be beneficial to the evaluation of forest ecological and hydrological functions in karst regions and the adoption of appropriate soil and water conservation and vegetation restoration measures.

For these reasons, broadleaved, coniferous, and mixed forest in the same growth environment in a karst region were selected for this study. The objective of the study was to explore the differences in the water-holding characteristics of leaf litter for different forest types in a karst area using field sampling and laboratory experiments.

Material and methods

Study area

The study area is located in the Huaxi district of Guiyang city, Guizhou province, in southwest China; the geographical position is 106.63°E, 26.38°N, and the average elevation is 1204.9 m (Figure 1). The area has typical karst topography with mountainous and hilly terrain. Because of the loss of surface soil and the destruction of vegetation, the landscape appears fragmented. The site is located in the subtropical monsoon humid zone. The annual average temperature is 14.9°C, with an annual accumulated temperature of 4504.7–4978.1°C above the standard temperature of 10°C. Calculated as averages, the annual maximum temperature is 35.1°C, the annual minimum temperature is −7.3°C, annual rainfall is 1178.3 mm, and annual evaporation is 738 mm. Although rainfall is abundant, surface-water resources are not, because of the large amount of underground leakage. The vegetation is middle-subtropical evergreen broadleaved forest. Because of destructive human activities such as logging and farming, secondary forest, shrub, and grass have increased. The bedrock is limestone, and the soil type is mainly Rendzic Leptosols.

Terminology

In this work, the water-holding characteristics are reflected in the following aspects: water-holding capacity, maximum water-holding capacity, maximum water-retention capacity, effective water-retention capacity,

TABLE 1 Characteristics of the sample plots.

Forest type	Mean trunk diameter (cm)	Mean height (m)	Canopy density	Density of trees (trees/ha)	Dominant species
Coniferous	16.1	12.6	0.90	2150	*P. massoniana* Lamb.
Broadleaved	13.2	10.8	0.77	1740	*Quercus acutissima* Carruth.
					Cinnamomum glanduliferum (Wall.) Nees
					Liquidambar formosana Hance
Mixed	14.4	12.1	0.87	1890	*P. massoniana* Lamb.
					Q. acutissima Carruth.
					C. glanduliferum (Wall.) Nees
					L. formosana Hance

temporal changes in water-holding capacity, and temporal changes in water-absorption rate. The above aspects eventually determine the water-conservation ability of leaf litter. The water-holding capacity is the amount of water that can be preserved in leaf litter, and the maximum water-holding capacity is the maximum amount of water that can be preserved in leaf litter. The maximum water-retention capacity is the maximum amount of water that can be retained after removing the amount of water contained in the leaf litter under normal conditions. Under natural conditions, litter is infiltrated by rainfall rather than completely submerged in water as in the immersion experiment. Therefore, usually the maximum amount of water that the litter can preserve during rainfall is less than in the immersion experiment. We defined the maximum amount of rainfall that the litter can preserve as the effective water-retention capacity. Similarly, the effective water-retention capacity is the amount of water contained in the leaf litter under normal conditions.

Sampling

In mid-October 2015, field sampling was conducted at the study site. Three 10×10-m standard sample plots were set up, one in each of the 3 forest types (broadleaved, coniferous, and mixed). Broadleaved forests are forests consisting almost entirely of broadleaved trees. Coniferous forests are forests composed almost entirely of conifer species. Mixed forests are forests with both broadleaved species and coniferous species. Within the plots, trunk diameter at 1.5 m height, tree height, canopy density, and tree density were measured (Table 1). In each plot, five 30×30-cm quadrats were also selected, as close to the plot's 4 corners and diagonal center as topography and rock exposure permitted, for the sampling of leaf litter. The thickness of the total litter layer as well as its semidecomposed and undecomposed components was

recorded, and the semidecomposed and undecomposed layers were sampled.

Measurements

Litter volume was measured with an oven-drying method (Carnol and Bazgir 2013). The litter samples were air dried and then placed in an oven to dry at 85°C; the dry weight was then taken as the litter mass. Litter water-holding capacity was determined by soaking in the laboratory (Gong et al 2007). A 50-g sample of dried litter was placed in a weighted gauze bag (pore size 0.2 mm), which was immersed in a plastic basin filled with clean water and soaked for time periods ranging from 5 minutes to a full day (5, 20, 30, 60, 90, 120, 240, 360, 480, 600, 840, and 1440 minutes). Maximum water-holding capacity was considered to have been reached after 24 hours (Gong et al 2007). The gauze bag was removed at the set time, and when water dripping had ceased, the bag was weighed using an electronic balance. Litter water-holding capacity was calculated as follows (Li et al 2015):

