frontiers | Frontiers in Forests and Global Change

TYPE Original Research
PUBLISHED 15 June 2023
DOI 10.3389/ffgc.2023.1199304

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RECEIVED 03 April 2023
ACCEPTED 30 May 2023
PUBLISHED 15 June 2023

CITATION
Liu Q, Cheng Y, Yu F and Fan C (2023) The effects of forest types and age groups on forest provisioning and supporting service value in Sanhu Nature Reserve, Northeast China.
Front. For. Glob. Change 6:1199304.
doi: 10.3389/ffgc.2023.1199304

The effects of forest types and age groups on forest provisioning and supporting service value in Sanhu Nature Reserve, Northeast China

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The promotion of forest resource protection and sustainable development relies greatly on the value of forest ecosystem services. In Jilin Songhuajiang Sanhu National Nature Reserve in Northeast China, a total of 169 sample plots were examined and analyzed to evaluate the provisioning and supporting services provided by the forest ecosystem. The study revealed that the near-mature and over-mature *Fraxinus mandshurica* forest have relatively high timber supply and species resources conservation values per unit area, respectively. Furthermore, the mature *Betula platyphylla* forest has the highest forest nutrient retention value, while the near-mature *Juglans mandshurica* forest has the highest soil conservation value, with the nitrogen fixation value accounting for the highest proportion. The forest ecosystem services in the reserve have a total value of 659.07 million $\$\cdot y^{-1}$. The main contributors to the value are the services of soil fertilizer conservation, timber supply, and species resources conservation, with the mixed broad-leaved forest and *Quercus mongolica* forest being the main contributors, accounting for 63.1 and 18.8% of the total value, respectively. Nonetheless, the service value of per unit area in *J. mandshurica* forest is the highest. Near-mature and mature forests are the main contributors to the total value, accounting for 42.3 and 34.9%, respectively. Forest lands exhibit significant variations in the values of provisioning and supporting services across different stand types and age groups.

KEYWORDS

nature reserve, forest ecosystem, forest type, age group, supporting service value, provisioning service value

1. Introduction

The forest ecosystem is a crucial component of the global natural ecosystem and plays an integral role in ensuring sustainable human development (Ma et al., 2021). Unfortunately, people's understanding of the forest ecosystem has been limited to its economic uses, particularly the provision of timber and forest by-products for economic development, with a lack of comprehensive understanding of its service values (Hettiarachchi and Ranasinghe, 2013). Despite the high economic value of forest wood, it is not adequately accounted for in political and economic policies resulting in insufficient investments in its protection and management. The one-sided pursuit of rapid economic development has led to significant damage to the ecosystem (Smith et al., 2019). Therefore, raising awareness regarding the importance of the ecosystem has become a pressing issue. A scientific and comprehensive evaluation of forest ecosystem service value has become a global focus and hot issue (Niu et al., 2012; Ninan and Inoue, 2013b).

Ecosystem services are essential for human survival as they provide nutritious food, and clean water, regulate disease and climate, support crop pollination and soil formation, and offer recreational, cultural, and spiritual benefits. Ecosystems provide four main types of services to the world, namely provisioning services, regulating services, supporting services, and cultural services (Food and Agriculture Organization, 2020). However, quantifying the aesthetic appreciation of nature and the inspiration it provides for culture and innovation remains challenging. To quantitatively estimate service values, scholars have employed various methods, including the conditional value method, market value method, emergy evaluation method, and income conversion method, to assess ecosystem service values (Costanza et al., 1997; Odum and Odum, 2000; Zhang, 2010; Hidemichi et al., 2017). Some researchers have evaluated the ecosystem service values based on ecology alone (Daily and Ehrlich, 1999), while others investigate the impact of biodiversity on ecosystem services to characterize their value (Fromm, 2000; Farnsworth et al., 2012). Given the structural complexity and peculiarities of different ecosystems, evaluation techniques, and methods have garnered significant attention to ensure accurate service value assessment (Villa et al., 2014; Cheng et al., 2019).

Since the 1950s, various methods such as the travel cost, replacement cost, and contingent valuation method have been utilized internationally to assess the direct use value of forest ecosystems (Tobias and Mendelsohn, 1991; Hanley, 1993; Beaumont et al., 2014). It has been estimated that the per unit area value of forest ecosystem services in Mexico is US$80 per year, totaling to US$4 billion (Adger and Weiguang, 1995). Some scholars have calculated the overall value of forest ecosystems in national nature reserves (Tobias and Mendelsohn, 1991; Hanley, 1993; Ninan and Inoue, 2013a; Beaumont et al., 2014; Jin et al., 2016; Chang et al., 2019; Liu et al., 2022). Moreover, utilizing NOAA-AVHRR and Landsat imagery, the ecosystem service value of land under various use methods was calculated (Konarska et al., 2002). By considering tourists' preferences for landscapes in the protected areas and utilizing the travel cost method, recreational value of the protected area can be inferred. The recreational value of the conservation area can be estimated by analyzing the tourists' demand for the landscape (Font, 2000), and other values such as timber supply value, soil conservation value, forest nutrient retention, and species conservation value can be evaluated based on stock volume, soil erosion, tree nutrients, and species composition (Villa et al., 2014; Cheng et al., 2019).

In recent years, there has been an increase in studies on the service values of different forest ecosystems based on small-scale areas, particularly forest nature reserves. These reserves can be classified into various value areas based on plant and animal species, environmental categories, species richness, and other factors, and the conservation priority can be ranked based on the evaluation value (Goodfellow and Peterken, 1981). By considering tourists' preferences for landscapes in the protected areas and utilizing the travel cost method, recreational value of the protected area can be inferred. The recreational value of the conservation area can be estimated by analyzing the tourists' demand for the landscape (Font, 2000), and other values such as timber supply value, soil conservation value, forest nutrient retention, and species conservation value can be evaluated based on stock volume, soil erosion, tree nutrient, and species composition (Villa et al., 2014; Cheng et al., 2019). The study on the value of forest nature reserves has garnered the attention of scholars worldwide, and the evaluation system of nature reserves has been scientifically divided into different types such as conservation value, resource value, and economic value (Zhang et al., 2011). However, there are still issues such as the lack of standardization and uniformity in evaluation methods, and incomplete evaluation metrics.

Forest type and forest have a significant impact on forest structure, plant growth, and vegetation biomass accumulation (Shengjun et al., 2009; Grytnes, 2010; Gamfeldt et al., 2013), so they are fundamental factors that strongly influence the ecosystem services provided by forests. As time passes, the biomass, biodiversity, and soil quality of forest ecosystems change, and different tree species exhibit significant differences in their biomass and nutrient content (Gamfeldt et al., 2013; Musavi et al., 2017; Kuuluvainen and Gauthier, 2018), compared with other service functions, the change of forest type and forest age has a more direct relationship with the function of support and provision service. Therefore, studying the support and provision of ecosystem services from the perspective of forest age and type can accurately quantify the value of these services, and the assessment results of the ecosystem service value in different forest types and ages are highly practical and scientific to provide evidence and guidance for the rational management, protection, and sustainable utilization of forests. Therefore, the primary aim of this study is to analyze the forest provision and support service values in Jilin Songhuajiang Sanhu National Nature Reserve under various forest types and age groups. Additionally, the study intends to perform a comprehensive evaluation of the forest supply value, species resource conservation value, forest nutrient retention value, and soil conservation value in forests with different types and ages. The results of this study can be used by policymakers to identify target forests for enhancing forest service values through operational strategies.

