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ORIGINAL RESEARCH ARTICLE

Research progress of forest ecological quality assessment methods

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ABSTRACT

Forests have ecological functions in water conservation, climate regulation, environmental purification, soil and water conservation, biodiversity protection and so on. Carrying out forest ecological quality assessment is of great significance to understand the global carbon cycle, energy cycle and climate change. Based on the introduction of the concept and research methods of forest ecological quality, this paper analyzes and summarizes the evaluation of forest ecological quality from three comprehensive indicators: forest biomass, forest productivity and forest structure. This paper focuses on the construction of evaluation index system, the acquisition of evaluation data and the estimation of key ecological parameters, discusses the main problems existing in the current forest ecological quality evaluation, and looks forward to its development prospects, including the unified standardization of evaluation indexes, high-quality data, the impact of forest living environment, the acquisition of forest level from multi-source remote sensing data, the application of vertical structural parameters and the interaction between forest ecological quality and ecological function.

Keywords: Forest Ecological Quality; Biomass; Productivity; Forest Structure; Remote Sensing Technique

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1. Introduction

Forest ecosystem is a key factor affecting the quality of the ecological environment, and plays a vital role in maintaining the global carbon balance and mitigating the greenhouse effect[1]. The strategy of reducing greenhouse gas emissions caused by deforestation and forest degradation to increase carbon stocks (REDD+) emphasizes the role of forests as carbon sinks, and the Kyoto agreement has also listed forests as an important measure to solve the problems of energy conservation, emission reduction and climate change[2]. In recent years, a large number of natural forests have been replaced by artificial forests, and the tree species and age structure of forests are generally single and young, resulting in the reduction of species diversity and the weakening of ecological functions. However, the protection measures carried out by various countries have failed to effectively curb the loss of forests, and the ecological quality of forests has been significantly degraded[3-5]. In this context, the problem of forest ecological quality has attracted much attention, and its evaluation has become a research hotspot of scholars at home and abroad.

The monitoring and evaluation of forest ecological quality is of great significance to quantitatively grasp the carbon source/sink characteristics, temporal and spatial distribution and dynamic changes of forest ecosystem, and also provide a basis for the evaluation of forest natural resources assets and the formulation of forestry management measures. It is an important way to understand the forest ecological quality, which will promote the improvement of forest ecological quality. Due to the differences in forest biophysical characteristics and environmental conditions on the space-time scale, domestic and foreign scholars evaluate the forest ecological quality in different research areas, different emphases and different scales, and their data acquisition methods, evaluation index systems and evaluation methods are also different[6-8]. Based on the existing research at home and abroad, this paper puts forward the key ecological parameters that characterize the forest ecological quality, systematically combs the evaluation methods of each ecological parameter, and makes prospects for the evaluation indicators, high-quality data, forest environmental impact factors, remote sensing means, etc., in order to provide reference for the in-depth study of forest ecological quality evaluation.

2. Connotation of forest ecological quality

Forest is a biological community mainly composed of woody plants, which has the characteristics of rich species, complex structure, strong stability and perfect functions. It can improve and maintain the ecological environment and provide necessary biological resources for human beings[9]. The forest ecosystem, which is composed of forests, other organisms and the environment, has ecological functions and ecological services to regulate and maintain ecological security. Among them, forest ecological services are the natural environmental conditions formed and maintained by the forest ecosystem and its ecological process, and the utility provided directly or indirectly for human beings[10,11]. Forest ecological function and ecological service capacity are important factors affecting its quality level.

In 1992, Stolton first proposed the term "forest quality", and then, together with Dudley *et al.*, defined its concept in the World Wide Fund for Nature (WWF) report as "the sum of all functions and values of forests in terms of ecological, social and economic benefits"[3]. Forest ecological quality reflects the connotation of forest quality from an ecological perspective, a comprehensive measure of forest ecological functions and ecological services, growth conditions and self-reg- ulation functions, and reflects the ability of forests to improve the ecological environment and maintain ecological balance[4,9]. Due to the abstraction of the concept, the connotation of forest ecological quality will be different for different research objectives, and a unified understanding has not been reached at present. Based on the existing research, this paper defines the forest ecological quality as that the forest has a variety of ecological functions such as water conservation, climate regulation, air purification, carbon fixation and oxygen release, nutrient accumulation, biodiversity maintenance, etc., provides human beings with natural living conditions, biological resources, intangible value and other ecological services, and reflects the stability, elasticity and resilience under the stress of biological and abiotic factors.