$$R_0 = (M_1 - M_2)/M_2 \times 100 \tag{1}$$

$$W_1 = M_{24} - M_0 \tag{2}$$

$$R_1 = (M_{24} - M_0)/M_0 \times 100 \tag{3}$$

$$W_2 = R_2 \times M_2 \tag{4}$$

$$R_2 = R_1 - R_0 \tag{5}$$

$$W = (0.85R_1 - R_0) \tag{6}$$

where M_0 is the litter weight after air drying in a well-ventilated indoor environment, M_1 is the fresh weight of the litter sample, M_2 is the weight of the litter after oven drying, and M_{24} is the weight of litter soaked for 24 h (all measured in grams); R_0, R_1, and R_2 represent mean water

FIGURE 2 Litter mass and thickness for each combination of forest and litter type. The large points represent the mean for each forest and litter combination, the smaller points represent the measured values for each sample, and the error bars represent the 95% CIs.
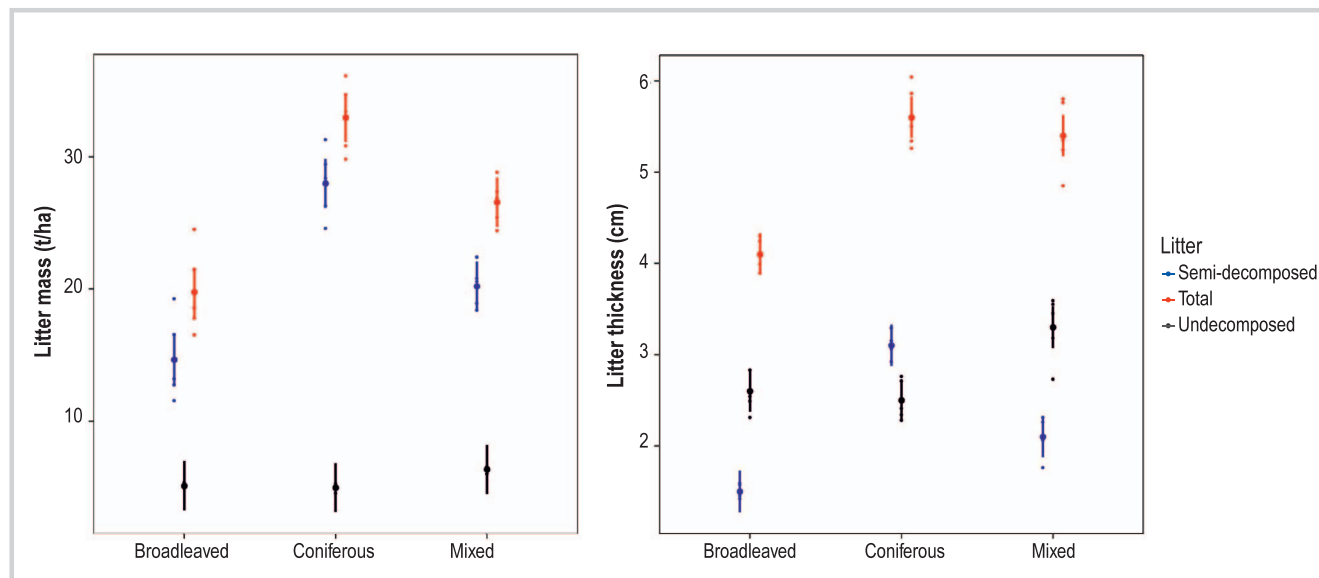
content, maximum water-holding capacity, and maximum water-retention capacity, respectively (all measured as percentages); W_1 and W_2 are the maximum water-holding capacity and the maximum water-retention capacity, respectively; W is the effective water-retention capacity; and M is the litter mass (the W and M values are all measured as t/ha). The maximum water-retention capacity is the maximum amount of water that the litter can retention in the immersion test. The effective water-retention capacity is the maximum amount of rainwater that can be retained by the litter layer under the forest in the natural field environment and is numerically smaller than the water-retention capacity. The measurements of litter water-holding capacity were obtained from the average of the 5 sample plots of each forest type.