2. Materials and methods

2.1. Study area

The Jilin Songhuajiang Sanhu National Nature Reserve is located in the central and eastern part of Jilin Province (42°20′10″∼43°33′06″N, 126°51′40″∼127°45′21″E) (**Figure 1**), which undertakes the functions of soil and water conservation and groundwater recharge in the Songhua River Basin, and it is an important hydropower base in Northeast China. The climate belongs to the continental monsoon climate of northern temperate zone. The annual average temperature is between 3.9 and 4.9°C. The average temperature in January and July is about −18 and 20°C, respectively. The average annual precipitation is about 644.8∼825.1 mm, and the rainfall is concentrated in June to August. The annual sunshine hours is 2,350∼2,450 h, and the frost-free period is 92∼134 days. The soil type is mainly dark brown soil. The reserve is dominated by mountain forest ecosystems, with abundant plant resources, which can be divided into seven types: coniferous forest, mixed coniferous and broad-leaved forest, deciduous broad-leaved forest, shrub, meadow, swamp, and aquatic vegetation. The forestland area is 122,800 ha, accounting for 78.4% of the total area of the reserve, and which is mainly closed forest land, with an area of 111,500 ha. The forest community types are mainly broad-leaved mixed forest and oak forest, and the main dominant tree species include *Pinus koraiensis*, *Fraxinus mandshurica*, *Phellodendron amurense*, *Chosenia arbutifolia*, *Tilia amurensis*, *Juglans mandshurica*, *Quercus mongolica*, and so on. However, affected by many factors such as man-made destruction, historical unreasonable development, natural disasters, and global climate change, the Sanhu Reserve is faced with a variety of ecological environmental problems and protection pressure (Lei, 2006), and clarifying the service value of the forest ecosystem in this region is an important basis for determining the protection object and strength. Maintaining the quality of air and soil, providing flood and disease control, or pollinating crops are some of the regulating services provided by ecosystems, and the non-material benefits of aesthetic inspiration, cultural identity, sense of home, and spiritual experience related to the natural environment are called cultural services, but it is still difficult to accurately and quantitatively evaluate the value of regulating services and cultural services from a large regional scale, especially considering the conditions of different forest types and ages.

2.2. Field investigation and sample analysis

According to the historical forest resource inventory data of study area, it is known that the main forest community types in the reserve include *Betula platyphylla* forest, *F. mandshurica* forest, *J. mandshurica* forest, *Q. mongolica* forest, mixed broad-leaved forest, and mixed coniferous broad-leaved forest. In order to obtain the values of the provisioning and supporting services provided by different forest types and age groups in the reserve, the sample plots in each forest type were selected based on the reserve's forest types, age groups, distribution area, and proportion of each forest type. A total of 169 plots were set up and investigated in different forest stand types in the reserve (**Figure 1**), the stand types, age groups, and number of plots in each forest type are shown in **Table 1**. The sample plots for the investigation of the basic characteristics of the community were selected from the representative sections of the typical community. The forest compass was used to enclose the rectangular basic survey plots of the community with an area of 20 m × 30 m (Song et al., 2002), and then measured the tree height and DBH (diameter at breast height) of each tree in the plot, and record the basic information of the tree species, and only record the tree species and tree height for the individuals whose tree height is <1.3 m. Five small quadrats with an area of 2 m × 2 m were set up at the corners and center of the plot to survey shrubs (Song et al., 2002; Yuan et al., 2015; see **Figure 2**), and we recorded the species, average height, and number of shrubs within these plots. Within each shrub plot, one small plot with an area of 1 m × 1 m was designated to survey herbaceous plants (Song et al., 2002; Yuan et al., 2015), and the species, height, number, and coverage of herbaceous plants were surveyed and recorded, and then the average plant height was obtained by calculating the average plant height of different species of herbaceous plants.

To clarify the age group and annual volume growth of forests, about five standard trees of dominant tree species in each survey plot were selected for the collection of annual ring strips, and the annual ring sample core was collected at 1.3 m above the ground of the sample tree with a growth cone to drill from south to north, and then put it into a straw, and record the tree species, DBH, skin thickness, and collection time. Then, the age group of forest was determined based on the average age of the group specie, and the criteria for age group classification are shown in **Table 1**, which mainly includes young forests, half-mature forests, near-mature forests, mature forests, and over-mature forests for each forest type. A total of 10 tree species (*B. platyphylla* Sukaczev, *Populus davidiana* Dode, *F. mandshurica* Rupr., *J. mandshurica* Maxim., *P. amurense* Rupr., *T. amurensis* Rupr., *Q. mongolica* Fisch. ex Ledeb., *Ulmus davidiana* Planch. var. *Japonica* (Rehd.) Nakai, *Acer pictum* Thunb., and *P. koraiensis* Sieb et Zucc.) sample cores were obtained, with 20∼25 ring sample cores for each tree species, and after processing the sample cores, the Lintab tree ring analyzer was used to accurately measure the annual ring width of the tree ring samples.

To determine the nutrient content and bulk density of the soil in each plot, we collected five surface soil samples, the sampling sites are shown in **Figure 2**. After being brought back to the laboratory, the samples are naturally air-dried, and then the dried particles, fine roots, and other impurities are removed from the air-dried soil with tweezers. The samples are then ground and screened through a 0.25 mm steel sieve for subsequent chemical property analysis. At the same time, a 100 cm^3 soil core sampler is used to collect undisturbed soil from each sampling point, which are then used for soil density determination (NY/T 1,121.4). The main analysis indicators include soil organic matter (LY/T 1,237–1,999), total nitrogen (LY/T 1,228–1,999), total phosphorus (LY/T 1,232–1,999), and total potassium (LY/T 1,232–1,999), etc. In addition, the leaf, branch, stem, and root organ samples from 55 trees of the 10 dominant tree species in the plots were collected, and a total of 220 mixed samples of each organ were obtained, and the total nitrogen, total phosphorus and total potassium in each sample were determined (LY/T 1,271–1,999).

2.3. Statistical analysis

Statistical analysis of the data was carried out using software such as SPSS16.0 and SAS9.1. The current study mainly evaluates the provisioning and supporting service functions according to the "Specifications for assessment of forest ecosystem services" (GB/T 38582-2020) (NFGA, 2020), and the main value indicators for evaluation include the forest supply value, species resource conservation value, soil conservation value, and forest nutrition retention value.