3. Overview of forest ecological quality assessment research

3.1 Evaluation index system

Scholars usually choose easily accessible indicators to evaluate the ecological quality of forests

Table 1. Forest ecological quality evaluation indicators

Involved level	Index factor	Application
Forest biomass	Biomass per unit area, net biomass per unit area, stock per unit area, etc	[12–15]
Forest structure	Stand origin, community structure, forest age, canopy structure, density, tree species, canopy density, etc	[9,12–15]
Forest productivity	Volume increment, biomass increment, forest growth per unit area, etc	[8,9,14,15]
Forest health	Healthy forest area ratio, forest vitality, forest disaster (disease, pest, fire, etc.) area ratio, dry loss rate, etc	[9,14,15]
Ecological service function	Water conservation, soil conservation, carbon fixation and oxygen release, biodiversity, etc	[9,12,15]
Site conditions	Altitude, slope direction, gradient, slope position, soil layer thickness, soil organic matter, etc	[8,12]

in terms of biophysical properties, site conditions and growth conditions (**Table 1**). Generally speaking, the main characterization parameters of forest ecological quality include forest structure, forest biomass, forest productivity, forest ecological service efficiency, health status and so on. Due to the diversity and complexity of forest in terms of geographical environment, species and spatial scale, the selection of evaluation indicators will face many problems, such as a large number, high correlation between factors, and difficult data acquisition.

3.2 Sources of evaluation data

The spatial scales involved in forest ecological quality assessment include forest farms, regions, and even the world. The differences of spatial scales affect the way of obtaining observation data. The traditional method to obtain the key parameters representing the forest ecological quality is mainly the sample survey. The data obtained by this method is more accurate, but it requires a lot of time, manpower and material resources, and it is unable to realize the inventory of large areas and duration time scales[14,16]. The development of remote sensing technology makes up for the shortcomings of traditional estimation methods, which can realize the rapid, continuous and nondestructive estimation of forest ecological parameters at local, regional and even global scales, meet the needs of forest investigation and biophysical parameter detection, and provide data sets with different spatial resolutions and time series for ecological quality assessment (**Table 2**). At present, the research on the dynamic change inversion of forest biomass, productivity and carbon storage at the regional level more combines remote sensing images with regional and national forest inventory data to generate the spatial distribution map of forest status[2,17-21], so as to realize the long-term, dynamic and fine spatial observation of forest ecological quality in the study area.

Table 2. Application characteristics of different remote sensing sensors in forest resource observation

Sensor	Characteristic	Application
Optical remote sensing	The spectral information is rich, and the forest level parameters can be obtained; however, it is easily affected by the atmosphere. For dense, multi-layer and complex canopy, there are problems of mixed pixels and easy saturation, and it is not sensitive to forest spatial structure information.	[22,23]
Microwave remote sensing	All weather, all day imaging, less atmospheric interference, can react with forest trunks to obtain forest vertical status parameters; however, due to the influence of terrain and surface roughness, there is also a problem of saturation.	[24,25]
Lidar	It can overcome the problem of easy saturation and obtain the vertical structure of forest; however, its high cost makes it difficult to obtain a wide range of image data, and it has not been widely used at present.	[26,27]
Multi source remote sensing	Multi-source remote sensing can avoid the limitations of a single data source and improve the accuracy of vegetation interpretation and inversion; however, there are problems in data source quality and fusion method selection.	[22,28]