Statistical analysis

The effects of both forest and litter type were compared against 5 response variables (litter mass, litter thickness, maximum water-holding capacity, maximum water-retention capacity, and effective water-retention capacity) using the general linear model

$$y_{i,f,l} = \alpha + \beta_f + \gamma_l + \tau_{f,l} + \varepsilon_{i,f,l} \qquad (7)$$

where y is one of the 5 response variables, α is the overall mean, β_f is the main effect of forest, γ_l is the main effect litter, and $\tau_{f,l}$ is the interaction between these effects. In all 5 models, the error was assumed to be normally distributed: $\varepsilon_{f,l} \sim N(0,\sigma^2)$. Each of the 5 models had a highly significant interaction term ($P < 0.001$), resulting in the retention of the full model.

The indoor soaking experiments were modeled using generalized additive models with the following structure:

$$g\left(E(y_{i,j,k})\right) = \alpha + f_j\left(log(t_i)\right) + S_i + \varepsilon_{i,j,k} \qquad (8)$$
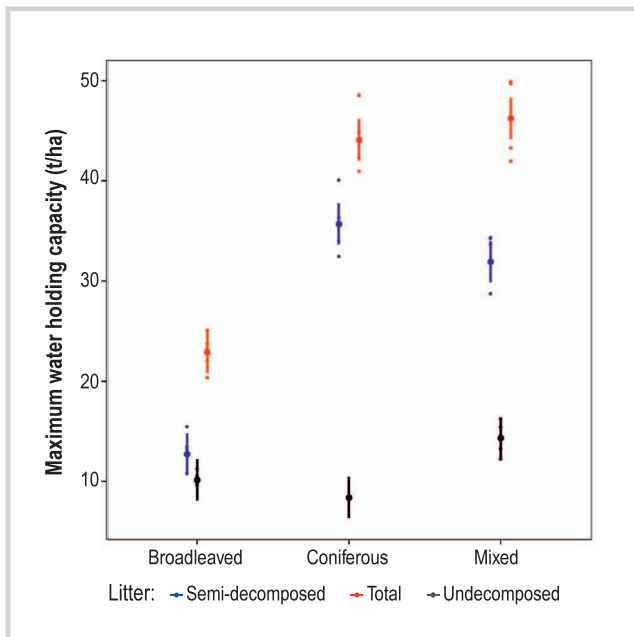
where y is water-holding capacity or absorption rate depending on which experiment is being analyzed, $g()$ is the link function, and α is the overall mean. The model combines each unique forest-litter type into one factor with j levels (9 levels in total) enabling the smooth function of the log-transformed soaking time to vary with each forest-litter level $f_j(log(t_i))$. The 5 samples for each combination of forest and litter types (45 samples in total) were incorporated as a random effect ($S_i \sim N(0,\sigma_S^2)$). The water-holding capacity model was assumed to have a Gaussian distribution ($\varepsilon_{ij} \sim N(0,\sigma^2)$) with an identity link ($g = 1$). The absorption rate model used a gamma (Γ) distribution ($\varepsilon_{ij} \sim \Gamma (a,b)$), where a and b are the shape and rate parameters; for this model, a log link ($g = log$) was used.

Results

Litter thickness and mass

Total and semidecomposed litter mass were significantly higher in the coniferous forest (33.0 and 28.0 t/ha) than in the mixed (26.6 and 20.2 t/ha) and broadleaved (19.8 and 14.7 t/ha) forests, whereas the mass of the undecomposed litter layers did not vary significantly between forest types, ranging from 5.0 to 6.4 t/ha (Figure 2). Semidecomposed litter accounted for 85% of the total litter mass in the coniferous forest, 76% in the mixed forest, and 74% in

Maximum water-holding capacity

The maximum water-holding capacity of the litter was affected by tree species composition, litter composition, and decomposition characteristics. The maximum water-holding capacity of the (total) litter differed among forest types (Figure 3), with the mixed (46.3 t/ha) and coniferous (44.1 t/ha) forests having significantly higher maximum capacity than the broadleaved forest (22.9 t/ha). The maximum water-holding capacity of the semidecomposed litter was more than twice that of the undecomposed litter for the coniferous (35.7 and 8.4 t/ha) and mixed forests (31.9 and 14.3 t/ha), but there was no significant difference in the broadleaved forest (12.7 and 10.2 t/ha).