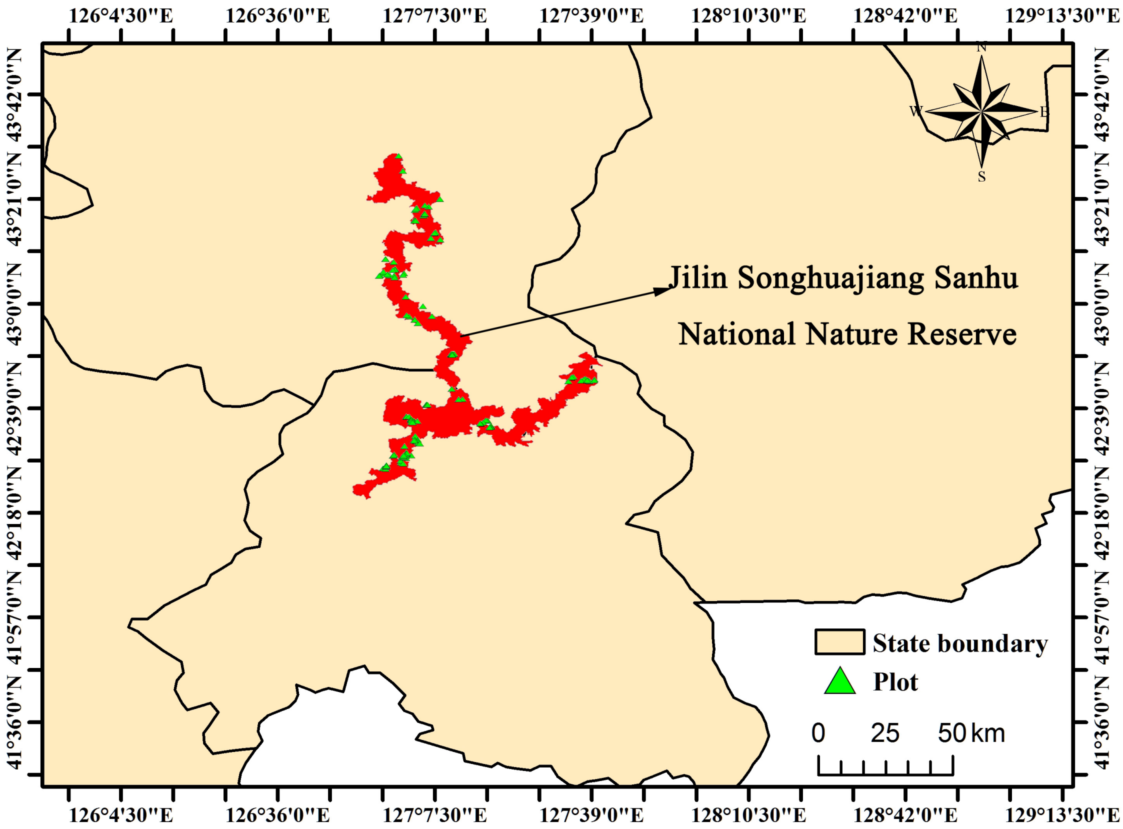

FIGURE 1
Study area and the plots of sites.

TABLE 1 Sample plots and forest distribution status.

Age group		Stand type					
		Betula platyphylla forest	*Fraxinus mandshurica* forest	*Juglans mandshurica* forest	*Quercus mongolica* forest	Mixed broad-leaved forest	Mixed coniferous broad-leaved forest
Young	Number of plots	6	1	1	3	11	2
	Area (ha)	297	179	44	393	836	2,000
	Age (years)	Below 30	Below 40	Below 40	Below 40	Below 40	Below 60
Half-mature	Number of plots	5	2	3	3	13	4
	Area (ha)	926	178	549	8,625	8,837	1,349
	Age (years)	31–50	41–60	41–60	41–60	41–60	61–100
Near-mature	Number of plots	4	1	4	3	33	4
	Area (ha)	2,028	691	2,682	1,415	25,645	1,512
	Age (years)	51–60	61–80	61–80	61–80	61–80	101–120
Mature	Number of plots	5	2	2	3	39	4
	Area (ha)	1,867	884	27,054	7,602	26,295	822
	Age (years)	61–80	81–120	81–120	81–120	81–120	121–160
Over-mature	Number of plots	1	1	1	1	5	2
	Area (ha)	147	232	177	1,188	2,983	416
	Age (years)	Above 81	Above 121	Above 121	Above 121	Above 121	Above 161

Age group classification is derived from "Technical regulations for inventory for forest management planning and design" (GB/T 26424-2010) (NFGA, 2010).

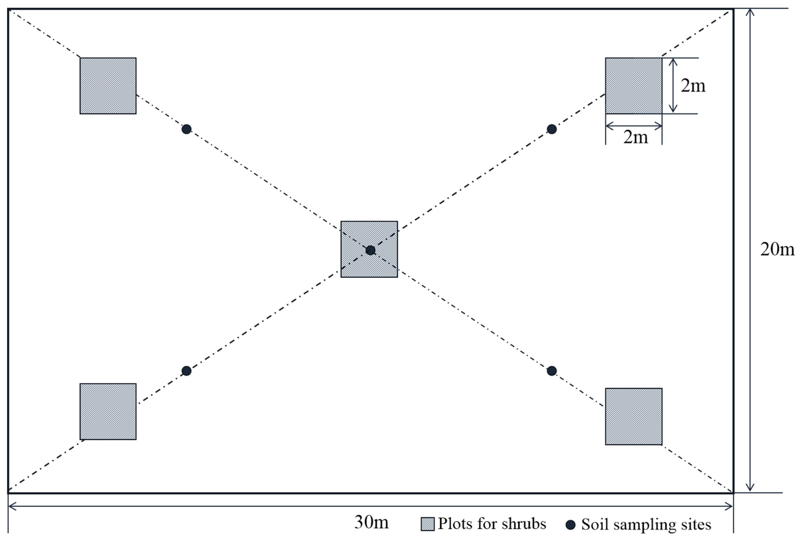

FIGURE 2
Distribution of quadrats and soil sample points.

2.3.1. Forest supply value

The supply values of different individual timber are calculated based on the annual volume growth of the main tree species in different stand types, and then sum up to obtain the forest supply value ($\$\cdot ha^{-1}\cdot\ y^{-1}$) of per unit area for different stand types and age groups, which mainly refers to the value of living trees in the study area, the calculation formula is as follow:

$$U_{\text{wood product}} = \sum_{i}^{n} (S_i U_i A_i) \quad (1)$$

where, $U_{woodproduct}$ is the annual timber supply product value in the study area ($\$\cdot y^{-1}$); A_i is the distribution area of the i-th wood product (ha); S_i is the annual volume growth per unit area of the i-th wood product ($m^3\ ha^{-1}\cdot y^{-1}$); U_i is the price of the i-th wood product ($\$\cdot m^{-3}$); $i = 1,2,3...n$.

This study conducted statistical analysis on the annual ring samples of 10 major tree species in the study area, and plotted their diameter growth curves. By using the fitting equation of the diameter growth curve of each tree species and the stand volume table for single trees in Jilin Province (JPFD, 2003), this study calculated and analyzed the 2-year volume and stand volume per unit area for each tree species. Furthermore, the study obtained the unit area increment of stand volume (Si) for different forest types. The arithmetic average of the measured annual ring width data of different tree species was used to eliminate differences in different growth processes and growth environments. And because there is an error in drilling the annual ring samples, there will be a difference between the DBH calculated from the annual ring sample and the actual measurement value. Therefore, it is necessary to correct the annual ring width and the values measured by the girth to improve the accuracy of the DBH, the correction formula is as follows (Eq. 1):

$$\theta = \frac{D_{bh} - D_{ic}}{2t} \quad (2)$$

where θ is the corrected value (cm); D_{bh} is the DBH measured by a tape (cm); D_{ic} is the product of the accumulation of complete growth core growth ring sequence and complete DBH (cm); t is the tree age from tree core determination. The corrected tree-ring sequence is obtained by adding the θ value to each tree-ring sequence, which takes the existing bark thickness as part of the xylem (Zhang et al., 2012).

2.3.2. Species resource conservation value

According to the calculation formula of species resource conservation value in the assessment standard of "Specifications for assessment of forest ecosystem services" (NFGA, 2020), endangered species and ancient trees are included in the species conservation value evaluation. In the current study, the classification and statistics of plant species in various plots are based on the "China Species Red List" and its index system and ancient tree age index system.

The formula for calculating species conservation value is as follows:

$$Ui_{biata} = \left(1 + \sum_{m=1}^{x} E_m \times 0.1 + \sum_{n=1}^{y} B_n \times 0.1 + \sum_{r=1}^{z} O_r \times 0.1\right) A_i S_{biota} \quad (3)$$

where, Ui_{biota} is the value of the forest to protect biodiversity every year ($\$\cdot y^{-1}$); E_m is the rare and endangered index assessing species m within a stand (or area); x is the counted number of rare and endangered species; B_n is the endemic index for assessing species n within a stand (or area); O_r is the ancient tree age index for evaluating species r in the stand (or area); z is the number of species for calculating ancient tree species; S_{biota} is the opportunity cost of annual species loss per unit area ($\$\cdot ha^{-1}\cdot y^{-1}$), and the corresponding Shannon-Wiener index classes and values are shown in **Table 2** (GB/T 38582-2020); A_i is the forest area (ha); $i = 1,2,3...n$.