3.3 Research methods of forest ecological quality

3.3.1 Determination of index weight

The evaluation of forest ecological quality can be achieved by building a suitable index system. Various indicators have different contributions to the evaluation results, so they need to be given different weights. The weight determination methods mainly include subjective weighting method and objective weighting method. The former has simple operation, high reliability and practicability, but it largely depends on the personal experience of decision makers, with strong subjectivity, such as analytic hierarchy process[9,14]; the latter is more objective, avoiding the deviation caused by human factors, but there will be the problem of insufficient sample size, and without considering the differences between evaluation indicators, there may be inconsistencies between the determined weight and the importance of indicators. The commonly used methods are mean square deviation comprehensive analysis[12], principal component analysis[13], factor analysis[8,15], entropy weight method[29,30].

3.3.2 Research methods

The selection of research methods is the key link to evaluate the forest ecological quality scientifically and accurately. Generally speaking, the research methods of forest ecological quality mainly include investigation method, remote sensing evaluation method, model method, single evaluation method, comprehensive evaluation method, etc. Regional and national forest surveys are the basis for obtaining forest carbon reserves, health status and ecological service functions. Long-term monitoring can obtain the dynamic changes of forest ecological quality. In addition, with the development and application of ecological models and 3S technology, more new methods are used to simulate and evaluate the change of forest ecological quality. For example, invest model can quantify the service function of forest ecosystem; the application of GIS and remote sensing technology in forest ecological quality assessment has also attracted much attention[14,31].

The indicator species method is a representative method in the single evaluation. By determining the key species, endemic species, endangered species or environmentally sensitive species in the forest ecology, its quantity, productivity, biomass, structure and function and other indicators are obtained, so as to establish a model to describe the health status of the forest ecology and reflect the level of forest ecological quality on the side[32,33]. Comprehensive evaluation method is a method used more in the evaluation of forest ecological quality, that is, using multiple evaluation indicators to evaluate the research object in many aspects. The commonly used methods are shown in **Table 3**. In the actual process, many methods are often integrated to avoid the disadvantages of a single method and solve problems reasonably[29,30].

Table 3. Comparison of index system method for forest ecological quality assessment

Evaluation method	Advantage	Inferiority	Application
Composite index method	The method is simple, the evaluation result is intuitive, the accuracy is high, and the information utilization rate is high.	It may cover up some evaluation factors with great influence, resulting in deviation of evaluation results.	[31]
Fuzzy comprehensive evaluation method	Turn factors with unclear boundaries and difficult to quantify into quantitative indicators; the evaluation effect is better for complex problems with multiple factors, multiple levels and fuzzy concepts.	The membership degree of fuzzy algorithm is subjective, and the model cannot be self-verified.	[33,34]
Cluster analysis	The algorithm is intuitive, easy to implement and occupies less memory.	The selection of classification number and initial class center location is highly subjective; it is not friendly to data with complex shapes.	[14]
Matter element analysis	Using matter-element transformation, structural transformation and other methods to solve incompatible problems, it is suitable for multi-factor evaluation.	The uncertainty of evaluation criteria and the definition of classical domain and node domain need to be further studied.	[9,30]
Set pair analysis	Solving the problem of certainty and uncertainty can deal with incomplete information.	There is still room for improvement in dealing with indicators of different contributions.	[9,35]

Table 4. Application of forest ecological parameter inversion model

Model	Features	Application
Multiple linear regression	The independent variable and dependent variable are required to have a linear relationship. This method is limited for non-linear ecological relationships or a small number of variables that cannot explain the variance of dependent variables.	[37,38]
Stepwise multivariate linearity	The iterative method is used to eliminate the factors with weak correlation and obtain the optimal fitting model, which requires the linear relationship between the prediction variables and dependent variables, and collinear and over fitting problems will occur when there are too many prediction variables.	[39]
KNN	There is no parameter estimation and it is simple, but in the case of large sample size, the workload will be increased and the problem of over fitting will occur.	[40]
ANN	It is suitable for dealing with the influence of multiple factors and the situation with fuzzy information, without making assumptions on the data, and can effectively deal with the nonlinear, non normal and collinear problems between the data; but there will be fitting.	[41–43]
RF	It can deal with complex and nonlinear ecological relationships, and has the advantages of efficient processing of massive data, less human interference, strong anti noise ability, and not easy to produce over fitting; however, it is very sensitive to the relationship between input variables, which will lead to the deviation of the prediction tree, so it is necessary to measure the importance of variables.	[8,44,45]
SVM	It can be used for classification and regression analysis, and can produce higher classification or more accurate estimation in solving small sample, nonlinear and high-dimensional pattern recognition problems.	[8]