Maximum and effective water-retention capacities

The maximum and effective water-retention capacities were used to measure the capacity of litter to intercept precipitation (note that 1 mm of precipitation is equivalent to 1 t/ha). These capacities varied among forest types (Figure 4). The maximum water-retention capacity of the semidecomposed litter was significantly higher for the coniferous (22.6 t/ha) and mixed (22.4 t/ha) forests than for the broadleaved forest (6.3 t/ha). The maximum water-retention capacity of the undecomposed litter was less than half that of the semidecomposed litter in the coniferous (7.1 versus 22.6 t/ha, $P < 0.001$) and mixed (11.5 versus 22.4 t/ha, $P < 0.001$) forests, but in the broadleaved forest it was slightly (although not significantly) higher for the undecomposed litter than for the semidecomposed litter (8.3 versus 6.3 t/ha, $P > 0.1$).

the broadleaved forest. Total litter thickness was significantly higher in the coniferous (5.6 cm) and mixed (5.4 cm) forests than in the broadleaved forest (4.1 cm). Whereas the semidecomposed litter was significantly thicker than the undecomposed litter in the coniferous forest (3.1 and 2.5 cm), the opposite pattern was observed in the mixed and broadleaved forests (Figure 2).

FIGURE 4 Maximum and effective water-retention capacity for each combination of forest and litter type. The large points represent the mean for each forest and litter combination, the smaller points represent the measured values for each sample, and the error bars represent the 95% CIs.
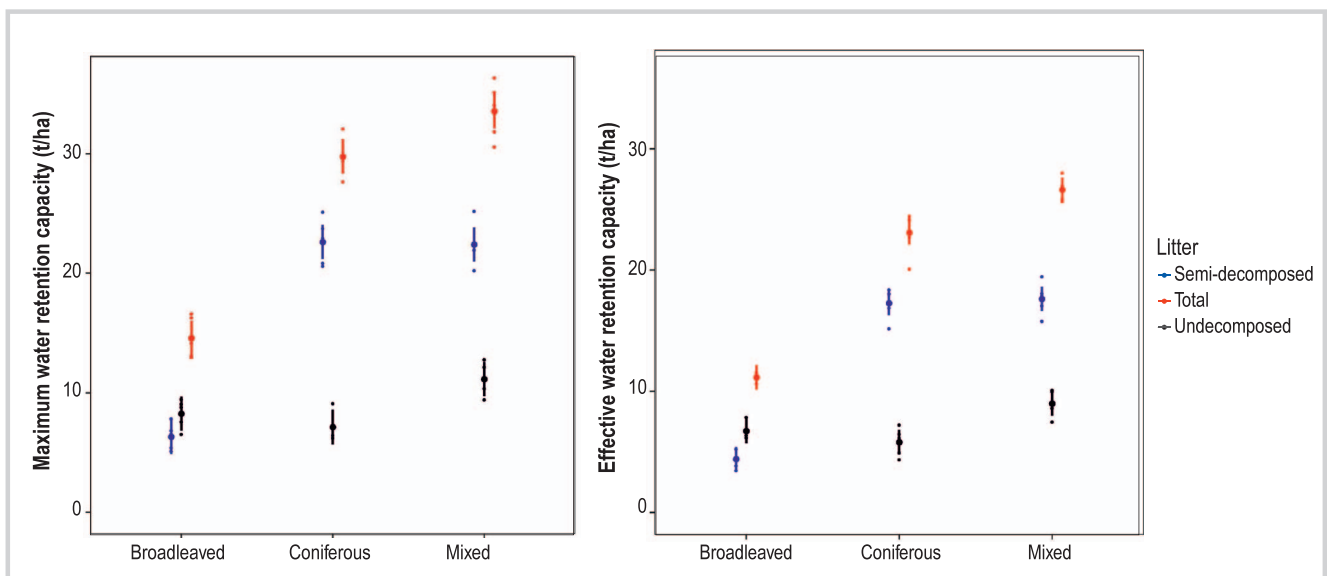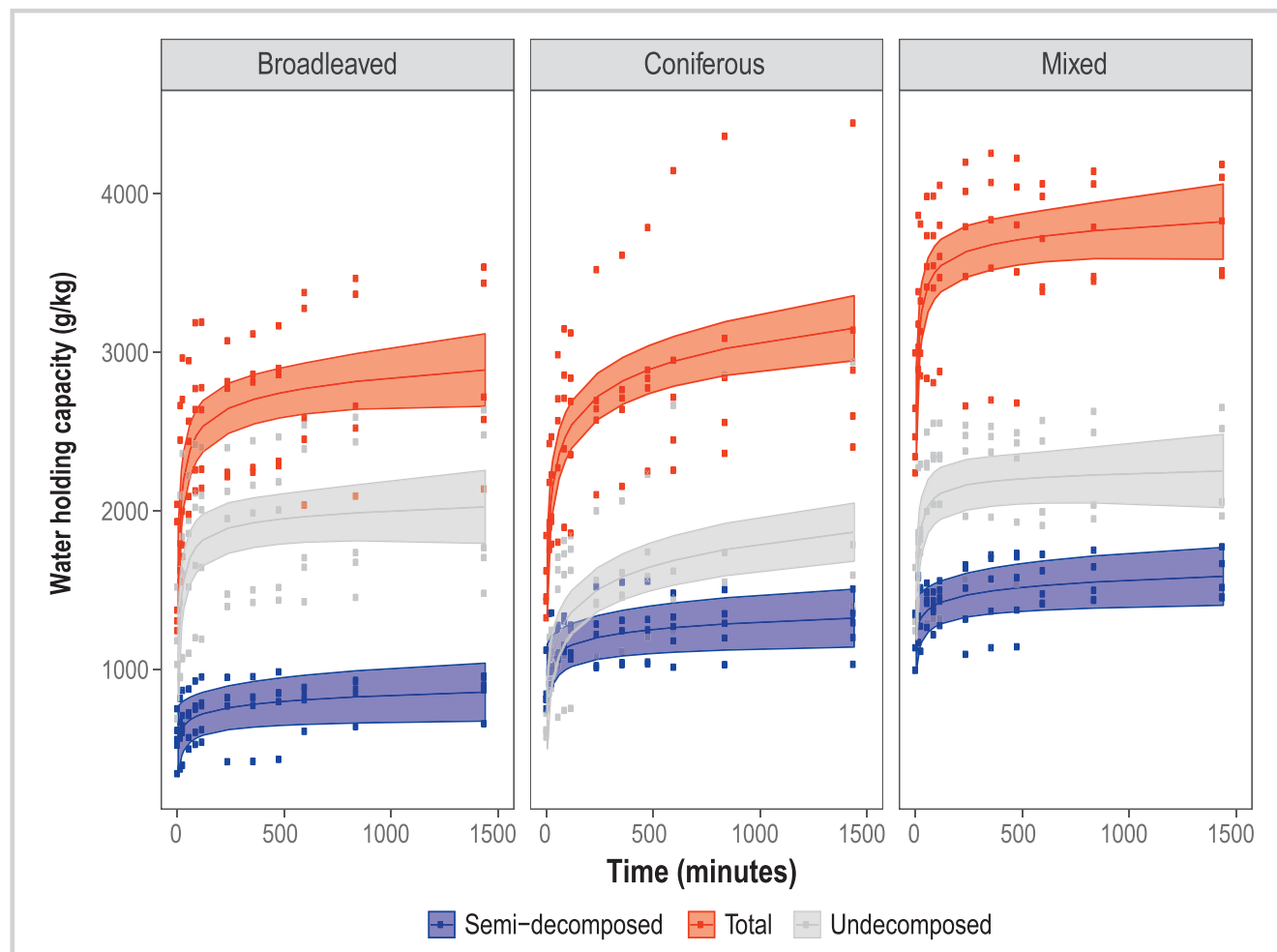
FIGURE 5 Water-holding capacity for each combination of forest and litter type during the soaking experiment. The points represent the measured values at each time step (from 5 minutes to a full day) for each of the 5 samples. The line represents the overall trend for each forest and litter type, and the shaded region represents the 95% CI.

