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Valuation of ecosystem services from forests in Chinese rural areas based on forest resource investment

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Forest resources provide rural areas with abundant products and ecosystem services. However, due to difficulties and shortcomings in assessing the ecosystem service value of these resources in rural areas, investors or funding institutions often lack a comprehensive understanding of their true value. Consequently, challenges such as difficulties in securing rural forestry guarantees, limited loan amounts, and inadequate compensation standards have emerged, resulting in severely restricted investments in rural forest resources. This study aims to address these issues by establishing a comprehensive valuation system for the ecosystem services provided by rural forest resources, thereby enabling a more accurate assessment of their value. This study focuses on Muyun She Nationality Township in Fuan City, China, and valuates the ecosystem service value of the forest resources in this locality. The findings reveal that the annual economic value of ecosystem services provided by forest resources in Muyun She Nationality Township amounts to 397,899,293.49 yuan. Direct value constitutes over 63% of the total, with forest by-products contributing the largest share at 32%, followed by forest-related rural tourism at 31%. This underscores the significant contribution of agricultural products and tourism from rural forest resources to the local economy. Moreover, the study highlights the crucial role of rural forest resources in providing agricultural by-products, promoting rural tourism, enhancing rural economic development, and facilitating rural revitalization efforts. In light of these findings, this paper advocates for private-sector investment, expanding financing channels, and developing tourism projects to diversify investment channels for rural forest resources and increase investment amounts.

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Introduction

Forests cover nearly one-third of the Earth's land, representing the biodiversity of a large portion of terrestrial life. As crucial natural resources that provide products and generate wealth for humanity, forests have suffered severe blows over the past century from unsustainable practices like excessive logging. Despite international efforts to stop deforestation and restore forest cover, the global forest area continues diminishing (FAO, 2020). Forest resources yield a wide array of products and ecosystem services. The Millennium Ecosystem Assessment defined ecosystem services as the benefits that humans can derive from ecosystems (Churchill, 2005). Forest ecosystem services not only preserve the environment but also play an important role in societal transformation, contributing to human well-being and income generation, especially for rural populations. In addition, forests can help contrasting climate change and biomass poverty, enhancing food security and sustainability (Morrow et al., 2024). This becomes crucial during times of increasing government deficits and economic hardship for households (FAO, 2020). Research on the spatial relationship between humans and forests indicates that in 2019, 95% (approximately 4.17 billion people) of the population outside of cities lived within 5 km of a forest, and 75% (3.27 billion people) lived within 1 km of a forest (Newton et al., 2022). At the same time, the wealth associated with forest ecosystem services, including leisure and hunting, habitat provision, non-timber forest products, and water services (excluding timber and carbon), has increased from $5 trillion in 1995 to $7.5 trillion in 2018, constituting 21% of the total wealth of land asset (World Bank, 2021). It is estimated that over half of the global GDP (which was $84.4 trillion in 2020) depends on ecosystem services, including but not limited to those provided by forests, with $31 trillion annually being moderately dependent and $13 trillion highly dependent on forests (World Economic Forum, 2020). Furthermore, industries such as tourism, real estate, and retail are highly dependent on ecosystem services due to their need for specialized supply chains (Foundation for Sustainable Development, 2022).

Forest resources hold significant value and provide rich benefits through products and ecosystem services to local communities, but they receive relatively limited investment. Investments in forests and trees fall short of the value they create for individuals, communities, and societies (OECD, 2022). The most comprehensive and explicit dataset on climate financing, which includes investments in the forestry sector, is provided by the Development Assistance Committee (DAC) of the Organization for Economic Co-operation and Development (OECD) (Whiteman et al., 2015). Since 2000, financing for climate-related sectors has significantly increased, but investments in the forestry sector remain minimal. From 2009 to 2019, climate financing for the forestry sector accounted for less than 4% of the total financing (FAO, 2020). Furthermore, increasing adaptation financing for the forestry sector is crucial. The latest report on climate financing from the Group of Multilateral Development Banks (2021) shows that only about 4% of the adaptation financing provided by these banks is allocated to "other agriculture and ecological resources" (including forests) (Group of Multilateral Development Banks, 2021). Adaptation financing provided by multilateral development banks accounted for 24% of their total climate financing in 2020, highlighting the severe lack of adaptation financing for the forestry sector. Given the limited forestry investment, investment in rural forest resources is particularly challenging (Renner, 2017). This challenge is notably pronounced in China. This is because of the long operational cycle and high risks associated with forest operation. In 2018, "National Reserve Forest Construction Plan (2018–2035)" was proposed by Chinese government. In recent years, the implementation models (financing models) of national reserve forest projects mainly include credit financing models (development-oriented and policy-oriented), government social capital cooperation models (PPP models), and equity cooperation models. For example, the total investment of the national reserve forest project is about 38.7 billion yuan, with a financing demand of 28 billion yuan. Among them, the first phase of the project planned to cultivate 7.5 million acres of afforestation, with a construction period investment of 12.566 billion yuan and a financing demand of over 10 billion yuan in Guangxi, China (China Construction Political Research Think Tank, 2022). However, other types of forest only received limited funds. In China, unlike state-owned reserve forests, collective forests have a multi-level ownership structure, including state ownership and collective ownership. The collective forests can only receive limited compensation from the government and community. Inadequate compensation standards mean that forestry operators do not receive sufficient returns on their invested capital, thus affecting expected economic benefits and resulting in insufficient investment in rural forest resources. Furthermore, another significant reason for the slow development of rural forestry investment is the difficulty and lack of assessment of the ecosystem service value of rural forest resources. This leads to an insufficient understanding of the value of resources by investors or fund-raisers (institutions), resulting in difficulties in securing forestry guarantees, limited loan amounts, and inadequate compensation standards. Therefore, assessing the ecosystem services of forest resources in rural areas is of great importance.

If governments and banks only consider returns- the use or direct valuation of the forest- they would not invest in rural forests. The Chinese government proposed the plan of "rural revitalization", which includes Industrial revitalization, Talent revitalization, Cultural revitalization, Ecological Revitalization, and Organizational revitalization. The "rural revitalization" can support the development of rural forests. Therefore, this study primarily focuses on valuating the ecosystem service value of rural forest resources. It aims to establish a valuation framework and employ case studies to delineate the value of rural forest ecosystem services, particularly emphasizing specialty agricultural products and rural tourism. The significance of this research is multifaceted: Firstly, it aids in explaining the stock and value of rural forest resources, facilitating subsequent management. Valuating rural forest resources is instrumental in ensuring the stable and beneficial operation of forest resources throughout the rural revitalization, preventing encroachment on operating forest resources, and ensuring the sustained efficacy of public forest resources. This, in turn, provides a robust guarantee for comprehensive rural revitalization. Secondly, understanding the ecosystem value of rural forest resources broadens investment and financing channels for these resources and bolsters rural revitalization efforts. By investigating the realization and investment of the value of rural forest resources, this research facilitates discussions on rural investment matters based on a clear understanding and realization of their value. This ensures that investments in rural forest resources are backed by tangible value, fostering a continual increase in investment intensity and total amount.

The paper is structured as follows: Section 2 presents the literature review; Section 3 discusses the valuation of ecosystem services; Section 4 presents the case study of Muyun She Nationality Township in Fuan City; and Section 5 concludes the paper and provides key suggestions.

Literature review

Classification of ecosystem services. Ecosystems provide a large number of products and services for human survival, livelihoods, health and well-being. (Costanza et al., 1997; Churchill, 2005; Kumar, 2012; De Groot et al., 2012). Ecosystem services began to be valued only in the late 1960s. Initially, ecosystem services were attributed to the characteristics of assets, such as the service value of natural assets proposed in Westman (1977). Subsequently, Costanza et al. (1997) proposed that when humans use natural resources, they undergo a property change from qualitative to quantitative, thereby becoming ecosystem services. They classified global ecosystem services into 17 types based on specific ecosystem functions from a value assessment perspective, including gas regulation, climate regulation, disturbance regulation, water regulation, water supply, erosion control and sediment retention, soil formation, nutrient cycling, waste disposal, pollination, biological control, shelter provision, food production, raw materials, genetic resources, leisure, and culture. Based on this, they analyzed the ecosystem service values of various ecological environments, such as oceans, and became a reference for much subsequent literature and research. De Groot et al. (2002) further refined it into 23 subcategories and classified them into four types: regulatory function, habitat support function, provisioning service, and information function. In 2005, the Millennium Ecosystem Assessment categorized ecosystem services into four major types: provisioning, regulating, supporting, and cultural services. Provisioning services provide basic resources such as food, raw materials, and water; regulating services adjust climate and water sources, thereby to some extent protecting humans from natural disasters; cultural services offer values such as recreation, education, and esthetics; and the value of supporting services lies in providing the necessary conditions for the above three services. Supporting services are different from other services because they are indirect or long-term.

In 2007, the Economics of Ecosystems and Biodiversity (TEEB) initiative, building upon the Millennium Ecosystem Assessment, introduced a framework for ecosystem services, enhancing the comprehensiveness, reasonableness, and completeness of ecosystem service assessments.

Identification of forests ecosystems services. The Millennium Ecosystem Assessment and the TEEB assessment framework provide categorizations and assessments of various ecosystem services. According to the TEEB's assessment framework, the value of forest ecosystem services can generally be divided into two categories: use value and non-use value. Due to the widespread and complex distribution of forest resources, these resources provide ecological and social benefits that are non-exclusive. Management entities of forest resources cannot completely control the direct and indirect economic benefits provided by those resources, but they can partly control certain potential economic benefits, such as forest products and by-products. Currently, only this portion of benefits generates actual financial inflow to the management entities through market-based actions (Zhang et al., 2023). The valuation of forest resources entails estimating the economic benefits a particular forest resource may yield for its owners. Therefore, if environmental costs and compensations cannot be assessed through means other than market actions, such as finance or taxation, it will result in a discrepancy between the economic benefits calculated by management entities and the actual economic benefits obtained. As environmental protection and the efficient utilization of natural resources attract more attention, there are three methods to realize the environmental service value of forest resources: firstly. due to their characteristics as public goods, environmental services provided by forest resources are often excluded from market transactions. Therefore, one common method is realizing them through relevant laws and regulations, such as taxation or financial subsidies. Secondly, some environmental services can be realized through the operation of property rights holders of forest resources, such as the scenic and recreational value. Additionally, certain environmental service values are gradually being promoted for market transactions with the improvement and expansion of market mechanisms, such as realizing the carbon sequestration of forest resources through carbon trading (Zhao et al., 2004). In our research, we will select the most significant forest ecosystem services to develop a framework and calculate their valuation, distinguishing their value relative to other services.

Valuation method of forest ecosystem services. Forests are one of the Millennium Ecosystem Assessment Reporting categories, providing provisioning, regulating, cultural, and supporting services. Valuation methods exist for each of these services.