The formula for the Shannon-Wiener index calculation is as follows:

$$H' = -\sum_{i=1}^{S} P_i \ln P_i \quad (4)$$

where, H' is Shannon-Wiener index; P_i represents the importance value of the i-th species; S represents the number of species in the community, and i = 1,2,3. . .n.

The formula for the calculation of the overall diversity of the community is as follows:

$$D_{total} = W_1D_1 + W_2D_2 + W_3D_3 \tag{5}$$

$$W_i = (C_i/C + h_i/h)/2 \tag{6}$$

where, D_1, D_2, and D_3 represent the diversity index of the tree layer, shrub layer, and herb layer, respectively;,W_1, W_2, and W_3 represent the weighting coefficients of the tree layer, shrub layer, and herb layer, respectively; C_i represents the coverage of different layers; C represents the total coverage of the community in different layers; h_i represents the average height of vegetation in different community layers; h represents the sum of the average heights of the community in different layers; i = 1,2,3. . .n.

2.3.3. Soil conservation value

In the current study, the shadow engineering method and the market value method (Li et al., 2011; Villa et al., 2014) were used to calculate the value of soil stabilization and soil fertility conservation, respectively, and the calculation formulas are as follows:

$$G_i = \sum_{i=1}^{n} A_i (X_2 - X_1) \tag{7}$$

$$U_{i\text{-soil}} = G_i \times C_{soil}/\rho \tag{8}$$

$$U_{i\text{-fertility}} = A_i (X_2 - X_1) \left(\frac{N_{nutrition}C_1}{R_1} + \frac{P_{nutrition}C_1}{R_2} + \frac{K_{nutrition}C_2}{R_3} + MC_3\right) \tag{9}$$

where, G_i is the amount of soil retained by the forest (t y^{-1}); A_i is the forest area (ha); X_1 and X_2 are the soil erosion modulus of forested land and unforested land in Northeast China, respectively ($t \cdot ha^{-1} \cdot y^{-1}$). U_{i-soil} is the market value of soil retained by the forest ($\$ \cdot y^{-1}$); C_{soil} is the cost of excavating and transporting a unit volume of earthwork in the market ($\$ \cdot m^{-3}$); ρ is the soil bulk density of forest woodland ($g \cdot cm^{-3}$); $U_{i-fertility}$ is the annual value of each stand to conserve soil fertility ($\$ \cdot y^{-1}$); $N_{nutrition}$, $P_{nutrition}$, $K_{nutrition}$, and M are the measured N content (%), P content (%), K content (%), and organic matter content (%) of soil, respectively; R_1 and R_2 are the N content (%) and P content (%) of the phosphoric acid fertilizer, respectively; C_1, C_2, and C_3 are the price of phosphoric acid fertilizer, potassium chloride fertilizer, and organic matter ($\$ \cdot t^{-1}$), respectively; i = 1,2,3. . .n.

TABLE 2 Value and classification of Shannon-Wiener index.

Class	Shannon-Wiener index	S_{biota} ($\$ \cdot ha^{-1} \cdot y^{-1}$)
I	S ≥ 6	7,345
II	6 ≥ S ≥ 5	5,876
III	5 ≥ S ≥ 4	4,407
IV	4 ≥ S ≥ 3	2,938
V	3 ≥ S ≥ 2	1,469
VI	2 ≥ S ≥ 1	735
VII	1 ≥ S	441

Value and classification of Shannon-Wiener index are derived from the "Specifications for assessment of forest ecosystem services" (GB/T 38582-2020) (NFGA, 2020).

2.3.4. Forest nutrition retention value

In order to obtain the value of the nutrients retained by the trees, the substitution value method is used to convert the large amount of N, P, K, and other nutrients that the trees absorb from the soil or air each year into the market value of chemical fertilizers, and the forest nutrition retention value is calculated as follows:

$$G_N = N_{nutrition}B_{year} \tag{10}$$

$$G_P = P_{nutrition}B_{year} \tag{11}$$

$$G_K = K_{nutrition}B_{year} \tag{12}$$

$$U_{i\text{-nutrition}} = B_{year}\left(\frac{N_{nutrition}C_1}{R_1} + \frac{P_{nutrition}C_1}{R_2} + \frac{K_{nutrition}C_2}{R_3}\right) \tag{13}$$

where, G_N, G_P, and G_K are the amounts of nitrogen, phosphorus, and potassium accumulated by trees each year ($t \cdot y^{-1}$), respectively; $U_{i-nutrition}$ is the accumulated value of nutrients in the tree year ($\$ \cdot y^{-1}$); $N_{nutrition}$, $P_{nutrition}$, and $K_{nutrition}$ are the ratios (%) of N, P, and K contained in forest trees, respectively; B_{year} is the annual growth of forest biomass (kg); R_1 and R_2 are the N content and P content (%) of the phosphoric acid fertilizer, respectively; R_3 is the K content (%) of potassium chloride fertilizer; C_1 and C_2 are the prices of diammonium phosphate fertilizers and potassium chloride fertilizers, respectively ($\$ \cdot t^{-1}$); i = 1,2,3. . .n.

Using the tree species DBH growth curve fitting results and the biomass allometric growth equation (Wang, 2006), the biomass growth of each tree species was obtained, and then the N, P, and K contents of different tree species were used to obtain the annual tree nutrient retention of each survey plot. Finally, the prices of different fertilizers and the contents of fertilizer nutrients are converted into market values to obtain the nutrient retention value per unit area of forest trees in different stand types and age groups ($\$ \cdot y^{-1}$). While the annual net productivity and nutrient content of different forest vegetation types are different, and the nutrient content of different organs of the same plant is also different, so the average nutrient content of plant branches, stems, leaves, and roots cannot truly represent the overall nutrient content of plants, and it is necessary to comprehensively consider the nutrient content and biomass weight. The calculation formulas are as follows:

$$G_{nutrition} = \frac{\sum C_i W_j}{W_t} \tag{14}$$

where, $G_{nutrient}$ is the weighted average nutrient ratio of the arbor; C_i is the percentage of nutrients in an organ of the tree; W_j is the biomass of a certain organ of the tree; W_t is the total biomass of tree; i = 1,2,3...n.

The related parameter values are listed in Table 3. The DBH growth fitting equations, volume growth, biodiversity index, soil nutrition contents and soil bulk density of different stand types, and weighted nutrient contents of different organs and individuals for each tree specie are showed in supplementary material.

3. Results

3.1. The value of provisioning services function of different stand types

3.1.1. Supply value of forest trees

The highest supply value of forest trees per unit area among different stand types is in near-mature *F. mandshurica* forest, which is 2,190 $·ha^{-1}·y^{-1} (Figure 3), and the young *B. platyphylla* forest is the lowest, only 388 $·ha^{-1}·y^{-1}, moreover, the difference in supply value of mixed coniferous broad-leaved forest among different age groups can reach 1410 $·ha^{-1}·y^{-1}.

3.1.2. Conservation value of species resources

The survey results showed that the vegetation types of the near threatened (LU) level in the study area were *F. mandshurica*, *P. amurense*, and *P. koraiensis*, which were mostly found in mixed broad-leaved forest and mixed coniferous and broad-leaved forest. And the ancient trees (100∼299a) included and other tree species totaling 94, mainly in the mature and over-mature forest stage. And a total of 94 ancient trees (100∼299a), including *P. koraiensis*, *Q. mongolica*, *F. mandshurica*, *T. amurensis*, and *J. mandshurica,* were found, mainly in the mature and over-mature forest stages. Based on the distribution of endangered species, precious ancient trees and endemic species in the study area and the Shannon-Wiener index classes and values, the species conservation value ($·y^{-1}) of per unit area of different stand types and age groups was calculated (Figure 3).