The effective water-retention capacity trends were similar to those observed for maximum water-retention capacity. The semidecomposed litter's effective water-retention capacity was approximately 4 times higher for the coniferous (17.3 t/ha) and mixed forests (17.6 t/ha) than for the broadleaved forest (4.4 t/ha). The maximum water-retention capacity of the undecomposed litter was less than 35% of that of the semidecomposed litter in the coniferous (5.8 t/ha) and mixed forests (9.0 t/ha), but in the broadleaved forest it was higher (to a marginally significant degree) than that of the semidecomposed litter (6.7 versus 4.4 t/ha, $P \approx 0.05$).

For both the maximum and effective water-retention capacities for the undecomposed litter layer, the trend was mixed forest > broadleaved forest > coniferous forest, whereas for the semidecomposed litter, the trend was mixed forest ≈ coniferous forest > broadleaved forest. For the total litter layer, both the maximum and effective retention capacities were slightly higher in the mixed forest (33.6 and 26.2 t/ha) than in the coniferous

forest (29.8 and 23.1 t/ha) and over twice as high as in the broadleaved forest (14.6 and 11.2 t/ha).

Temporal changes in water-holding capacity

The results of the soaking experiment highlight the differences in how the litter layers from each forest type absorb water (Figure 5). In all cases an asymptotic relationship was found, with the majority of the water absorbed within the first 30 minutes. The total water-holding capacity at the end of the experiment was lowest in the broadleaved forest (2889 g/kg; 95% confidence interval [CI]: 2660–3116 g/kg), in large part because of the low water-holding capacity of the semidecomposed litter (857 g/kg; 95% CI: 675–1039 g/kg). The coniferous forest total water-holding capacity (3153 g/kg; 95% CI: 2947–3357 g/kg) was slightly higher than that of the broadleaved forest, driven largely by a significantly higher water-holding capacity of the semidecomposed litter (1324 g/kg; 95% CI: 1141–1506 g/kg). The mixed forest water-holding

capacity (3825 g/kg; 95% CI: 3588–4061g/kg) was approximately 21% higher than that of the coniferous forest. The difference was due to a strong contribution from both the undecomposed (2252 g/kg; 95% CI: 2022–2482 g/kg) and semidecomposed (1587 g/kg; 95% CI: 1405–1769 g/kg) litter layers.

Temporal changes in water-absorption rate

The soaking experiment measured how quickly the different litter layers were able to absorb water (Figure 6). The absorption rates for both the undecomposed and semidecomposed litter declined rapidly during the first 30 minutes of the experiment. Many of the differences between forest and litter types were difficult to discern during this initial phase, but the initial absorption rates for total (semidecomposed and undecomposed) litter were about 60% higher for the mixed forest (33,524 g/[kg·h]; 95% CI: 29,252–37,796 g/[kg·h]) than for the 2 other forest types. The difference in absorption rate held throughout the experiment; after 24 hours, the mixed forest absorption rate (167.9 g/[kg·h]; 95% CI:151.1–184.7 g/[kg·h]) was still higher than that of either the coniferous (138.6 g/[kg·h]; 95% CI: 124.7–152.5 g/[kg·h]) or broadleaved (129.2 g/[kg·h]; 95% CI: 116.2–142.1 g/[kg·h]) forest. The absorption rates of both the undecomposed and semidecomposed litter layers in the mixed forest (100.5 g/[kg·h] and 67.5 g/[kg·h]) were also higher than the absorption rates of the equivalent litter layer in either the coniferous (83.2 g/[kg·h] and 56.5 g/[kg·h]) or broadleaved (92.8 g/[kg·h] and 36.5 g/[kg·h]) forest after 24 hours.

At the start of the experiment, the absorption rate of the undecomposed litter was higher for the mixed and broadleaved forests (19,235 g/[kg·h] and 14,680 g/[kg·h]) than that of the semidecomposed litter (14,274 g/[kg·h] and 6536 g/[kg·h]); conversely, in the coniferous forest, the absorption rate was slightly higher for the semidecomposed litter (11,071 g/[kg·h]) than for the undecomposed litter (9092 g/[kg·h]). In the coniferous forest, the absorption rate of the undecomposed litter declined more slowly, and after 60 minutes it was slightly higher than the absorption rate of the semidecomposed litter. Throughout the remainder of the soaking experiment, the absorption rate was higher for the undecomposed litter than for the semidecomposed litter for all 3 forest types.

Discussion

The forest plays an important regulatory role in the water cycle. Although much research has already examined the relationship between forests and water, there are still many unresolved issues. Karst areas are mainly mountainous and ecologically fragile; they are characterized by a lack of water and soil, which serve as environmental constraints. Although there has been a great deal of research into the hydrological properties of forest litter in other types of forests, the litter water-holding characteristics of karst forests have not been well studied (Keith et al 2010a, 2010b). In this study, the water-holding characteristics of the litter layer were investigated by field sampling and a laboratory experiment. The aim of this study was to explore the differences in water-holding characteristics for different forest types in karst areas.

The hydrological effect of the litter layer in karst forests is obvious. In general, the water conservation ability of the litter layer was stronger in mixed forests than in coniferous and broadleaved forests, whereas the water conservation ability of the semidecomposed litter was stronger than that of the undecomposed litter for the coniferous and mixed forests, especially the coniferous forest. In this study, the litter layer thickness varied from 4.1 to 5.6 cm, the litter mass from 19.8 to 33.0 t/ha, and the maximum water-holding capacity from 22.9 to 46.3 t/ha. Wu et al (2013) studied the water-holding characteristics of forest litter in a high-elevation karst area 300 km from our study site, where the average elevation was more than 2000 m. They found that effective water-retention capacity was greater for mixed forest litter (2.59 t/ha) than for coniferous forest litter (1.63 t/ha) and maximum water-holding capacity was greater for mixed forest (5.38 t/ha) than for coniferous forest (2.63 t/ha). Their results and the results of this study both showed that the maximum water-holding capacity was greater for mixed forest than for coniferous forest. High-elevation karst areas are dry and cold; the growth of vegetation is restricted by these conditions, and litter layer water-holding performance is weak. Cui et al (2007) studied the maximum water-holding capacity of the litter layer in a northern subtropical karst area. Their results showed that this capacity was greater in broadleaved forest litter (12.80 t/ha) than in mixed forest (10.40 t/ha) and *Pinus massoniana* forest (8.20 t/ha). The maximum water-holding capacity of the forest litter layer in high-elevation karst areas was found to be lower than that found in this study.