Common methods for valuating the value of forest resources primarily aim to assess the economic benefits they provide. Most valuations of ecosystem services have no market price, but can be considered the non-tradable public benefits (De Groot et al., 2012). Most methods can estimate the use value, shown in Fig. 1, as following: (1) the replacement cost method values forest ecosystem services based on the actual expenditures, only when the expenditures have been generated. (2) the travel cost method applies the travel expenditures spend to visit a specific site. (3) The hedonic pricing method is used when the differences in the market prices of goods (typically, house prices) are presumed to reflect the value of the forest ecosystem services. (4) The commercial value method utilizes market prices to assess the value of forest ecosystem services, but this method only includes the parts of forest ecosystem services having market prices, ignoring other values. (5) The economic impact method measures the economic value changes of forest ecosystem services and their impact on the regional economy. (6) the benefit transfer method can be used to estimate the valuation of similar forest ecosystem services in similar locations and settings, when considering certain conditions in a specific location and setting. (Nolander and Lundmark, 2024). For non-use value, (1) the contingent valuation method involves surveys asking people about their willingness to pay for a change in an forest ecosystem services. (2) The choice experiments method, a variant of the contingent valuation, asks individuals to choose among different scenarios.

The valuation of forest ecosystem services can be affected by some factors. Nolander and Lundmark (2024) identified and considered the spatial and background of economic valuations of forest ecosystem services. They suggest that forests near urban areas may have a different valuation than those further away due to higher recreational activity. Ninan and Inoue (2013) believed that the valuations of forest ecosystem services are related to the number of the services valuated, the applied prices and method, and the local contexts. Sun (2007) adjusted the price of larch by comparing it with similar cases for valuation. In our research, we identify proximity, location, and disaster as important factors that could affect the valuation of forest ecosystem services.

The location of the forest influences the valuations of forest ecosystem services. Hu and Liu (2010) estimated the forest resource assets in the Jianlagou working circle of the Maoershan experimental forest farm of Northeast Forestry University using methods, such as replacement cost, net present value, and market price inversion. Wang et al. (2007) valuated the forest ecosystem services in Tibet, mainly using methods such as market valuation, opportunity cost, shadow pricing, replacement project, and travel cost. Ninan and Inoue (2013) considered valuations on different forest ecosystem services from different forest sites and countries (regions). Wu et al. (2021) assessed the forest ecosystem services in

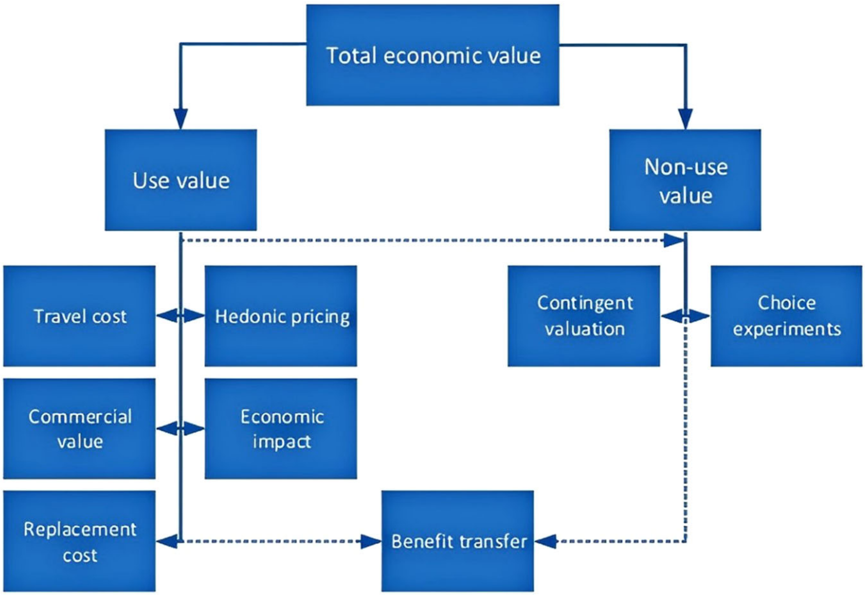

Fig. 1 Valuation methods for use and non-use values. (Nolander and Lundmark, 2024).

Huzhou, including the production of organic matter, absorption of carbon dioxide, release of oxygen, recycling of nutrients, water retention, and soil and water conservation, among others. It can be seen that the theory and technical methods of forest resource valuation are becoming increasingly mature, from traditional assessment to models integrating functional characteristics. However, most of the current literature focuses on methods for assessing the value of forest resources and valuating ecosystem services of forest resources in specific provinces or regions, with little emphasis on rural areas. With the development of "rural revitalization" and increased attention on forest resource utilization in China, the valuation of ecosystem services in rural areas become significant. This study aims to fill this gap; therefore, we will choose the most common and important ecosystem services relating to Muyun She Nationality Township. Through forming a framework of rural forest ecosystem services, we will estimate the valuation of the services.

Forest investment. A forestry investment can be used for growing trees, managing existing trees, and both. The trees can be from a natural forest or built artificially in a plantation. Forestry has long offered opportunities to institutional investors. However, the scope for forestry investment remains limited (Binkley et al., 2020). Many countries' governments proposed the forest investment plan. In China, implementation models for national reserve forest projects mainly include credit financing models (development-oriented and policy-oriented), government social capital cooperation models (PPP models), and equity cooperation models. Reserve Forest Project in Guangxi, China, has three main funds sources: bank (80%), self-raised funds (14%) and National financial forest subsidies (6%) (China Construction Political Research Think Tank, 2022). In Indonesia, there are ten Forest Management Units applying decentralized forest management, which strengthens a forest investment program supported by foreign funding (Massiri, 2023). Given the relatively limited forestry investment and the challenges in its application, we will present the valuation of forest ecosystem services by building our own assessment framework and calculating the value of different services, thereby suggesting improved investment strategies.

Valuation of ecosystem services

Economists are striving to provide more reliable estimates of the economic value associated with forest resources. Wood, timber fuel, various forest fruits, resins, and other non-timber products have local, national, and international markets, contributing to income generation, employment opportunities, and production value—all of which should be duly recorded within national accounting systems. Despite many scholars endeavors to broaden the international classification of forest products to encompass non-timber items, the valuation reports for these products remain inadequate in achieving a dependable quantification of forest output (Sorrenti, 2017). Quantifying the societal benefits of forest ecosystem services poses even greater challenges due to the widespread absence of markets for these services. Even in cases where markets exist for certain services, such as carbon, they are still in their infancy. Moreover, many countries have yet to incorporate forest resource assets into national asset accounting, potentially leading to significant errors and biases in decision-making during policy formulation and implementation. In the long run, the depletion of natural assets could adversely affect the growth of other assets. If climate change and natural resource depletion persist at their current rates, it is unlikely that any nation's economy will be able to maintain its current levels of wealth and well-being (FAO, 2020). Understanding the scale, stock, and associated value of natural resource assets is essential as it pertains to formulating governments' sustainable development policies and identifying investment opportunities and risks.

Ecosystem services began to be valued only in the late 1960s. The conceptualization of ecosystems providing services to human societies emerged with the publication of Man's Impact on the Global Environment (SCEP, 1970). This landmark study introduced the term "environmental services" and outlined several crucial examples, encompassing pest control, insect pollination, fisheries provision, soil formation, soil and water conservation, and climate regulation. In 1974, Holdren and Ehrlich studied the role of ecosystems in soil fertility and gene maintenance, and analyzed the impact of biodiversity loss on ecological services, as well as the question of whether advanced science and technology can be used to replace the services of natural ecosystems, and expanded the concept of "environmental services" to "global environmental services" (Holdren and Ehrilich, 1974).

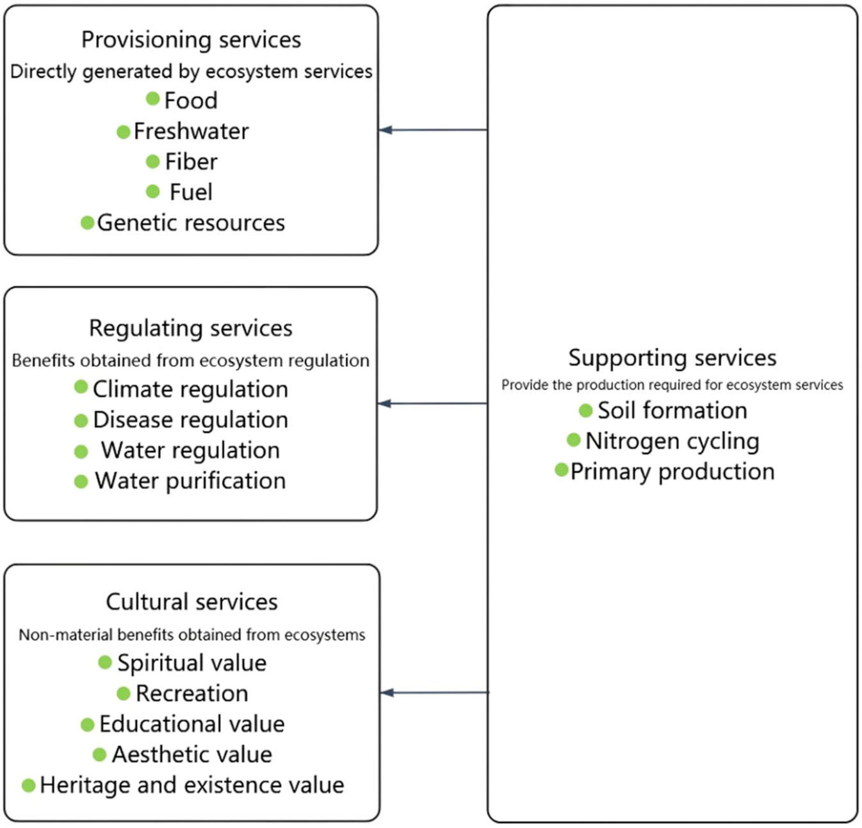

Fig. 2 Millennium Ecosystem Assessment: Classification of Ecosystem Services.

Westman (1977) highlighted the social valuation of ecosystem benefits as a crucial factor in rationalizing policy and management frameworks, introducing the term "Nature's services" to represent these societal benefits. Ehrilich and Ehrilich (1981) undertook a synthesis of related concepts, including "environmental services," ultimately promoting Westman's "Nature's services." This terminology subsequently transitioned to the now-established and widely adopted "ecosystem services." Following Ehrlich and Ehrlich's introduction of the ecosystem services concept, various scholars have offered distinct definitions. Daily (1997), in Nature's Services: Societal Dependence on Natural Ecosystems, emphasized the role of natural ecosystems and their species in providing essential conditions and processes that support human well-being. Costanza et al. (1997) focused on the benefits derived from ecosystem functions, encompassing both tangible products (e.g., food) and intangible services (e.g., waste disposal), referring to these collectively as "ecosystem services." Their work further delineated 17 specific categories of these services, each corresponding to distinct ecosystem functions.

The 2005 Millennium Ecosystem Assessment (MA) defined ecosystem services as the benefits derived by humans from ecosystems, and established a framework of four interconnected categories: provisioning, regulating, cultural, and supporting services. Supporting services form the foundation upon which the other three depend, providing the biophysical conditions necessary for their functioning. Provisioning services represent the material outputs of ecosystems, such as food, freshwater, raw materials, and genetic resources. Regulating services encompass the ecosystem's capacity to moderate natural processes and mitigate hazards, including climate regulation, hydrological regulation and natural disaster mitigation. Cultural services provide non-material benefits that enrich human well-being, such as recreational, esthetic, and educational opportunities (Fig. 2) (Liu and Zhuang, 2021). However, this classification has been criticized for its lack of clear distinction among intermediate services, final services, and benefits, which can complicate the analysis of trade-offs in natural resource management (Fisher and Turner, 2008).