With the increase of the age, the species conservation value per unit area of *B. platyphylla* forest, *J. mandshurica* forest, and *B. platyphylla* forest showed a unimodal change (Figure 3), and the peaks appeared in mature forest, near-mature forest and near-mature forest, respectively. The species conservation value of *Q. mongolica* forest showed a continuous increasing trend as a whole, and reached the maximum value in over-mature forest, and the value for *F. mandshurica* forest was relatively high in near-mature forest and over-mature forest, while those in mixed coniferous broad-leaved forest were higher in mature and half-mature forests. Among the six stand types, the conservation value of over-mature *F. mandshurica* forest is the highest, which is 1,777 $·ha^{-1}·y^{-1}, and the value of half-mature *Q. mongolica* forest is the lowest, which is only 539 $·ha^{-1}·y^{-1}.

3.2. The value of supporting services function of different stand types

3.2.1. Soil conservation value

The soil reinforcement value per unit area of different stand types is as follows: *J. mandshurica* forest (231 $·ha^{-1}·y^{-1}) > mixed broad-leaved forest (200 $·ha^{-1}·y^{-1}) > *F. mandshurica* forest (199 $·ha^{-1}·y^{-1}) > *B. platyphylla* forest (195 $·ha^{-1}·y^{-1}) > mixed coniferous broad-leaved forest (194 $·ha^{-1}·y^{-1}) > *Q. mongolica* forest (176 $·ha^{-1}·y^{-1}) (see Figure 4). The soil fertilizer retention value per unit area of different stand types and age groups ranges from 1,073 to 6,414 $·ha^{-1}·y^{-1}, the highest value is in the near-mature *J. mandshurica* forest, and the lowest is in the young *F. mandshurica* forest. Among them, the retention value of N element is relatively high, ranging from 301 to 4,501 $·ha^{-1}·y^{-1}, and the highest and lowest values are in young *F. mandshurica* forest and near-mature *J. mandshurica* forest, respectively. The retention values for K and P are 344∼1,165 and 6∼1,485 $·ha^{-1}·y^{-1}, respectively, and the lowest values both appear in the young *F. mandshurica* forest, and the highest values are in the near-mature *Q. mongolica* forest and half-mature *F. mandshurica* forest, respectively. The soil fertilizer retention value of organic matter is between 49 and 825 $·ha^{-1}·y^{-1} with the highest value in over-mature *F. mandshurica* forest.

3.2.2. Forest nutrient retention value

The tree nutrient values of N, P, and K elements per unit area of different stand types and age groups were ranked as follows: N > P > K (Figure 5). The forest nutrient retention values of per unit area of N and P are 43∼177 and 9∼61 $·ha^{-1}·y^{-1}, respectively, and the highest value is in mature *B. platyphylla* forest. The retention value of K is between 2 and 16 $·ha^{-1}·y^{-1}, and the near-mature forest of *F. mandshurica* forest is relatively high. The lowest retention values of N, P, and K are the over-mature mixed coniferous broad-leaved forest. Based on N, P, and K, the retention value of different stand types is between 53 and 252 $·ha^{-1}·y^{-1}, and the value of mature *B. platyphylla* forest is relatively high, while the mixed coniferous broad-leaved forest is the lowest. The nutrient retention values of near-mature forest and mature forest are relatively high among different age groups, for example, the values of mature *B. platyphylla* forest and near-mature *F. mandshurica* forest are more than 235 $·ha^{-1}·y^{-1}. The values of young and over-mature forests are relatively low, such as the retention values of young and over-mature mixed coniferous broad-leaved forest are only 63 and 53 $·ha^{-1}·y^{-1}, respectively.

3.3. The value of supporting services function of different stand types

The total forest area of the reserve is 116,234 ha, and the forest composition is mainly mixed broad-leaved forest and *Q. mongolica* forest, accounting for 83.1% of the forest area. The forest areas of *B. platyphylla* forest, *J. mandshurica* forest, and mixed coniferous broad-leaved forest are similar, which are between 4 and 6%, while the *F. mandshurica* forest has the smallest area (1.9%). Based on the calculation results of the services function value per unit area of different forest types and age groups, combined with the survey data, the value of forest community provision and support service function in Sanhu Nature Reserve ($·y^{-1}) was obtained (Figure 6). The total value of forest ecosystem provision and support services in the reserve is 659.07 million $·y^{-1}, and the average value per unit area is 5,670 $·ha^{-1}·y^{-1}. The value of different service functions are as follows: soil fertilizer retention value (319.30 million $·y^{-1}) > forest trees supply value

TABLE 3 Related parameter value.

Parameter	Value	Unit	Data sources
Price of standing forest stock	191 for *Betula platyphylla*, 118 for *Populus davidiana*, 391 for *Fraxinus mandshurica*, *Juglans mandshurica*, *Phellodendron amurense*, *Tilia amurensis*, and *Acer pictum*, 257 for *Quercus mongolica*, 206 for *Ulmus davidiana* var. *Japonica*, and 494 for *Pinus koraiensis*	$\$\cdot m^{-3}$	http://www.chinatimber.org/
Soil erosion modulus for unforested land	12.5	$t\cdot(ha^{-1}\cdot y^{-1})$	Classification standard for soil erosion (SL190-2007)
Soil erosion modulus for forested land	75	$t\cdot(ha^{-1}\cdot y^{-1})$	Classification standard for soil erosion (SL190-2007)
Soil excavation cost	2.5	$\$\cdot m^{-3}$	http://www.jooxoo.com/
Nitrogen content of diamine phosphate fertilizer	14	%	Fertilizer use guide (Wu, 2001)
Phosphorus content of diamine phosphate fertilizer	15		
Potassium content of potassium chloride fertilizer	50		
Price of organic matter	47	$\$\cdot t^{-1}$	http://www.jgjcndrc.org.cn/
Price of diamine phosphate	353	$\$\cdot t^{-1}$	http://www.jgjcndrc.org.cn/
Price of potassium chloride fertilizer	323	$\$\cdot t^{-1}$	http://www.jgjcndrc.org.cn/

The exchange rate used in the calculation is 1 RMB yuan = 0.1469 $.

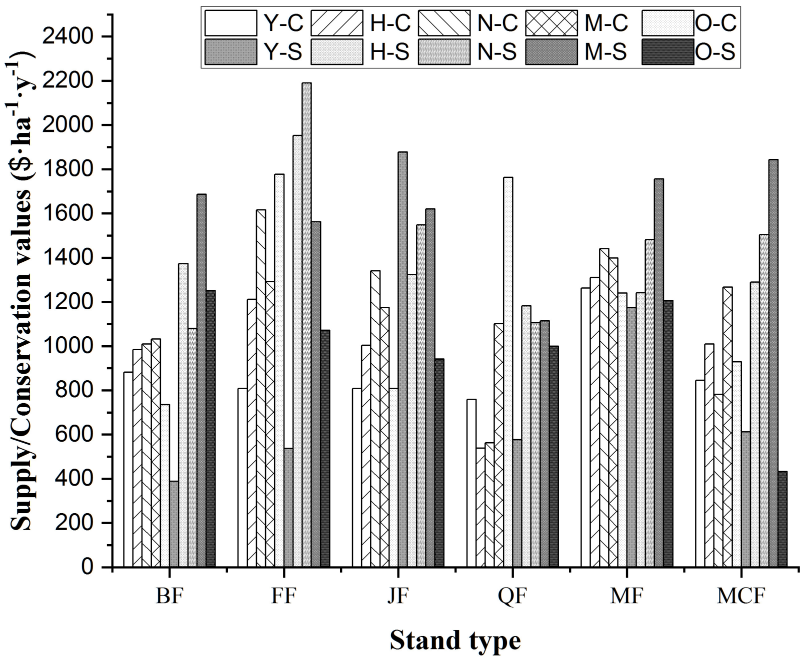

FIGURE 3
Supply value and species resources conservation value of per unit area of different stand types and age groups. Y-C, H-C, N-C, M-C, and O-C are the conservation values of species resources of young forest, half-mature forest, near-mature forest, mature forest and over-mature forest, respectively; Y-S, H-S, N-S, M-S, and O-S are the supply values of young forest, half-mature forest, near-mature forest, mature forest and over-mature forest, respectively. Stand types include *Betula platyphylla* forest (BF), *Fraxinus mandshurica* forest (FF), *Juglans mandshurica* forest (JF), *Quercus mongolica* forest (QF), mixed broad-leaved forest (MF), and mixed coniferous broad-leaved forest (MCF).