Rao and Zhu (2007) studied the water-holding characteristics of evergreen broadleaved forest in a middle subtropical monsoon climate zone. The litter layer thickness for different forest types was 2.2–3.0 cm, the storage volume was 6.80–20.21 t/ha, the maximum water-holding capacity was 18.24–46.37 t/ha, and the maximum water-holding rate was 284–477%. It was found that the water conservation ability of the litter layer was greater in the karst area in Guizhou than in evergreen broadleaved forest in a middle subtropical monsoon climate zone. Zhang et al (2009) studied the water-holding characteristics of the litter layer in a southern subtropical monsoon climate zone. The results showed that the maximum water-holding capacity of evergreen broadleaved forest litter (32.10 t/ha) was greater than that of the forest litter in mixed forest (30.20 t/ha) and *P. massoniana* forest (27.60 t/ha). Wang et al (2016) studied the

FIGURE 6   Absorption rates for each combination of forest and litter type during the soaking experiment, presented on the natural scale and the logarithmic scale. The logarithmic scale is used to highlight the differences in absorption rates throughout the experiment, as they cannot be easily differentiated using the natural scale; this is due to the large and rapid declines in absorption rates during the first 60 minutes of the experiment. The points represent the measured values at each time step (from 5 minutes to a full day) for each of the 5 samples. The line represents the overall trend for each forest and litter type, and the shaded region represents the 95% CI.
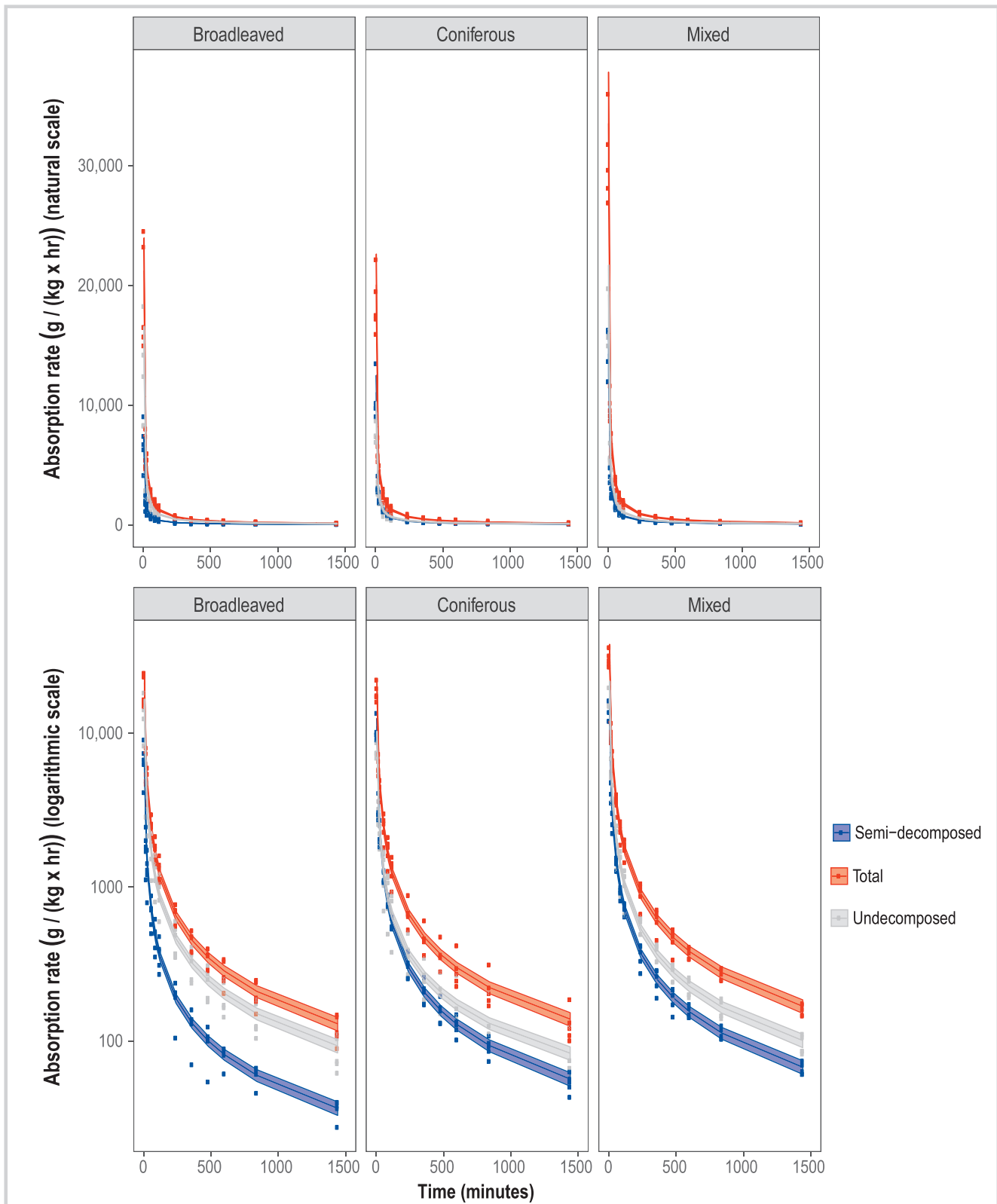
water-holding characteristics of forest litter in a warm temperate semihumid continental monsoon climate zone. They found that the maximum water-holding capacity and absorption rate were both greatest in coniferous forest (14.01 t/ha, 115.30%), followed by broadleaved forest (13.72 t/ha, 108.28%) and mixed forest (11.41 t/ha, 82.38%). Thus, the water conservation ability of forests in a southern subtropical monsoon climate and in a warm temperate semihumid continental monsoon climate were found to be lower than those in the karst area.