Boyd and Banzhaf (2007) advanced a significant clarification of the ecosystem services concept, asserting that it is not merely the resultant benefits obtained by humans from ecosystems, but rather the ecological components that generate those benefits. This assertion carries two important implications: first, it defines ecosystem services as tangible phenomena or active processes occurring within ecosystems; second, it establishes the criterion of direct or indirect utility to humans as essential for qualifying an ecological component as an ecosystem service (Feng et al., 2009). Thus, under this definition, ecosystem services comprise ecosystem structures, processes, or functions that can be demonstrably utilized by human societies. Consequently, ecosystem processes or functions are recognized as ecosystem services only when they demonstrably provide such utility to humans.

Driven by growing concerns regarding biodiversity loss and ecosystem degradation, the TEEB was launched at the 2007 Potsdam Summit in Germany. This initiative was designed to provide a robust economic valuation of the benefits derived from ecosystems and biodiversity, while also quantifying the economic costs associated with their decline. By integrating expertise from both the natural and social sciences, TEEB aimed to bridge the gap between scientific understanding and policy implementation, facilitating the development of improved methodologies and comprehensive frameworks for the assessment of ecosystem services.

According to TEEB's assessment framework, the value of forest ecosystem services can generally be divided into two categories (Fig. 3): use value and non-use value. (1). Use value can further be

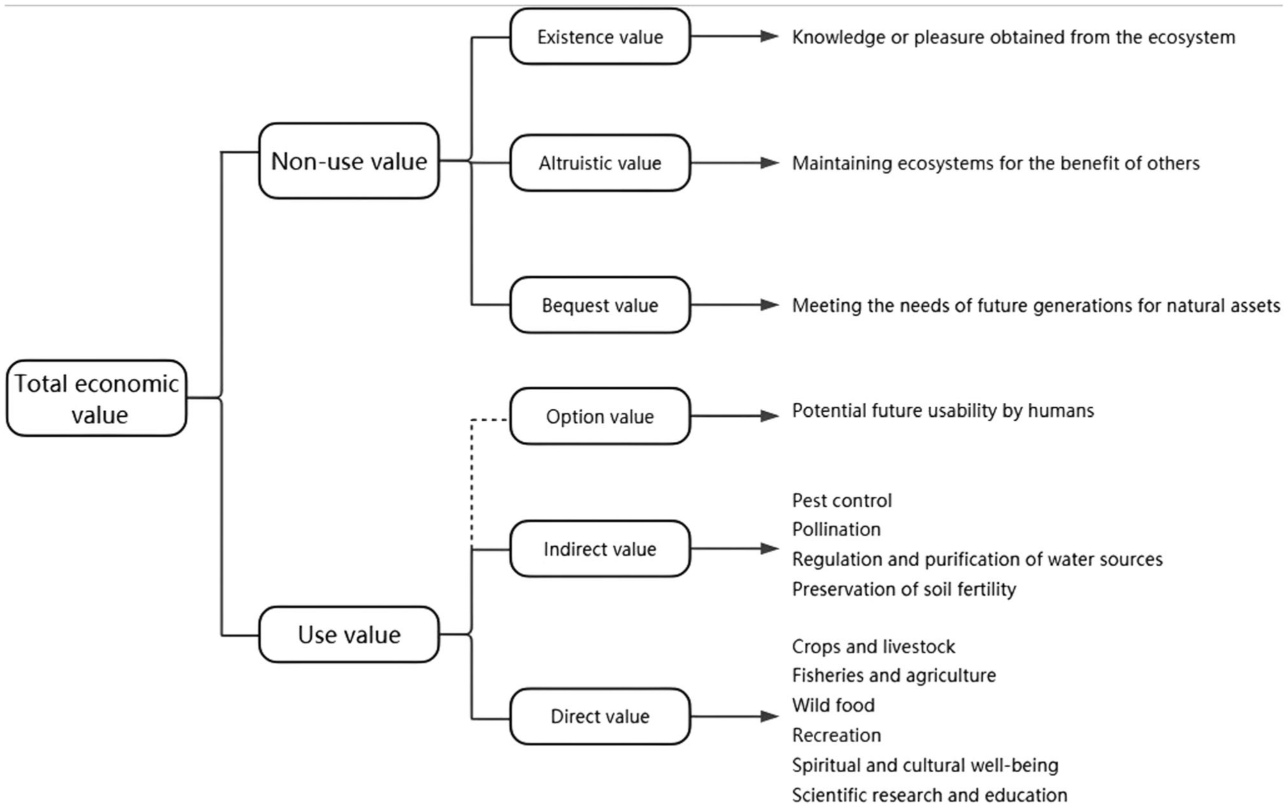

Fig. 3 Classification of forest ecosystem service values.

classified into direct use value, indirect use value, and option value. Direct value encompasses the worth of timber and forest by-products, recreation, spiritual and cultural enrichment, scientific research, and education. Indirect value covers pest control, water regulation, soil conservation, and similar benefits. Option value refers to the worth of resources that may be available for human use in the future. (2). Non-use value, on the other hand, denotes the value of forest resources beyond their direct use. This includes bequest value, altruistic value, and existence value. Non-use value does not relate to values associated with direct and indirect use. Non-use value reflects human cognitive and esthetic experiences, as well as the satisfaction of physical and mental well-being derived from forest resources, offering opportunities for people to engage with and understand nature (Kumar, 2012).

A significant challenge in ecosystem service valuation lies in the assessment of non-use values, which are inherently difficult to quantify due to their dependence on subjective factors such as ethics, religion, emotional experiences, and esthetic preferences. These subjective influences preclude the establishment of objective valuation criteria and the availability of market prices. TEEB, building on the foundation of the MA, made a substantial contribution by categorizing ecosystem service functions in terms of use value (direct value and indirect value). Moreover, TEEB also expanded upon the MA framework by incorporating previously unexamined dimensions and consolidating categories with similar attributes, thereby providing a more comprehensive and robust approach to ecosystem service assessment. This enhanced classification system has subsequently been widely adopted as a basis for ecosystem service valuation in numerous recent studies (Table 1) (Liu and Zhuang, 2021).

In 2013, the United Nations Statistical Division (UNSD) introduced the Common International Classification of Ecosystem Services (CICES) as a standardized framework for classifying ecosystem services. This framework was constructed through the integration of existing classifications from the Millennium Ecosystem Assessment (MA) and The Economics of Ecosystems and Biodiversity (TEEB) initiative, synthesizing their respective strengths. Following a review and subsequent adjustments based on a 2016 study conducted by the European Environment Agency (EEA), the fifth iteration of CICES was published in 2017. The CICES classification retains key criteria originally proposed within the TEEB framework (Table 2) (Liu and Zhuang, 2021).

In September 2022, the State Forestry and Grassland Administration (SFGA) of China issued the Technical Specifications for Asset Evaluation and Accounting of Forest Resources (draft for comment), hereafter referred to as the Specifications. This publication aimed to refine the conceptual and methodological basis for asset valuation and accounting related to forest resources within China. Critically, the Specifications propose a framework for assessing forest ecosystem services that is grounded in the Common International Classification of Ecosystem Services (CICES) but explicitly adapted to reflect the unique ecological, economic, and social characteristics of the Chinese context (Table 3).

Effective management of natural resources requires a robust approach to ecosystem service assessment, which involves not only defining a suitable valuation framework but also quantifying the capacity of ecosystems to provide a range of services and subsequently valuating these services based on prevailing societal demand. This valuation process typically employs one of three primary methodologies: physical quantification, which measures the biophysical output of services; monetary valuation, which assigns economic values based on market or non-market valuation techniques; and energy analysis, which assesses the energy embodied within ecosystem processes and outputs (Boyd and Banzhaf, 2007; Watanabe and Ortega, 2014).

The purpose of ecosystem service valuation is often to provide a common metric, typically monetary, for quantifying diverse

Table 1 Forest Ecosystem Services: An Introduction.

Main category	Sub-category	Characterization
Provisioning Services	Food	Ecosystems maintain the necessary environmental conditions for food production, and human-managed agroecosystems represent the principal source of human sustenance.
	Raw materials	Ecosystems yield a diverse array of raw materials, encompassing plant resources procured from wild populations or through domestication and subsequent cultivation.
	Fresh water	Ecosystems exhibit inherent capacities for regulating hydrological regimes and enhancing water quality. The interplay between vegetation, particularly forested ecosystems, and the hydrological cycle profoundly affects water availability across diverse landscapes.
	Medicinal resources	Ecosystems and their inherent biodiversity represent a vital source of phytopharmaceuticals, providing a rich repository of plant-derived compounds employed in traditional ethnomedicine and contemporary pharmaceutical development.
Regulating Services	Local climate and air quality	Arboreal vegetation provides shade, thereby influencing microclimatic conditions. Forested ecosystems, however, exert a more pronounced influence on hydrological processes, affecting both local and regional precipitation and water resource dynamics. Moreover, the collective action of trees and other plant life contributes significantly to the sequestration and removal of atmospheric pollutants.
	Carbon sequestration and storage	Ecosystems possess the inherent capacity to store and sequester atmospheric greenhouse gases, thus exerting a significant influence on global climate regulation and contributing to long-term climate stability.
	Moderation of extreme events	Ecosystems function as natural buffers against the impacts of extreme meteorological events and geophysical hazards, such as floods, storms (including hurricanes and typhoons), and tsunamis. These natural buffers attenuate the force of these events, thereby reducing the vulnerability of coastal and inland communities.
	Waste-water treatment	Ecosystems provide essential environmental services by functioning as natural buffers that mitigate environmental stressors and also by serving as natural filters that facilitate the decomposition and assimilation of anthropogenic and zoogenic waste through complex biogeochemical processes.
	Erosion prevention and maintenance of soil fertility	Vegetation offers essential ecosystem services by regulating soil erosion. Intact ecosystems support fertile soils that are rich in the nutrients required for plant growth and development.
	Pollination	Insect and wind pollination are essential processes for the reproductive success of trees and plants, directly affecting the formation and production of fruits, vegetables, and seeds, which are crucial for both natural ecosystems and agriculture.
	Biological control	Pests and diseases that affect human, plant, and animal populations can be regulated and suppressed through the introduction of natural enemies, including predators such as birds, bats, frogs, and certain flies and wasps, as well as parasites like some fungi, which disrupt pest life cycles and reduce disease transmission.
Habitat Services	Habitats for species	Habitats offer the resources essential for the survival and reproduction of all organisms, including both flora and fauna: sustenance (food), water, and protection from predators and the elements (shelter).
	Maintenance of genetic diversity	Genetic diversity encompasses the genetic variation both among different species and within populations of a single species, providing a foundation for developing varieties adapted to diverse environments and serving as a valuable genetic resource for economic crops and livestock breeding.
Cultural Services	Recreation and mental and physical health	The role of green spaces in promoting human mental and physical health is gaining increasing recognition.
	Tourism	Natural ecosystems and biodiversity are major tourist attractions, with natural beauty generating substantial economic benefits and contributing significantly to the economies of numerous nations.

services and facilitating communication with policymakers and the public. A typical analytical framework for this process includes quantifying service provision, assessing monetary value, and informing management decisions (Polasky, 2008). Costanza et al. (1997) conducted a landmark global valuation study, quantifying the value of 17 ecosystem service types by estimating per-unit-area values and aggregating them to derive total values. This study was subsequently updated by Costanza et al. (2014) using revised land-use data to reflect changes in global ecosystem service values between 1997 and 2011. While physical quantification offers a robust method for capturing the spatial variability of ecosystem service provision, particularly at regional and landscape scales (Su and Fu, 2013), the use of different measurement units can complicate comparisons across different service types. Energy analysis, by contrast, offers a potential solution to the problem of double counting inherent in some valuation approaches by converting diverse energy forms into a common unit (Cao et al., 2016).