(61.96 million $\$\cdot y^{-1}$) > species resources conservation value (134.48 million $\$\cdot y^{-1}$) > soil reinforcement value (22.63 million $\$\cdot y^{-1}$) > forest nutrient retention value (19.02 million $\$\cdot y^{-1}$), and soil fertilizer retention value accounts for the highest proportion, followed by forest trees supply value (24.6%) and species resources conservation value (20.5%) (Figure 7). The proportion of provision and service function value of different stand types is mainly affected by the size of the stand area. The mixed broad-leaved forest has the highest proportion, accounting for 62.9%, followed by the *Q. mongolica* forest with 19.0%, accounting for 81.9% in total, which are the main body of the reserve's service function value. The value proportion of *J. mandshurica* forest was 7.1%, while the values of *F. mandshurica* forest, *B. platyphylla* forest, and mixed coniferous broad-leaved forest all accounted for less

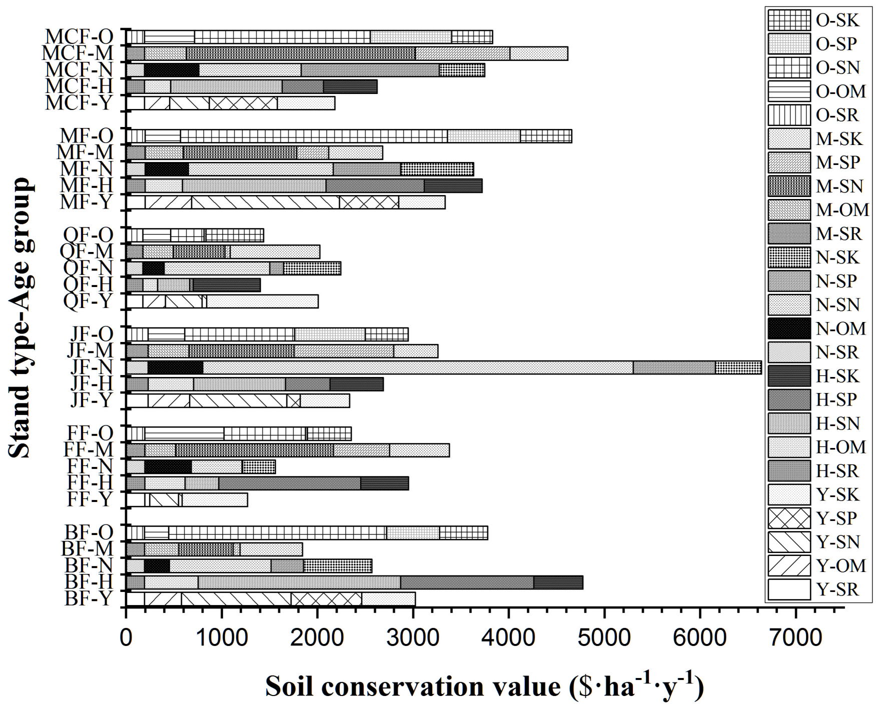

FIGURE 4

Soil conservation value of per unit area of different stand types and age groups. Y-(SN, SP, SK, OM, SR), H-(SN, SP, SK, OM, SR), M-(SN, SP, SK, OM, SR), and O-(SN, SP, SK, OM, SR) are the soil conservation value for N, P, K, organic matter and soil retention of young forest, half-mature forest, near-mature forest, mature forest, and over-mature forest, respectively; *Betula platyphylla* forest (BF)-Y, H, N, M, O, *Fraxinus mandshurica* forest (FF)-Y, H, N, M, O, *Juglans mandshurica* forest (JF)-Y, H, N, M, O, *Quercus mongolica* forest (QF)-Y, H, N, M, O, mixed broad-leaved forest (MF)-Y, H, N, M, O, and mixed coniferous broad-leaved forest (MCF)-Y, H, N, M, O are the young forest, half-mature forest, near-mature forest, mature forest, and over-mature forest of different stand types, respectively.

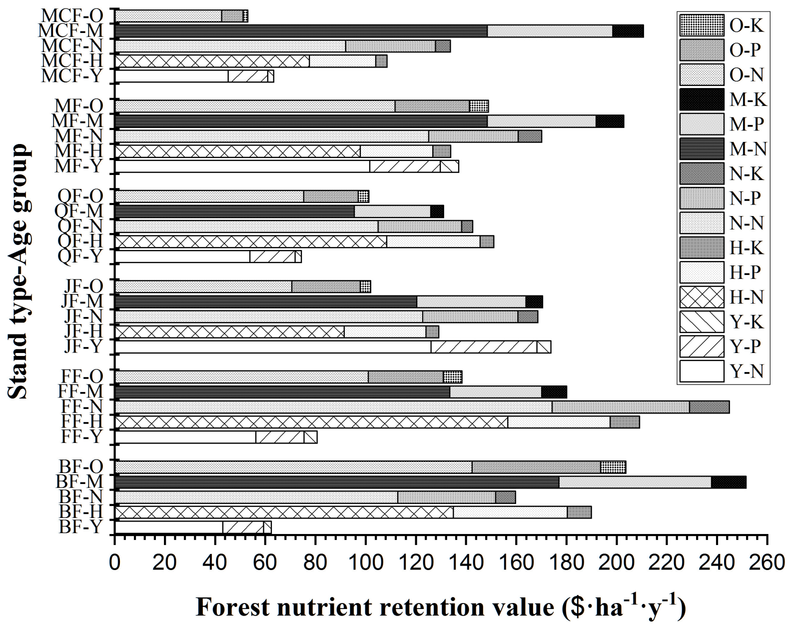

FIGURE 5

Forest nutrient retention value of per unit area of different stand types and age groups. Y-(N, P, K), H-(N, P, K), M-(N, P, K), and O-(N, P, K) are the forest nutrient retention values of young forest, half-mature forest, near-mature forest, mature forest, and over-mature forest, respectively; *Betula platyphylla* forest (BF)-Y, H, N, M, O, *Fraxinus mandshurica* forest (FF)-Y, H, N, M, O, *Juglans mandshurica* forest (JF)-Y, H, N, M, O, *Quercus mongolica* forest (QF)-Y, H, N, M, O, mixed broad-leaved forest (MF)-Y, H, N, M, O, and mixed coniferous broad-leaved forest (MCF)-Y, H, N, M, O are the young forest, half-mature forest, near-mature forest, mature forest, and over-mature forest of different stand types, respectively.

than 5% with a total of 11.0% (**Figure 7**). The service value per unit area is between 7,595 and 5,259 $\$\cdot ha^{-1}\cdot y^{-1}$, which is represented by *J. mandshurica* forest > mixed broad-leaved forest > *F. mandshurica* forest > mixed coniferous broad-leaved forest > *B. platyphylla* forest.