3.3.3 Parameter inversion model method

The selection of forest ecological parameter inversion model directly affects the accuracy and reliability of the results[21]. Model methods mainly include two categories: parametric methods and nonparametric Machine Learning Algorithm (MLA). Compared with linear model, MLA has some advantages: it can deal with nonlinear ecological relations; it can fit the inversion model from the limited training data; it can solve classification problems that are difficult to distinguish[36]. MLA includes k-nearest neighbor (KNN), artificial neural network (ANN), random forest (RF), support vector machine (SVM), etc. (**Table 4**).

4. Study on key parameters of forest ecological quality evaluation

Forest biomass and productivity are two widely used indicators of forest research[12,17]. Forest biomass is one of the important parameters for monitoring forest carbon storage, forest fire, land use change, global climate change, etc., which can be used to reveal the process laws of forest ecosystem energy balance and material cycle[2,46,47]. Forest productivity can also describe the ecological function of forests in terms of accumulation of organic matter, which is of great significance to the level of forest ecological quality[8]. In addition, forest structure reflects the characteristics of forest evolution mode and growth state in the process of forest dynamic change, and becomes an important factor in monitoring and managing forest ecosystem, which helps human beings understand the current situation, dynamic changes and development trends of forests[48]. According to the principles of scientificity, comprehensiveness, relative independence, feasibility, representativeness and generalization, we believe that forest biomass, forest productivity and forest structure can comprehensively measure forest characteristics, growth status and ecological functions, which are the three key parameters to evaluate forest ecological quality.

4.1 Remote sensing estimation of forest biomass

Forest biomass consists of aboveground and underground parts. Most studies often use standard root shoot ratio to calculate Belowground Biomass (BGB) from Aboveground Biomass (AGB)[2,49,50]. Relatively speaking, forest AGB assessment is intuitive and feasible, and scholars at home and abroad have studied it more at present.

There are many methods for estimating forest AGB, which can be divided into non remote sensing methods and remote sensing methods. Non remote sensing methods mainly include measurement methods, model estimation methods, stock conversion methods, etc. These methods are suitable for small-scale biomass research; the estimation of large-scale forest biomass needs the help of remote sensing, that is, by establishing a linear or nonlinear model between the image spectral information and the biomass at the sampling point, the forest biomass can be retrieved.

4.1.1 Remote sensing characteristic parameters

Different vegetation and the same kind of vegetation have different shapes and characteristics of reflection spectrum curve in different growth stages, so as to reflect vegetation information, and vegetation biomass is related to different elements of vegetation or a certain characteristic state[22]. For complex vegetation remote sensing, vegetation index has better sensitivity and anti-interference than single band estimation of biomass, and can be used to remove changes caused by canopy geometry, soil background, illumination angle and atmospheric conditions[51]. Widely used vegetation indexes include Ratio Vegetation Index (RVI), Normalized Difference Vegetation Index (NDVI), Difference Vegetation Index (DVI), etc. With the development of relevant research, domestic and foreign scholars have proposed some modified vegetation indexes (Soil-adjusted Vegetation Index (SAVI), Transformed Soil-adjusted Vegetation Index (TSAVI), Modified Soil-adjusted Vegetation Index (MSAVI), etc.) to weak soil background and atmospheric impact, so as to enhance vegetation information (**Table 5**).