Methodological advancements in the monetary valuation of ecosystem services are evident in the transition from reliance on traditional monitoring and statistical data to the integration of diverse data sources, such as remote sensing and ground-based observations. Concurrently, research has evolved from static, point-based valuations to the analysis of spatial patterns and their dynamic changes over time. This evolving field increasingly emphasizes sophisticated modeling techniques, enhanced precision in valuation estimates, and a deeper understanding of the processes governing ecological function and the mechanisms of service generation.

Despite ongoing efforts to refine ecosystem assessment methodologies, significant challenges remain, particularly in achieving accurate and widely accepted valuations. A primary

Table 2 A Comparison of the CICES and TEEB Typologies of Ecosystem Services.

CICES Main category	CICES Sub-category	The TEEB ecosystem services classification category			
Provisioning	Nutrition	Food	Fresh water		
	Materials	Raw materials	Genetic Medicinal resources	Medicinal resources	Ornamental resources
	Energy				
Regulating and Maintance	Regulation of waters	Air purification	Waste treatment (esp.water purification)		
	Flow regulation	Disturbance prevention or moderation	Regulation of water flows	Erosion Prevention	
	Regulation of Physical environment	Climate regulation (including C.sequestration)	Maintaining soil fertility		
	Regulation of biotic environment	Gene pool protection	Lifecycle maintenance	Pollination	Biological control
Cultural	Symbolic	Information for cognitive development			
	Intellectual and experiential	Esthetic information	Inspiration for culture, art and design	Spiritual Experience	Recreation and tourism

concern is the difficulty in obtaining consensus on both physical and monetary valuations of ecosystem services. This challenge is compounded by the frequent reliance on value transfer from existing studies and the inherent non-market nature of many services. Ecosystem services, defined as benefits derived from ecological assets within specific temporal frameworks, often lack established market prices, hindering their valuation. For example, while a forest ecosystem represents a form of natural capital, its associated services, such as gas regulation, water retention, and air purification, are not readily traded in markets, making their societal value difficult to ascertain. Furthermore, physical quantification methods are subject to uncertainty due to the variability in service provision across different ecosystem types and geographic contexts. The services provided by lake and farmland ecosystems, for instance, differ substantially, and even within a single ecosystem type, such as forests, service provision can vary based on factors like slope, with slope forests providing crucial soil erosion prevention services absent in forests on flat terrain (Xie et al., 2006).

The inherent link between ecosystem services and human well-being underscores their importance in both natural and socio-economic systems. This interconnectedness necessitates an interdisciplinary approach to their study, drawing upon fields such as geography, ecology, and economics. Human needs, as described by Maslow's hierarchy, shape preferences for various ecosystem service categories, including provisioning, regulating, cultural, and supporting services (Foley et al., 2005; Swallow et al., 2009). Natural resource management decisions driven by these preferences can lead to imbalances, particularly between provisioning services and other categories (Cao et al., 2016). From a welfare economics standpoint, the design and implementation of economic (e.g., fiscal and monetary policies), political (e.g., legal and social security systems), and cultural (e.g., moral and customary norms) systems aimed at improving human well-being directly influencing the utilization of ecosystem services, subsequently affecting both the mode and intensity of use, and ultimately impacting service outputs and human well-being (Cao et al., 2016).

China's extensive forest resources (Zuo and Cai, 2006), particularly located in the mountainous and hilly regions that comprise 69% of the country's land area (Zuo and Cai, 2006), play a crucial role in rural livelihoods. Rural communities, as key stakeholders, depend on forests for various resources, including timber, fuelwood, and non-timber forest products (NTFPs), such as fruits and medicinal herbs. Furthermore, forests contribute to the development of rural economies through activities like tourism and recreation. With rural collective forests constituting 57.55% of China's total forest area (Sixth National Forest Inventory), their management has significant implications for rural economic development, the well-being of rural populations, and the overall trajectory of the national forestry sector (Zuo and Cai, 2006). These rural collective forests, referred to herein as rural forests, are defined as forest resources owned and managed by rural collective economic organizations, such as village committees and cooperatives. These communally held forests are typically situated within rural landscapes. Valuating the ecosystem services provided by rural forests is essential for understanding their comprehensive value and for informing strategic investment decisions in specific services. For example, if the assessed value of the forest or its by-products is high, private investment may be a viable option, as private investors are typically more attracted to assets that generate direct economic returns. Alternatively, if the assessed environmental value is high, public-sector investment is more likely, given the Chinese government's environmental policy of "green mountains are gold mountains".

Table 3 Accounting Framework for Forest Ecosystem Service Indicators.

Main category	Sub-category	Specific items		
Provisioning services	Timber products			
	Forest by-products			
Regulating services	Water conservation	Regulation of water flows	Water purification	
	Soil conservation	Erosion prevention		
	Carbon sequestration and oxygen release	Carbon sequestration	Oxygen release	
	Air purification	SO_2 purification	Dust retention	Other Hazardous Air Purification
	Forest protection	Ranch protection	Farmland protection	
	Biodiversity protection			
Cultural services	Recreation and tourism			

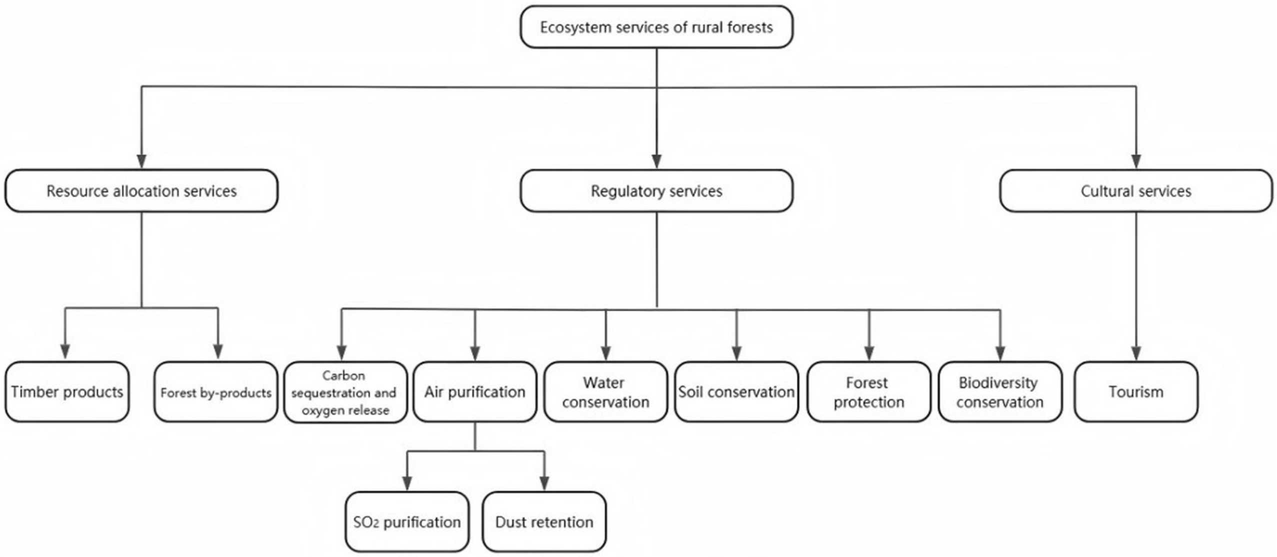

Fig. 4 Framework for Valuating Ecosystem Services of Rural Forests.

A rigorous assessment of rural forest ecosystem services requires a structured approach, beginning with the establishment of a comprehensive assessment framework and subsequently proceeding with the selection of appropriate valuation methods for each service type. This study utilizes the Technical Specifications for Asset Evaluation and Accounting of Forest Resources issued by China's State Forestry and Grassland Administration (SFGA) as the basis for developing a framework tailored to rural forest ecosystems. These Specifications developed and endorsed by national governmental authorities, provide a standardized methodological guideline for conducting forest ecosystem service assessments throughout China, ensuring consistency and comparability across different regions.

Drawing on the Specifications, this study establishes a valuation framework suitable for ecosystem services of rural forest resources in China (Fig. 4). The framework consists of three parts: first, resource allocation services, which include the provision of food and raw materials by forest resources; second, regulatory services, mainly comprising carbon sequestration and oxygen release, air purification, soil and water conservation, forest protection and biodiversity conservation; third, cultural services, primarily referring to rural tourism services generated by forest resources. The value generated by timber and forest by-products in the resource allocation services can be regarded as the direct value of forest ecosystems, while the value generated in the regulatory services is indirect, and the tourism value brought by cultural services is also direct. For the valuation methods of these three parts, the intensity of ecosystem services is first quantified, then the valuation method and price coefficients are determined, thereby obtaining the value of ecosystem services. The formula and parameter description of indicator systems for rural forest ecosystem services valuation are as follows (Table 4).

Case study - Muyun She Nationality Township in Fuan City

This study focuses on Muyun She Nationality Township (hereafter referred to as Muyun) in Fuan City, Fujian Province, China, aiming to estimate the ecosystem service value of forest resources in Muyun. This estimation serves as a basis for investment decisions regarding rural forest resources. Muyun is situated in the western part of Fuan City, covering a total area of 121.17 km^2. It comprises 33 village committees, including 14 She nationality villages. The terrain of Muyun is predominantly mountainous, and its climate falls under the subtropical maritime monsoon type, characterized by distinct seasons and abundant rainfall. The vegetation is primarily composed of subtropical evergreen broad-leaved forests. Situated in Fujian Province, a region dominated by mountainous terrain (90% of land area) and extensive forest cover (62.96%), Muyun Township reflects these regional characteristics. The township's forest coverage reaches 76.5%, earning it recognition as a provincial "Forest Township" (People's Government of Muyun Township, 2024). These forest resources underpin a thriving specialized forest by-products industry, with peach, grape, and tea production generating an output value of 340 million yuan. Moreover, forest ecosystems serve as the foundation for tourism, with scenic attractions such as Baiyun Mountain, the Water People's Landscape Belt, and the ecotourism area of Muyun She Nationality Township attracting

Table 4 Formula and parameter description of indicator systems for forest ecosystem services valuation.