Among all age groups, the value of provision and supply of near-mature forest is the highest, reaching 272.50 million $\$\cdot y^{-1}$, accounting for 42.3% of the total value, followed by mature forest (34.9%). The proportion of half-mature forest is 15.5%, and the proportions of over-mature forest (4.8%) and young forest (2.4%) are relatively small. The service value of the near-mature *J. mandshurica* forest is the highest (9,607 $\$\cdot ha^{-1}\cdot y^{-1}$), and the young *F. mandshurica* forest is the lowest (2,703 $\$\cdot ha^{-1}\cdot y^{-1}$). Near-mature forest not only occupies the largest area of forest land in the reserve, but also has high supply value and soil fertilizer retention value, which is crucial for the sustainable and stable performance of ecological functions and value growth of nature reserve, followed by mature forest (**Figures 6**, **7**).

4. Discussion

There are noticeable variations in economic utilization, species conservation, nutrient retention, soil stabilization, and fertilizer conservation among different types of trees, shrubs, and herbs. As critical biological resources, forest plants, and their products are now an essential aspect of human life and production. They serve various purposes such as production of wood products, provision of food and medicine, and industrial production (Weckwerth, 2011). The varying vegetation compositions of forest ecosystems in different stand types cause differences in the value of their service functions (Blattert et al., 2017; Uhde et al., 2017). The increase in population and domestic economy has significantly heightened the demand for timber products in recent years (Wenda et al., 1999), Evaluating the provision value of forests across different stands and age groups is crucial for achieving sustainable and efficient usage of trees. In this study, *F. mandshurica* forest has the highest provision value of forest products per unit area, attributed to a higher volume growth and wood price. Meanwhile, young *B. platyphylla* forest has the lowest value, primarily due to its low volume growth, and comprising mostly low-priced tree species such as *B. platyphylla* and *P. davidiana*. Forest products' provision values are primarily affected by stock volume, as the *B. platyphylla* forest, *F. mandshurica* forest, *J. mandshurica* forest, and *Q. mongolica* forest have relatively single species. While the values of mixed broad-leaved forest and mixed coniferous broad-leaved forest are affected not only by the difference in volume growth of age groups, but also by the proportion of tree species due to their complex compositions. Therefore, the forest type is closely linked to the ecological service value (Guan et al., 2022). The growth rate of each tree species at different age stages determined the growth of the forest, and although the DBH growth curves of the 10 primary tree species studied demonstrated that the growth rate gradually declined with an increase in DBH, it remains affected by species-specific factors (Lee et al., 2004; Chen et al., 2020). In this study, all forest types except for *J. mandshurica* forest showed low annual supply value during the young forest stage, and a significant decline in supply value during the over-mature forest stage. This is mainly because growth volume was relatively high during the half-mature, near-mature, and mature stages, and relatively small in the young stage, with a significant decrease in the over-mature stage (Wang, 2006), which is why half-mature, near-mature, and mature forests have higher supply value. Furthermore, significant differences in the annual volume growth of different stand types were the main reason for the variation in the annual supply value among forest types (Faccoli and Bernardinelli, 2014). Therefore, the growth potential of forest provision values should be comprehensively considered before logging. Overall, to enhance the supply value of forest ecosystems in the study area, decision-makers should focus on the management and operation of *F. mandshurica* forest during the half-mature to mature stages, followed by the mixed coniferous broad-leaved forest.

Maintaining biodiversity is the basis for ensuring the stability of forest ecosystem functions, and how to quantify the values of these functions is an important issue at home and abroad (Chazdon et al., 2009). Among the species conservation values of different stand types, the value of *F. mandshurica* forest is the highest, mainly because of its large diversity index, and there are many endangered tree species and precious ancient trees in this stand type. The conservation value of the half-mature *Q. mongolica* forest was the lowest, which should be attributed to the absolute dominance of *Q. mongolica* in the community, and the low diversity index (Sang and Bai, 2009). Moreover, with the development of the forest, the species conservation value of *B. platyphylla* forest, *J. mandshurica* forest, and mixed broad-leaved forest shows an increasing trend up to the mature and over-mature forest stages, while the *Q. mongolica* forest maintains continuous growth (He et al., 2016). Overall, to enhance the conservation value of species diversity in the reserve, it is recommended to strengthen the management and operation of *F. mandshurica* forest and *Q. mongolica* forest during the over-mature forest stage.

Soil is a crucial component and environmental factor in the forest ecosystem that maintains energy flow and dynamic balance. The forest ecosystem plays a key role in soil reinforcement and fertilizer protection to ensure soil quality (Guo et al., 2001). Among the six main stand types examined in this study, the *Q. mongolica* forest demonstrated the largest soil bulk density (0.75), with *B. platyphylla* forest and mixed coniferous broad-leaved forest following closely behind, followed by *F. mandshurica* forest and mixed broad-leaved forest. *J. mandshurica* forest had the smallest bulk density. Soil with a small bulk density is looser and conducive to intercepting seepage, storing water, and slowing down runoff scouring. In contrast, soil with higher density is typically more susceptible to erosion (Qian, 1999). Therefore, the *Q. mongolica* forest has relatively low soil reinforcement value. Moreover, the soil organic matter and nutrient contents of different stand types varied significantly (Gan et al., 2020). The mixed coniferous broad-leaved forest had relatively high organic matter, N and P contents, whereas the *Q. mongolica* forest had low contents for these parameters. However, the *Q. mongolica* forest had relatively high K content in the soil (Li et al., 2017). Using the market value method to estimate soil fertility retention value, the results showed that N element had the highest fertility retention value, followed by K and P, while the organic matter had the lowest value. Additionally, the soil fertilizer retention value was higher in *J. mandshurica* forest and mixed broad-leaved forest, followed by *B. platyphylla* forest and mixed coniferous broad-leaved forest, and was lower in *F. mandshurica*

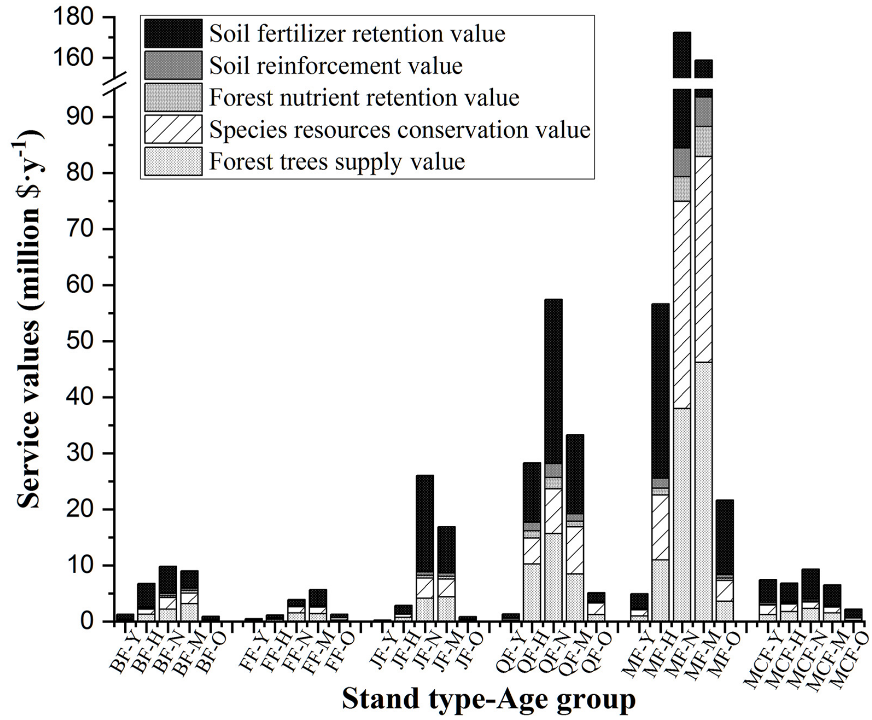

FIGURE 6
The values of provision and support service functions in Sanhu Reserve. *Betula platyphylla* forest (BF)-Y, H, N, M, O, *Fraxinus mandshurica* forest (FF)-Y, H, N, M, O, *Juglans mandshurica* forest (JF)-Y, H, N, M, O, *Quercus mongolica* forest (QF)-Y, H, N, M, O, mixed broad-leaved forest (MF)-Y, H, N, M, O, and mixed coniferous broad-leaved forest (MCF)-Y, H, N, M, O are the young forest, half-mature forest, near-mature forest, mature forest, and over-mature forest of different stand types, respectively.