The above analysis shows that water conservation ability is greater in the region covered by this study than in other regions. This is partly because the study area is in a high-elevation subtropical region. The temperature is relatively mild and is cooler than in low-elevation subtropical regions, and precipitation is moderate. These climatic conditions will not limit the growth of trees, and are conducive to litter accumulation. However, experimental error also has a certain influence. Thus, it could be the case either that the accumulation conditions in this study were better than those in other karst areas or that we sampled the semidecomposed litter layer too deeply, resulting in a collected litter mass that was too large and yielded a higher calculation for the maximum water-holding capacity.

From the above analysis, it can be seen that the relative water-holding characteristics' values for coniferous, broadleaved, and mixed forest in different areas may be inconsistent. There is no consistent pattern showing that water conservation ability is greater in coniferous forest than in broadleaved forest or vice versa. There is also no consistent pattern of water conservation ability for different climate zones or geological or soil conditions. It is not clear whether this inconsistency is a result of natural or experimental conditions. For example, under different natural conditions in various forest litter studies, the differences in water conservation ability can double (Liu et al 2000).

Research on the water-holding characteristics of forest litter began in the 1950s when the concept of the water-harvesting capacity of forest litter was first articulated (Rowe 1955). Since this time, interest in forest litter hydrology has increased (Kittredge 1955; Wang et al 2015), and there continues to be a great deal of research on the topic. This work focuses on a karst forest located in a mountainous region; karst forests are often located in mountainous regions, and because of various geological factors both soil and water loss are major conservation concerns.

Individual forest litter hydrological studies tend to use different evaluation indicators or different combinations of evaluation indicators. In addition to differences in indicators, methods for measuring the water-holding characteristics of forest litter also vary, making the results difficult to compare (Gerrits et al 2010; Ilek et al 2017). These differences impact forest litter hydrological research. Studies of forest litter hydrology, such as this one, are difficult to compare. This may delay progress in synthesizing the results of these studies and inhibit our understanding of general patterns of forest litter hydrology.

Conclusions

In the Guizhou karst area, the water conservation ability of leaf litter in 3 forest types (coniferous, broadleaved, and mixed) was stronger for the semidecomposed layer than for the undecomposed layer, especially in coniferous forests. The water conservation ability of the entire litter layer was higher in the mixed forest than in the coniferous and broadleaved forests. The effective water-retention capacity of the undecomposed layer was relatively high for the mixed (26.6 t/ha) and coniferous (23.1 t/ha) forests but was significantly lower for the broadleaved forest (11.2 t/ha). There were clear differences in the hydrological effect of the different forest types in this karst region, with the mixed forest generally having the most favorable hydrological properties. Therefore, in the process of forest restoration in karst areas, the preservation and restoration of mixed forests should be strengthened to improve soil and water conservation and maximize karst forest water conservation and its ecological benefits.

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