Function	Index	Formula	Parameter description	Parameter sources
Timber products	V	$V = G \times T \times P$	Where *V* represents the value of timber production in the forest, *G* represents the forest stock, *T* represents the recovery ratio of timber, and *P* represents the price of timber per m^3.	(Wang et al., 2007), (Yu et al., 2005), (Zhao et al., 2004), (Wei and Qi, 2016)
Forest by-products	U	$U = C \times P$	Where U represents the value of forest by-products, C represents annual output of forest by-products, and P represents the price of forest by-products per ton.	(Wang et al., 2007), (Yu et al., 2005), (Zhao et al., 2004), (Wei and Qi, 2016)
Carbon sequestration and oxygen release	V	$Q = \sum_{i=1}^{n} S_i \times (NPP_i \times 1.63 \times 0.273)$ $V = Q \times P$	Where Q represents the total carbon sequestration of forests, n represents the number of forest types. NPPi represents the net primary productivity of type i forest per unit area, Si represents the area of type i forest, 1.63 is the carbon sequestration coefficient, and 0.273 is the carbon content of carbon dioxide. V represents the value of carbon sequestration, Q represents the total carbon sequestration by forest, and P is valuated using the Chinese afforestation cost method, at 273.3 yuan/ton of carbon sequestration or the Chinese afforestation cost method of 369.7 yuan/ton of oxygen.	(Statistical Bureau of Guangxi Zhuang Autonomous Region, 2019), (Hou et al., 1995), (Zhao et al., 2004)
Air purification (SO_2 purification and Dust retention)	V_S	$V_S = R_i \times S_i \times P$	Where V_S represents annual value of SO_2 purification, R_i represents the capacity to absorb SO_2 per unit area of forest type i, S_i represents the area of type i forest, and P represents the investment and treatment cost of SO_2.	(Zhao et al., 1999), (Editorial Committee of State Report on Biodiversity of China Committee, 1997), (Zhao et al., 2004)
	V_D	$V_D = R_i \times S_i \times P$	Where V_D represents annual value of dust retention, R_i represents the capacity to stagnant dust per unit area of forest type i, S_i represents the area of type i forest, P represents dust removal costs.	
Water conservation	V	$V = Q \times P = (R - E) \times S \times P$	Where V represents the economic value of the annual water conservation in forests Muyun forests (yuan/year), Q represents the water conservation volume (m3/year), R represents the average precipitation in the region (mm/year), S represents the forest area in the region (hectare), and E represents the average evaporation of forests in the region (mm/year). P represents the unit cost of water conservation.	(Hou et al., 1995), (Yu et al., 2005), (Liu et al., 2021)
Soil conservation	V	$Q = \sum_{i=1}^{n} S_i (X_{1i} - X_{2i}) V = Q \times P$	Where Q represents the total soil conservation of forests, n represents the number of forest types, Si represents the area of type i forest (in hectares), X_{1i} represents the potential soil erosion of type i forest, X_{2i} represents the actual soil erosion of type i forest, in tons/hectare·year. V represents the value of soil conservation, and P represents the clearing each ton of sediment costs.	(Statistical Bureau of Guangxi Zhuang Autonomous Region, 2019), (Dong et al., 2020), (Zhao et al., 2004)

Table 4 (continued)

Function	Index	Formula	Parameter description	Parameter sources
Forest protection	$V_{protection}$	$V_{protection} = V_{forest} \times S_{forest} \times 10^{-4}$	Where $V_{protection}$ refers to the value of windbreak protection of forest, in 10,000Yuan/year, V_{forest} refers to the value of windbreak protection per unit of protection forest, in Yuan/hectare year, and S_{forest} refers to the area of protection forest, in hectare, 10^{-4} is a unit conversion coefficient.	(Forestry Bureau of Fuan City, 2017), (Statistical Bureau of Guangxi Zhuang Autonomous Region, 2019)
Biodiversity conservation	V	$V = P \times H \times A$	Where V represents the value of biodiversity conservation, P represents the willingness to pay of each individual, H represents total population, and A represents the percentage of protected species in forest ecosystems.	(Zhao et al., 2000), (Yu et al., 2005), (Wang, 1998), (Editorial Committee of State Report on Biodiversity of China Committee, 1997)
Tourism	V	$V = H \times P$	Where V represents the value of tourism, H represents total number of tourists, and P represents the cost per person traveling.	(Zhao et al., 2004), (Liu et al., 2013)

approximately 800,000 visitors each year. Consequently, forest ecotourism is a significant emerging sector in Muyun Township's economy.

Given that this study focuses on forest resources in rural areas, the estimated value of ecosystem services does not encompass state-owned forest farms, but it is limited to forest resources collectively owned by rural communities. The estimation is based on data from the year 2020. China's forest ownership structure comprises two principal forms: state ownership and collective ownership. State-owned forests are subject to centralized management under the purview of state forestry authorities, adhering to state planning directives. In contrast, collective forests are owned by village collectives and managed by a variety of collective economic entities, including village committees and cooperatives. Management practices in collective forests vary, encompassing both unified collective operations and household-based contracting arrangements. Therefore, rural collective forests play a crucial role in rural economic development and the socio-economic well-being of farmers. The scope of this study is limited to rural collective forests, thereby excluding state-owned forest farms.

According to the 2020 data on forest resources in Fuan City, Muyun has a forest land area of 10,215 hectares, with forest land accounting for 74% and non-forest land for 26%. The forest land includes various types, such as arbor forests, bamboo forests, shrub forests, non-afforested land, cut-over land, and land suitable for afforestation. Non-forest land includes areas with trees on the periphery and forested areas on non-forest land (Table 5). The total forest and timber volume in Muyun amounts to 198,995 m^3, encompassing protection forests, special-purpose forests, and timber forests, among others (Table 6). Tables 5 and 6 also provide data on the land area and volume of key public welfare forests, normal public welfare forests, and commercial forests. Public welfare forests, encompassing both key and normal designations, are crucial for maintaining vital ecosystem services in ecologically sensitive or vulnerable areas. These services include water and soil conservation, wind and sand control, and biodiversity protection. Conversely, commercial forests are managed primarily to achieve economic objectives through timber production, with timber-producing stands being the dominant type in this region. Using the "Assessment Framework for Ecosystem Services of Rural Forests" depicted in Fig. 4, this study valuates the ecosystem services of forest resources in Muyun She Nationality Township. The framework consists of three parts: first, resource allocation services, which include the provision of food and raw materials by forest resources; second, regulatory services, mainly comprise carbon sequestration and oxygen release, air purification, soil and water conservation, forest protection and biodiversity protection; third, cultural services, primarily referring to rural tourism services generated by forest resources. Among these, the value generated by timber and forest by-products in the resource allocation services can be regarded as the direct value of forest ecosystems, while the value generated in the regulatory services is indirect, and the tourism value brought by cultural services is also direct.

Resource allocation services

Timber products. The forest ecosystem provides a significant amount of timber products for human use. The formula for calculating the value of timber, as proposed by Wang et al. (2007), Yu et al. (2005), Zhao et al. (2004), and Wei and Qi (2016), is as follows:

$$V = G \times T \times P \tag{1}$$

Where V represents the value of timber production in the forest, G represents the forest stock, T represents the recovery ratio of timber, and P represents the price of timber per m^3.

Table 5 Muyun Township's Forest Area in 2020 (in hectares).

Forest (Woodland) category	Total land area	Forest land								Non-forest land
		Total	Arbor forest	Bamboo forest	Sparse forest	Shrub forest	Non-afforested land	Cut-over land	Afforestation land	Total
Total	10214.99	7562.13	5632.98	697.65	81.34	919.94	78.58	12.34	139.30	2652.86
Key public welfare forests	2803.32	2803.32	2370.02	161.25	35.92	123.27	35.38	9.28	68.19	
General public welfare forests	29.08	29.08	23.50	0.83		4.29			0.46	
Commercial forests	7382.60	4729.73	3239.46	535.57	45.41	792.38	43.20	3.06	70.65	2652.86

Data source: Forestry Bureau of Fuan City.

Table 6 Muyun Township's Forest Stock in 2020 (in m^3).

Forest (Woodland) category	The total forest and timber volume										
	Total	Arbor forest						Sparse forest	Scattered trees	Boundary trees	Forest on non-forest land
		Total	Protection forest	Special purpose forest	Timber forest	Fuelwood forest	Economic forest		Stock (volume)	Stock (volume)	
Total	198995	198412	166109	1489	30814			125	458		589
Key public welfare forests	167668	167299	165810	1489				80	289		
General public welfare forests	299	299	299								
Commercial forests	31028	30814			30814			45	169		589

Data source: Forestry Bureau of Fuan City.

According to the data in the "Statistical Yearbook of Fuan City 2020," the average price of timber in villages and areas below villages in Fuan City in 2020 was 1,271.44 yuan/m^3. The recovery ratio of timber used is 46%, based on the average recovery ratio of subtropical hardwood forests nationwide (Wang et al., 2007). The total forest stock is 198,995 m^3 (Table 6). The Forest Law of the People's Republic of China imposes significant restrictions on harvesting within key and normal public welfare forests, effectively prohibiting felling. Therefore, the valuation of timber products is based solely on the stock of commercial forests. It can be derived that the total value of timber stock in Muyun for the year can be calculated as 18,147,110.55 yuan. Although the Forest Law and related regulations stipulate procedures for harvesting, regeneration, and sustainable management of collective commercial forests, including rigorous approval processes such as application, on-site inspection, and expert assessment. These procedures, coupled with market factors, often deter farmers from harvesting. Consequently, the contribution of timber and other forest products to the local economy of Muyun Township is limited. Hence, his study does not incorporate a valuation of timber products.

Forest by-products. The value of forest by-products, a component of forest ecosystem services, encompasses the economic benefits derived from products and services provided by forests other than timber. These are commonly known as non-timber forest products (NTFPs) and are significant for both human society and the natural environment. They are particularly important for rural communities that rely on forest resources as a key source of livelihood, contributing to increased incomes and improved living standards. In this study, forest by-products primarily include food products (such as tea, citrus fruits, loquats, bayberries, peaches, grapes, persimmons, and kiwifruit) and ornamental resources (such as peach blossoms, grape vines, and forest landscapes). Given that the economic value of ornamental resources is largely captured through tourism and recreation, this section focuses solely on estimating the economic value of food products using the market price method. This method directly assesses the economic value of market-traded forest by-products by utilizing their market prices(Wang et al., 2007; Yu et al., 2005; Zhao et al., 2004; Wei and Qi, 2016). Based on data from the "Statistical Yearbook of Fuan City 2020," the annual output value of forest by-products, obtained by multiplying the output of each type of forest by its respective price, reaches 126,705,052.55 yuan (Table 7).

Table 7 2020 Statistical report on the output value of forest by-products in Muyun.

Item	Output (tons)	Price (yuan)	Value (tons/yuan)
Tea	481	45,989.56	22,120,978.36
Citrus fruits	252	7470.17	1,882,482.84
Loquat	657	13,913.89	9,141,425.73
Bayberry	1136	10,535.59	11,968,430.24
Peach	6303	7210.16	45,445,638.48
Grape	3981	8918.9	35,506,140.9
Kiwifruit	50	12,799.12	639,956
Total			126,705,052.55

Data source: Forestry Bureau of Fuan City.

Regulatory services

Carbon sequestration and oxygen release. In this study, carbon sequestration primarily refers to the process by which forest vegetation, absorbs atmospheric carbon dioxide and stores it in vegetation or soil through photosynthesis, thereby reducing its concentration in the atmosphere. Forests serve as the largest terrestrial carbon reservoir, playing a crucial role in reducing greenhouse gas concentrations and mitigating global climate change. Due to the lack of soil carbon sequestration data in the Muyun region, the estimated carbon sequestration value here primarily pertains to the carbon sequestration value exerted by vegetation.