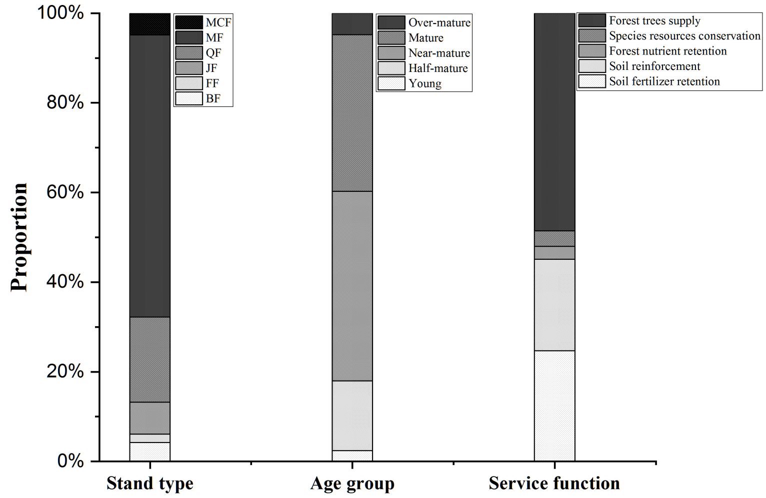

FIGURE 7
Proportion of the values of different service functions, stand types, and age groups. Stand types include *Betula platyphylla* forest (BF), *Fraxinus mandshurica* forest (FF), *Juglans mandshurica* forest (JF), *Quercus mongolica* forest (QF), mixed broad-leaved forest (MF), and mixed coniferous broad-leaved forest (MCF).

forest and *Q. mongolica* forest, the results of this study are similar to other related research findings in the same Changbai Mountain range (Zhang et al., 2017; Liu et al., 2023). Although there was no significant temporal change in the soil conservation value in this study, forests during the half-mature to mature stages, especially the *J. mandshurica* forest, exhibited higher soil conservation value, making it the primary management and operational target for improving soil conservation value in the reserve.

In addition, the conservation of nutrient elements by forest trees is also one of the important service functions of forest ecosystems (Fan et al., 2015). Organ biomass is an important basis for estimating the level of tree nutrient content, and due to the differences in the growth rate of different tree species, the current study used the allometric growth equation of various tree species to calculate the organ biomass (Wang, 2006), and based on the weight of the organ biomass of trees with a DBH of 5–100 cm and the organ nutrient content of each tree species, the N, P, and K nutrient elements content (%) of individual trees were calculated (Fan, 2014). There are obvious differences in the nutrient content of different tree species (Eriksson and Rosen, 1994), and there are also significant differences in nutrient contents of different organs of trees (Deng et al., 2019), in the current study, the N and K content of each organ is the highest in leaves, followed by branches, and relatively small in stems and roots, so the difference in forest biomass and organ nutrient content directly determines the N, P, and K nutrient retention capacity of trees. And as the basic element of protein, compared with P and K, N has the highest average content in individuals of different tree species (Liu and Wang, 2018), so the tree nutrient value of N element per unit area of different stand types and age groups is the highest, followed by P and K. As the forest age increases, the overall annual nutrient retention value of the forest shows a trend of first increasing and then significantly decreasing when it reaches the over-mature forest stage. In particular, the near-mature and mature *F. mandshurica* forests and *B. platyphylla* forests should be the primary management targets for enhancing the nutrient retention value of forestry in the reserve.

The average value of provision and support service functions per unit area of forest ecosystem in Sanhu Nature Reserve is 5,670 $\$\cdot ha^{-1}\cdot y^{-1}$, which is higher than the average value per unit area of reserves in China and the world (Taye et al., 2021; Kang et al., 2022), but it is significantly lower than the Shennongjia Nature Reserve (14,896 $\$\cdot ha^{-1}\cdot y^{-1}$) (Wu, 2018), which has very rich biological resources. Affected by tree species composition, ecosystem structure, distribution area, etc., the unit area value of different reserves presents significant differences in terms of forest supply, species conservation, nutrient fixation, and soil conservation (Uddin et al., 2013; Bai et al., 2019; Wang, 2022). Compared with the Ailao Mountain Reserve in Yunnan, the supply value of timber per unit in the Sanhu Reserve is relatively small, because there are more precious wood species in the Ailao Mountain Reserve (Tang, 2021). From the perspective of the entire reserve, the near-mature and mature forests have high provision and support service values, especially the mixed broad-leaved forest. The per unit area service values of *J. mandshurica* forest and mixed broad-leaved forest are relatively high. Therefore, in Jilin Songhuajiang Sanhu National Nature Reserve, management and operation should focus on near-mature and mature mixed broad-leaved forests in order to maintain and enhance the supply and support service values of the forest ecosystem. Additionally, the service functions of *Q. mongolica* forest and *J. mandshurica* forest should be gradually improved.

5. Conclusion

There are significant differences in the provision and support service values of forests with different types and ages. The near-mature *F. mandshurica* forest has a high provision value, with the value peak appearing mainly in the half-mature and mature forest stages. The over-mature *F. mandshurica* forest and mature *Q. mongolica* forest both show high species conservation value. Moreover, with the development of the forest, the species conservation value of *B. platyphylla* forest, *J. mandshurica* forest, and mixed broad-leaved forest shows an increasing trend up to the mature and over-mature forest stages, while the *Q. mongolica* forest maintains continuous growth. In terms of nutrient retention value, mature *B. platyphylla* forest has a significant advantage, and near-mature and mature forests have high nutrient retention capacity. The near-mature *J. mandshurica* forest has a high soil conservation value, with overall high soil conservation value observed from the half-mature to mature forest stages. From the perspective of the entire research area, the soil fertilizer conservation value is the highest, followed by the forest trees supply value and species conservation value, and the mixed broad-leaved forest and *Q. mongolica* forest are the main body of the reserve's provision and support service functions. In addition, near-mature and mature forests in the reserve are the main contributors to the service function value, especially the mixed broad-leaved forest in the reserve. It is of great practical significance to specifically protect and manage forest types with high service value in different forest development stages for promoting the sustainable development of regional forest resources.

Data availability statement

The original contributions presented in this study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Author contributions

QL, YC, and CF contributed to conception and design of the study. QL and CF organized the database. FY performed the statistical analysis. QL wrote the first draft of the manuscript. QL, YC, FY, and CF wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

Funding

The authors acknowledge the support of the Technology Development Program of Jilin Province (YDZJ202201ZYTS494), the Science and Technology Research Project of the Education Office of Jilin Province (JJKH20220063KJ), the Incubation Programme Project of Youth Innovation Team (Research team on vegetation-soil-microbial interaction effects and synergistic mechanisms in forest ecosystems), the National Key Technology Research and Development Program of the Ministry of Science and Technology of China (2021FY100802-04), and the Doctoral Scientific Research Foundation of Beihua University (Characteristics of Heavy Metal Pollution and Accumulation in Vegetable Soils in the Suburbs of Typical Industrial Cities).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/ffgc.2023.1199304/full#supplementary-material

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