This study utilizes the estimation method. The carbon sequestration of forest resources outlined in the Guidelines for Natural Capital Accounting and Valuation of Ecosystem Services Pilot Projects (Draft) released by the Statistical Bureau of Guangxi Zhuang Autonomous Region in 2019. Since August 2016, the Statistical Bureau of Guangxi Zhuang Autonomous Region has widely referred to domestic and foreign literature and taken the lead in formulating the Guidelines for the Valuation of Ecological Services in Guangxi, which was used to guide the valuation of ecological services in Guangxi. In November 2017, Guangxi was designated as one of the pilot areas in China for the United Nations' Natural Capital Accounting and Valuation of Ecosystem Services Project at the Start-up and Consultation Meeting of the China Natural Capital Accounting and Valuation of Ecosystem Services Project, which was jointly organized by the National Bureau of Statistics, the United Nations and the European Union in Beijing. In 2018, a project valuation delegation from the United Nations Statistics Division visited Guangxi and gave some instructions on the technical problems encountered in the pilot work in Guangxi. Based on the consensus reached at the start-up and consultation meeting, and the with specific requirements of the expert team set up by the National Bureau of Statistics and the United Nations for the Natural Capital Accounting and Valuation of Ecosystem Services Pilot Project, the Statistical Bureau of Guangxi Zhuang Autonomous Region organized relevant professionals to revise the original Guidelines for the Valuation of Ecological Services in Guangxi, thereby forming the Guidelines for the Pilot of Natural Capital Accounting and Valuation of Ecosystem Services Project. Given its authoritative and instructive nature, this guide is anticipated to have a significant positive impact on the assessment of forest ecosystem services in other regions.

The formula used in this study to estimate the carbon sequestration of forest resources in Muyun is as follows:

$$Q = \sum_{i=1}^{n} S_i \times (NPP_i \times 1.63 \times 0.273) \quad (2)$$

Where Q represents the total carbon sequestration of forests, n represents the number of forest types. NPP_i represents the net primary productivity of type i forest per unit area, NPP of forest ecosystems demonstrates considerable heterogeneity across different forest typologies. S_i represents the area of type i forest, 1.63 is the carbon sequestration coefficient, and 0.273 is the carbon content of carbon dioxide (Statistical Bureau of Guangxi Zhuang Autonomous Region, 2019).

The value of carbon sequestration is calculated as:

$$V = Q \times P \quad (3)$$

Where V represents the value of carbon sequestration, Q represents the total carbon sequestration by forest, and P is valuated using the Chinese afforestation cost method at 273.3 yuan/ton of carbon sequestration (Hou et al., 1995).

Given that the net primary productivity of subtropical evergreen broad-leaved forests in China is 17.27 tons/hectare·year (Zhao et al., 2004), the carbon sequestration value of forest resources in Muyun is calculated to be 21,452,757.01 yuan. Additionally, the oxygen release value of forests in this area is valuated using the same calculation method and parameters as for carbon sequestration, utilizing the Chinese afforestation cost method of 369.7 yuan/ton of oxygen (Zhao et al., 2004; Hou et al., 1995). Consequently, the oxygen release value of forest resources in Muyun is estimated at 29,019,700.94 yuan. Finally, the combined annual value of carbon sequestration and oxygen release of forest resources in Muyun is 50,472,457.95 yuan.

Air purification. Forest ecosystems provide air purification through various mechanisms, including the absorption of pollutants, dust retention, bacteria elimination, and noise reduction (Li, 1999). Forests' capability to purify the atmosphere is generally considered a latent function that has been effectively utilized to combat widespread issues, like acid rain and dust pollution in China. Sulfur dioxide (SO_2) and particulate matter (PM) represent significant air pollutants that pose substantial risks to both human health and ecological integrity. Reducing emissions of these pollutants is essential for safeguarding public health and environmental quality. Based on the current research status and availability of basic data on the mechanism of purification function, combined with the significance of the purification function in the valuation process, this study selected two forest functions, SO_2 absorption and dust retention, attempting to reflect the importance of air purification to a certain extent (Zhao et al., 2004).

SO_2 absorption: According to measurements, broad-leaved forests can absorb 88.65 kg/hectare·year of SO_2, resulting in a potential capacity of Muyun forests to purify 905.56 tons of SO_2 (Zhao et al., 1999). Meanwhile, the investment and treatment cost of SO_2 is 600 yuan/ton, leading to an annual value of SO_2 purification in Muyun forests of 543,335.57 yuan (Editorial Committee of State Report on Biodiversity of China Committee, 1997).

Dust retention: Research indicates that 1 hectare of pine forest can adsorb 36.0 tons of dust annually, while fir forests can absorb 30.0 tons, and oak forests can absorb 67.5 tons (Zhao et al., 2004). In well-greened urban areas, the dust reduction is only 1/9 to 1/8 of that in urban areas lacking trees (Editorial Committee of State Report on Biodiversity of China Committee, 1997). Generally, the annual dust retention capacity of coniferous forests is 33.20 tons/hectare, and that of broad-leaved forests is 10.11 tons/hectare (Zhao et al., 2004). Therefore, the potential dust retention capacity in Muyun forests is estimated to be 103,273.60 tons, and an annual value of the ecosystem's dust retention function in Muyun forests is calculated at 17,556,511.56 yuan (excluding dust removal costs at 170 yuan/ton·year) (Editorial Committee of State Report on Biodiversity of China Committee, 1997).

Based on the calculation results above, the total value of the annual absorption of SO2 and dust retention of forest resources for Muyun is approximately 18,099,847.14 yuan/year.

Water conservation. According to research methods and findings both domestically and internationally, the total water conservation of forests can be calculated using methods such as the water balance method in forested areas or by assessing the water retention capacity of soils and runoff. Among these methods, the water balance method better reflects the actual situation (Hou et al., 1995). In this study, the water balance method was employed to calculate the annual water conservation of the forest ecosystem in Muyun, and the economic value was estimated as follows:

$$V = Q \times P = (R - E) \times S \times P \tag{4}$$

Where V represents the economic value of the annual water conservation in Muyun forests (yuan/year), Q represents the water conservation volume (m^3/year), R represents the average precipitation in the region (mm/year), S represents the forest area in the region (hectare), and E represents the average evaporation of forests in the region (mm/year). P represents the unit cost of water conservation (0.67 yuan/m^3) (Yu et al., 2005). Since there are no observation stations in Muyun (27°03'46"N, 119°32'19"E) to measure the precipitation and evaporation, data from observation stations with similar geographical locations and environments were used—specifically, data from Fankeng Township, Fuan City (27°19'12"N, 119°41'24"E) (Liu et al., 2021). Muyun Township and Fankeng Township, both situated in Fuan City, share similar natural environments characterized by predominantly mountainous and hilly terrain and subtropical evergreen broad-leaved forest vegetation. The two townships are located 57 kilometers apart. The annual precipitation in this area is 2050.17 mm, and the annual evaporation is 348.51 mm. Finally, $Q = 17{,}382{,}448.05$ m^3/year, and the annual water conservation economic value in Muyun forests is 11,646,240.19 yuan/year. The Fuan government has consistently prioritized the Muyun Township tap water project, allocating annual funding ranging from 100,000 to 150,000 yuan for infrastructure improvements. In July 2023, the Fuan Development and Reform Bureau implemented a tariff adjustment, increasing residential water prices from 1.55 to 1.86 yuan per tonne. This price adjustment reflects the recognized importance of forest ecosystems in maintaining water resources.

Soil conservation. Forest ecosystems play a significant role in soil conservation. The canopy intercepts precipitation and reduces the direct impact and erosion of raindrops on the soil surface. The root system helps stabilize the soil, prevent particle loss, and improve soil structure (Borrelli et al., 2017; Zhang et al., 2015). According to the Guidelines for Natural Capital Accounting and Valuation of Ecosystem Services Pilot Projects (Draft) released by the Statistical Bureau of Guangxi Zhuang Autonomous Region in 2019, the formula used to estimate the total soil conservation of Muyun forest resources is as follows:

$$Q = \sum_{i=1}^{n} S_i (X_{1i} - X_{2i}) \tag{5}$$

Where Q represents the total soil conservation of forests, n represents the number of forest types, S_i represents the area of type i forest (in hectares), X_{1i} represents the potential soil erosion of type i forest, and X_{2i} represents the actual soil erosion of type i forest, in tons/hectare·year (Statistical Bureau of Guangxi Zhuang Autonomous Region, 2019). The data in this study used information from the Heshan observation station, which has a similar geographical environment to Muyun (Both regions are located in subtropical zones, and their forest soils are predominantly red soils). A comparison of environmental data between Heshan and Muyun forests is shown in Table 8 (Dong et al., 2020). Heshan, a representative forest ecosystem observation site within the China Ecosystem Research Network (CERN), exemplifies the red soil type commonly found across the network's stations. CERN stations encompass a diverse array of forest ecosystems, including deciduous coniferous, evergreen coniferous, deciduous broadleaf, evergreen broadleaf, and man-made pure forests. This comprehensive representation facilitates research on soil characteristics and conservation strategies across different forest ecosystem types (Dong et al., 2020). Ultimately, $Q = 5{,}683{,}112.36$ tons/year. According to the current pricing department's approved standards for mechanical construction fees in China, the cost of clearing sediment in river channels is 3 yuan/m^3. Since each cubic meter of sediment in river channels is equivalent to 2 tons, clearing each ton of sediment costs 1.5 yuan (Zhao et al., 2004).

Table 8 Comparison of forest environment between Heshan and Muyun Township.

Name	Ecosystem type	Location	Soil type	Slope/(°)	Precipitation/(mm/a)	Forest age/a
Heshan	Subtropical evergreen broad-leaved forest	22.68°N 112.90°E	Red soil	18–23	1505.78	30
Muyun	Subtropical evergreen broad-leaved forest	27°N 119°E	Red soil	24	2050.17	22

Therefore, the economic value of annual soil conservation in Muyun forests is 8,524,668.54 yuan/year.

Forest protection. Coastal forests provide essential ecosystem services that function as a vital natural buffer, protecting agricultural lands and contributing to the overall health of the coastal environment. These services are particularly evident during typhoons, when forests effectively reduce wind velocity and pressure, minimizing damage to build infrastructure and agricultural production. Additionally, their capacity to intercept rainfall and decelerate surface runoff mitigates the risk of flooding. According to the estimation method for the windbreak function of forest resources outlined in the Guidelines for Natural Capital Accounting and Valuation of Ecosystem Services Pilot Projects (Draft) released by the Statistical Bureau of Guangxi Zhuang Autonomous Region in 2019, the formula used in this study to estimate the windbreak function of forest resources in Muyun is as follows:

$$V_{protection} = V_{forest} \times S_{forest} \times 10^{-4} \quad (6)$$

Where $V_{protection}$ refers to the value of windbreak protection of forest, in 10,000Yuan/year, V_{forest} refers to the value of windbreak protection per unit of protection forest, in Yuan/hectare year, S_{forest} refers to the area of protection forest, in hectare, 10^{-4} is a unit conversion coefficient.

The area data of the protection forest is the total forest area, and regarding the value of windbreak protection per unit of protection forest, we use the cost of shelterbelt construction for the calculation, which is 5471Yuan/hectare year (Forestry Bureau of Fuan City, 2017). Finally, the total value of forest protection in Muyun for the year can be calculated as 55,886,236.55 yuan.

Biodiversity conservation. Forest ecosystems, among the most complex on Earth, are essential for the conservation of global biodiversity. These ecosystems provide critical habitat for a diverse range of flora and fauna and represent a fundamental component of the biosphere. Notably, tropical rainforests are estimated to contain up to half of the world's species, while the remaining biodiversity is distributed across a variety of other terrestrial and aquatic ecosystems (Zhao et al., 2000). Assessing the value of biodiversity conservation remains a global challenge. Current methods include baseline pricing for species conservation, contingent valuation surveys, benefit capitalization techniques, cost-benefit analyses, direct market valuation, and opportunity cost assessments (Yu et al., 2005). This study employs the contingent valuation method to valuate the value of maintaining biodiversity in the Muyun forest ecosystem.

According to the "Report on the State of Biodiversity in China," the annual per capita payment made by Chinese citizens for biodiversity conservation can be estimated by examining China's population size. Then, based on the proportion of forest ecosystem species among China's first-level protected animals recorded in the "China Red Data Book of Endangered Animals," the Willingness to Pay (WTP) value for maintaining biodiversity in forest ecosystems can be estimated (Wang, 1998). Willingness to Pay (WTP) represents the maximum price a consumer is willing to pay for a good or service. In this context, it reflects the maximum amount consumers are willing to pay to maintain the biodiversity provided by forest ecosystem services.

According to the survey results in the "Report on the State of Biodiversity in China," the average annual donation per capita is 10 yuan (Editorial Committee of State Report on Biodiversity of China Committee, 1997). With a resident population of 609,779 in Fuan City in 2020, the estimated WTP for biodiversity conservation in Muyun is 6,097,790.00 yuan. Among the 164 species of first-level protected animals recorded in the "China Red Data Book of Endangered Animals," species from the forest ecosystem account for 68.3%. Based on this proportion, the estimated WTP for maintaining biodiversity in the forest ecosystem of Muyun is 4,164,790.57 yuan per year (Editorial Committee of State Report on Biodiversity of China Committee, 1997; Wang, 1998).

Cultural services. Muyun Township boasts breathtaking and unique natural landscapes. The township exhibits a forest cover of 76.5%, with tourism development reliant on the provision of forest ecosystem services and emphasizing eco-tourism. Among these attractions, the Xita Grape Valley Scenic Area, designated as a national AA-level scenic spot and a model site for agricultural tourism in Fujian Province, seamlessly blends agricultural sightseeing with the cultural richness of the She ethnic group. The Baiyun Mountain National Scenic Area is also nestled within; which, in 2010, was successfully recognized as the "Ningde World Geopark," marking the onset of a golden era in tourism development for the She nationality region. Simultaneously, Muyun, leveraging the scenic allure of Baiyun Mountain, has catalyzed neighboring villages such as Nanshan and Yulin into becoming burgeoning tourist destinations. Delighting in peach blossoms, savoring grape wine, and exploring the Grape Valley have become focal points for leisurely sightseeing. Furthermore, the villages of Hutou and Xita, through hosting events like the She Ethnic Peach Blossom Festival and Grape Picking Festival, annually draw over 800,000 visitors. In 2021, following a principle of comprehensive planning and village-by-village advancement, the Muyun Township government finalized the revision of the "Master Plan for the Tourism of Muyun She Nationality Township," laying a robust foundation for holistic tourism development. The infrastructural enhancements supporting tourism in the ecotourism area of Muyun She Nationality Township, a 3A-rated scenic spot, continue to progress, gradually shaping a "one to three-day boutique tour" route centered around Hutou, Xita, and Xiafeng Village, thereby steering tourism in Muyun Township towards a holistic approach. The region's forest resources nurture nearly all tourism attractions and initiatives in Muyun.

The network-style tourist routes in Muyun She Nationality Township offer visitors many options, with rural tourism directly contributing to economic prosperity. We employed the Travel Cost Method (TCM) to assess the recreational value of forest tourism. This method estimates the value that tourists place on forest-based recreational services by analyzing their travel expenditures, including transportation, accommodation, and entrance fees (Zhao et al., 2004; Liu et al., 2013). This study

Table 9 Tourism routes and cost.

Route	Content	Price (Yuan/per)
Baiyun Mountain-Hutou-Xita	The area encompasses several notable attractions, including the National 4A Scenic Area, Peach Blossom Forest, and Grape Gully. Xita is situated within the ecotourism area of Muyun She Nationality Township. These sites offer opportunities to experience local forest production through the consumption of regional produce such as peaches and grapes.	Expenses include transportation, meals, guide services, insurance, and entrance fees, at a cost of 159 yuan per person.
Xiafeng-Hutou-Xita	The area encompasses several notable attractions, including the beautiful Leisure Villages in Fujian Province, Peach Blossom Forest, and Grape Gully. Xita is situated within the ecotourism area of Muyun She Nationality Township. These sites offer opportunities to experience local forest production through the consumption of regional produce such as peaches and grapes.	Expenses include transportation, meals, guide services, insurance, and entrance fees, at a cost of 153 yuan per person.

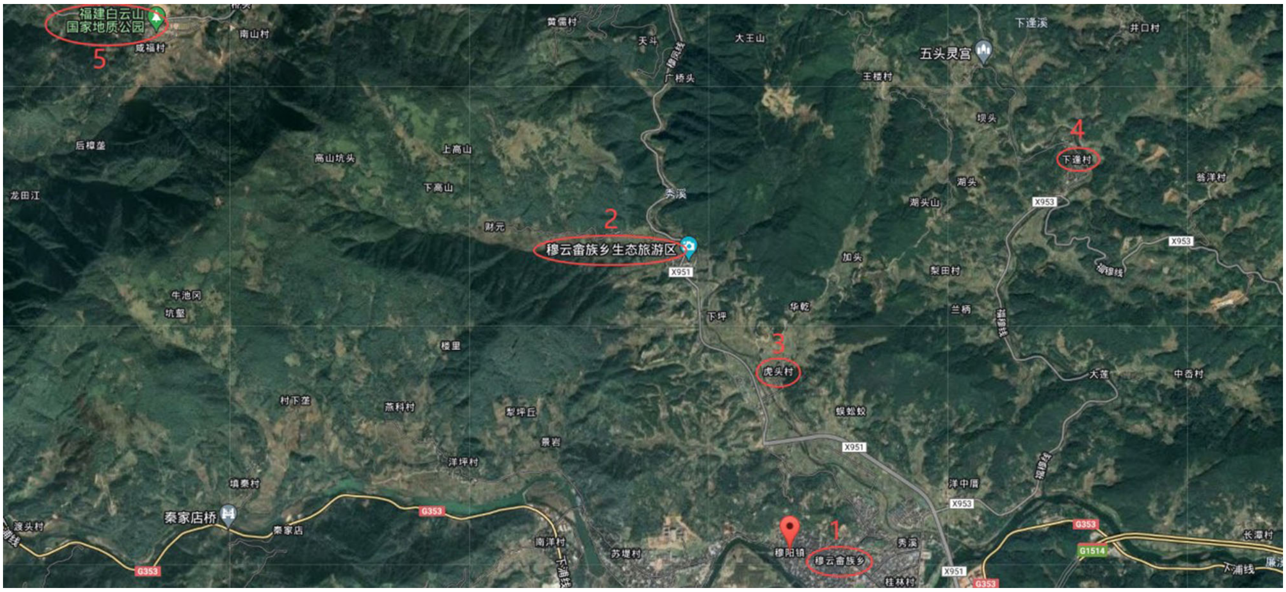

Fig. 5 Satellite map of Muyun Township. Annotation: 1 People's Government of Muyun Township. 2 Ecotourism area of Muyun She Nationality Township (Xita Village). 3 Hutou Village. 4 Xiafeng Village. 5 Baiyun Mountain National Scenic Area.

estimates the tourism value of Muyun Township's forest ecosystems based on two selected tourism routes and cost data (entrance fees, transportation, and catering) obtained from local tour operators (Table 9). Figure 5 presents a satellite map of Muyun Township, identifying five key locations to delineate the tourism routes. A conservative estimate of 153 yuan per person was adopted for individual tourism expenditure. Applying this figure to the average annual tourist influx of 800,000 visitors yields an estimated annual tourism revenue of 122,400,000.00 yuan that is attributable to forest resources.

Further discussion. While forest ecosystems provide essential services to humans, natural disturbances such as typhoons and forest fires can diminish these benefits. Therefore, an assessment of the impact of such events on forest ecosystem service provision is warranted. Fujian Province, situated on the southeastern coast of China, is susceptible to typhoon activity. According to the Fujian Provincial Meteorological Station, six typhoons made landfall or impacted the province in 2020, slightly below the average of 6.9. With the exception of Typhoon Mikaela, which made landfall near Zhangpu and caused wind and rain damage in southern Fujian, the remaining typhoons primarily resulted in gale-force winds with limited overall impact (Fujian Branch of China Weather Network, 2021). Consequently, typhoon-related damage in Fujian during 2020 was relatively minor. Furthermore, proactive fire management by the Forestry Bureau of Fuan City, involving an annual investment of 800,000 yuan in preventive measures, has effectively reduced forest fire incidence by 95% (Forestry Bureau of Fuan City, 2021). Thus, the impact of typhoons and forest fires on forest ecosystem service reduction in Muyun Township during 2020 is considered negligible.

Conclusions and recommendations

Based on the valuation results above, the total economic value of forest ecosystem services in Muyun of Fuan City is determined to be 397,899,293.49 yuan (Table 10). Timber products, forest by-products, and tourism can be considered as the direct value of forest ecosystems. Meanwhile, the regulating and supporting functions, such as carbon sequestration and oxygen release, constitute their indirect value. Thus, the direct and indirect values of forest ecosystem services in Muyun are 249,105,052.55 yuan and 148,794,240.94 yuan, respectively. The direct value is 1.67 times higher than the indirect value. These findings indicate that forest ecosystem services in Muyun also have indirect use value besides providing direct product value to society. The value of forest by-products ranks first, accounting for 32%. The value of tourism ranks second, accounting for 31%. The indirect value generated by rural forest resources is 37%. This underscores the

Table 10 The annual value of forest ecosystem services in Muyun (in yuan).

Function	Resource allocation service		Regulatory services						Cultural services
	Timber products	Forest by-products	Carbon sequestration and oxygen release	Air purification	Water conservation	Forest protection	Soil conservation	Biodiversity protection	Tourism
Valuation results		126,705,052.55	50,472,457.95	18,099,847.14	11,646,240.19	55,886,236.55	8,524,668.54	4,164,790.57	122,400,000.00
Classified total	126,705,052.55		148,794,240.94						122,400,000.00
Total	397,899,293.49								

significant contribution of agricultural products and tourism resources generated by rural forest resources to the local area (Fig. 6). This also underscores the important role of rural forest resources in providing agricultural by-products, promoting rural tourism, improving the rural economy, and realizing rural revitalization. It should be noted that this is only a partial estimate, and as people's understanding of forest ecological functions deepens, their ecological and economic value will become more apparent.

We found that tourism and forest by-products contribute the two highest value. Forest protection contributes the third value, compared with other forest ecosystem services. Other valuations of forest ecosystem services are relatively smaller, but the effect cannot be ignored. The conclusions presented here diverge significantly from those of other forest ecosystem service assessments. These previous studies, whether valuating forest ecosystem services in China as a whole (Yu et al., 2005; Zhao et al., 2004), within a specific province or region (e.g., Tibet) (Wang et al., 2007), or even within an ecological reserve (Wei and Qi, 2016; Liu et al., 2013), consistently concluded that the value of regulating services predominated. We attribute this discrepancy to the distinct characteristics of rural areas, which typically exhibit relatively less developed economies, simpler industrial structures, and a greater reliance on forest resources. Forest by-products (e.g., wild fruits, medicinal herbs, mushrooms) constitute a significant source of income and sustenance for local residents. Furthermore, the scenic natural landscapes and healthy ecological environments of rural forests offer substantial potential for eco-tourism development, which can directly stimulate local economies. Consequently, the value of forest by-products and tourism plays a prominent role in the overall ecosystem service value of rural forests. However, at the national or provincial level, economic structures are more diversified, and the direct economic outputs of forests (e.g., timber and forest by-products) represent a smaller proportion of the overall economy. In these broader contexts, the environmental benefits of forests—including water conservation, carbon sequestration and oxygen release, soil and water conservation, and air purification—become paramount for regional and national ecological security and sustainable development. Therefore, the value of regulating services assumes greater importance in forest ecosystem service valuations at the national or provincial scale.

Following the completion of the forest ecosystem service assessment in Muyun, a key question remains: Can the assessment results translate into satisfactory loans and government compensation? First, Forest Right Mortgages, secured by forest rights, are a primary source of funding for rural forest owners. However, limitations exist. Rural credit unions and agribusiness banks in Fujian Province restrict loans to a maximum of 50% of the collateralized forest rights' assessed value (Fujian Banking Association, 2013). Additionally, some regions stipulate that only commercial forests qualify for mortgages (Enshi Prefecture Local Financial Work Bureau, 2023). According to government forest eco-efficiency compensation, current compensation appears limited. In 2020, Fuan city government provided 757,082 yuan in compensation to Muyun Township, which is significantly lower than the estimated value (Finance Bureau of Fuan city, 2020). This limited compensation is due to the current standard, which bases payment on forest land area multiplied by a fixed rate; therefore, it fails to reflect the value of different ecological benefits. In conclusion, the potential for both forest right mortgages and government compensation seems constrained.

Based on the findings of this study, the following recommendations are proposed for investing in rural forest resources:

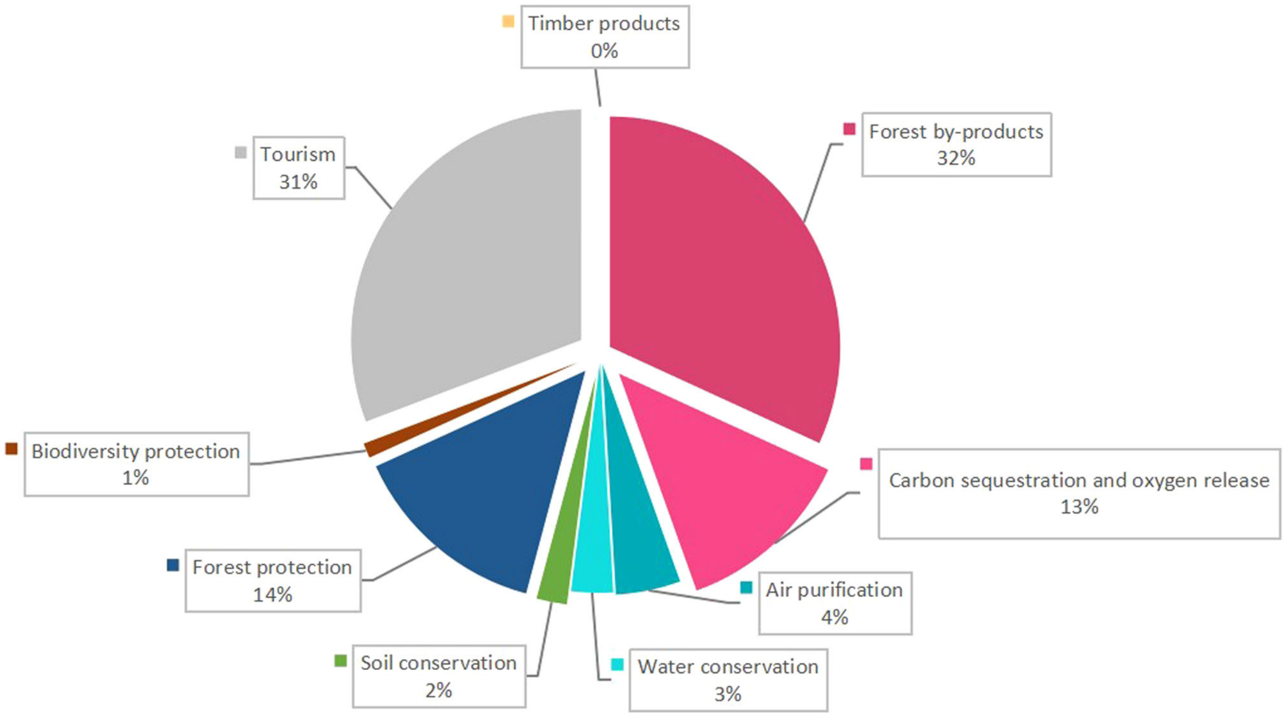

Fig. 6 The annual value of forest ecosystem services in Muyun (%).

First, private sector funding for rural forests should be encouraged and monitored. For instance, in Muyun of Fuan City, the direct benefits from forest resources, such as tourism and agricultural by-products, are substantial. Therefore, incentivizing private sector investment is advisable. Although determining the exact amount of private sector investment may be challenging, it holds significant potential for supporting investments in forests and can yield direct benefits. For example, the "Ten Thousand Enterprises Revitalize Ten Thousand Villages" initiative, implemented since 2021 in Chongqing, China, guides urban capital and talent to rural areas, develops rural tourism, and carries out deep processing of agricultural products through a series of activities, such as the "Famous Private Enterprise County Tour" and "Chamber of Commerce County Tour" (Upstream News, 2024). This type of activity can also be applied to rural forests.

Second, government and financial institutions could issue an appropriate amount of green bonds. Green bonds are financial instruments issued in the market to finance projects with environmental benefits. These bonds not only serve the purpose of raising funds but also contribute to sustaining the ecological value of forest resources. For instance, some projects supported by funds raised from Industrial Bank's green finance bonds comply with the scope of the "Catalog of Green Bond Support Projects (2021 Edition)", covering all six major areas, including energy conservation and environmental protection industry, clean production industry, clean energy industry, ecological environment industry, infrastructure green upgrading, and green services (Industrial Bank, 2024). The development of forest resources in Muyun can be involved in the major areas and apply for the green bond.

Third, public and private institutions in expanding financing channels for investment projects should be supported. In many developing countries, the question of where financing funds for forest resources go often hampers progress in forest-based projects. Despite substantial capital investment, there's a need for a corresponding number of investment opportunities. To attract significant funds for forest restoration and sustainable utilization, scalable and reliable channels must be established to support high-quality projects based on forest resources, such as forest tourism projects in Muyun. One approach to opening such channels is to establish investment institutions that assist rural collective organizations along the value chain of forests in integrating production, adding value, and developing high-quality projects. For example, Jiangxi Province has established the country's first provincial-level forestry financial service platform, which mainly includes functions such as forest rights loan collaborative services, loan interest subsidy processing, insurance and claims collaborative services, and financing demand docking, relying on the Southern Forestry Property Rights Exchange. This platform can realize the online and offline collaborative service mechanism between forestry departments and financial institutions (China Green Times, 2024b).

Fourth, forest projects and plans can join the carbon trading market. A crucial step for various forest resource projects and plans to enter the carbon trading market is compliance with carbon trading standards and registration at trading registries. Whether large forestry companies, small and medium-sized ones, or small farmers, they all face challenges when entering the carbon trading market. Rural collectives, on the other hand, require professional assistance to enter this market. Project developers capable of aggregating hundreds of small-scale producers into sizable project areas may provide such assistance. For instance, as a national pilot city for forestry carbon sequestration, Bijie government in Guizhou vigorously develops forestry carbon sequestration and promotes the realization of ecological product value. As of November 2024, the city has issued 6 forestry carbon tickets and completed 7 carbon sink transactions. To promote carbon ticket financing, a work plan is being developed to support the reform of forestry carbon tickets by banking and insurance institutions in Bijie, endowing these tickets with functions such as circulation, storage, credit, pledge, and insurance (China Green Times, 2024a).

Fifth, tourism projects that are suitable for rural forest resources and do not harm them could be developed, such as costume photography related to the She nationality minority. For example, during the Chinese New Year and other important Chinese Festivals, villages in Muyun could invite the Fujian Opera Troupe to perform plays for the villagers. These performances, held in rotation, would enhance the festive atmosphere, liven up the event, and convey good luck. These activities would not cause harm to rural forest resources and would generate tourism revenue. Tourism revenue could support and protect rural forest resources.

Valuating the economic value of the rural forest ecosystem services offers a fresh perspective, allowing for a deeper understanding of the uses of rural forest resources and their relationship with humans on a new level. This further solidifies the economic and ecological status of forests, thereby achieving classified management and policies to ensure the full realization of the ecosystem services of rural forest ecosystems. Following the principles of sustainable development, local forest communities should strategically apply investment and fully leverage the ecosystem services of rural forest ecosystems to ensure local ecological security and sustainable economic development, thereby achieving the goal of rural revitalization.

This study also has some limitations. Most of the parameters cited in this study come from previous research results and may not accurately reflect the true status of the local ecosystem functions in Muyun. Moreover, due to limitations in data and research methods, this study provides only rough and conservative estimates of the various service functions and values of forest ecosystems in Muyun. However, even such a conservative estimate helps people understand the value of rural forest ecosystems, providing important guidance for the scientific and effective implementation of sustainable development strategies and contributing to "the new era of rural revitalization." It should be emphasized that as people's understanding of forest ecosystems deepens, their ecological and economic values will become clearer. As science and technology advance and societal awareness of ecological environmental protection grows, the valuation of forest ecosystem services will become increasingly integrated, precise, and dynamic. In the future, we can expect to use more innovative assessment methods applying technologies such as big data, artificial intelligence, and remote sensing. Furthermore, the assessment system will likely place greater emphasis on public participation and the integration of diverse values. These advancements will provide more scientifically sound decision that support ecological protection, resource management, and sustainable development. Importantly, upcoming policies shall try to protect existing forests, establish new forests, and recover forest loss, fostering afforestation and reforestation programs (Gatto and Sadik-Zada, 2024).

Data availability

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

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Lu Xu: Conceptualization, Data curation, Writing - Original draft preparation, Writing - Reviewing and Editing. Xijing Liu: Literature review, Software, Investigation, Writing - Reviewing and Editing. Andrea Gatto: Methodology, Visualization, Supervision, Writing - Reviewing and Editing. László Vasa: Validation, Writing - Reviewing and Editing. Xin Zhao: Funding Acquisition, Supervision, Investigation, Visualization, Writing - Reviewing and Editing.

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