Table 5. Characteristics of common vegetation index in biomass estimation

Vegetation index	Advantage	Inferiority	Application
RVI	RVI is a sensitive indicator parameter of green plants and has a good correlation with biomass.	When the vegetation coverage is higher than 50%, RVI has high resolution, but it is affected by atmospheric conditions; when the vegetation coverage is less than 50%, the RVI resolution decreases.	[22,55]
NDVI	It enhances the reflection contrast between vegetation and soil, effectively highlights vegetation, and is more suitable for vegetation monitoring with medium coverage or in the middle stage of development.	It is easy to be saturated in the high vegetation coverage area; under the condition of low vegetation coverage, it is sensitive to soil brightness.	[22,56,57]
DVI	It performs well in the case of low vegetation coverage, and can better identify vegetation and water bodies, which is conducive to the monitoring of vegetation environment.	When the vegetation cover is dense, it is extremely sensitive to the change of soil background.	[22,58]
SAVI, TSAVI, MSAVI	The soil adjustment coefficient is introduced to correct the sensitivity of NDVI to soil background.	Some vegetation signals may be lost, making the vegetation index low.	[59–62]
Enhanced Vegetation Index (EVI)	The blue band is added to enhance the vegetation signal, improve the sensitivity to high biomass areas, and correct the effects of soil background and aerosol scattering.	It is mostly used in areas with dense vegetation.	[22,63]
Greenness Vegetation Index (GVI)	The influence of soil background value on plant spectrum is excluded or weakened.	GVI is susceptible to solar radiation, atmospheric radiation, environmental radiation and other external conditions.	[22,58]
Perpendicular Vegetation Index (PVI)	It is less affected by soil background, and its ability to resist atmospheric effects is also significantly better than other vegetation indexes.	As the leaf area index increases, it will become very sensitive to the soil background.	[52,64]

Texture is one of the important features used to identify objects or regions of interest in the image[52]. The texture features of vegetation have great potential for distinguishing vegetation types, more effectively reflecting remote sensing image ground object information and adjusting inversion models[6,53,54].

4.1.2 Overview of forest AGB remote sensing inversion research

Scholars use different remote sensing data sources in the process of forest biomass estimation in order to achieve better inversion results. The types of remote sensing data mainly include passive optical remote sensing, active or passive microwave remote sensing and lidar remote sensing.

Optical remote sensing is one of the common methods to obtain forest biomass information, which can accurately obtain forest canopy information and extract vegetation parameters to estimate forest biomass[39,64]. Liu estimated the forest biomass of Chongqing by using the vegetation index, tassel transform component and principal component variable information of TM data[18]. Zhou generates vegetation index (SVIs) and texture factors through high-resolution optical remote sensing images, and then combines terrain factors and field sampling data to quantify the biomass on Robinia pseudoacacia plantation[65]. Considering that the accuracy of NDVI estimation of biomass in a single season is insufficient and there is a problem of saturation, Zhu *et al*. used NDVI values of Landsat images in different seasons to perform forest AGB inversion[39].

Microwave (such as synthetic aperture radar) can penetrate the canopy and interact directly with the main body of forest biomass—leaves, trunks and branches. The ability of microwave remote sensing makes it a practical method for accurate estimation of forest biomass. On the other hand, the combination of lidar data and ground measured data can obtain a more effective distribution map of forest carbon resources and forest aboveground biomass[27].

Multi source remote sensing data can make up for the lack of a single data source and improve the accuracy of biomass inversion. Common multi-source data combination modes include: optical remote sensing sets with different spatial and spectral resolutions; optical remote sensing and SAR data of different polarization modes; optical remote sensing and lidar remote sensing. Xu *et al*. used

Landsat-8 OLI image and GF-2 image as data sources, and used single band, vegetation index and other spectral information as well as fixed sample land data of forest resources survey to estimate forest biomass in Jishui County, Jiangxi Province[66]. Li *et al*. used fully polarized C-band SAR data and Landsat-5 TM optical data to build a remote sensing information model to quantitatively retrieve the forest biomass of natural secondary forests in the greater Hinggan Mountains[67]; Wang *et al*. fused Synthetic Aperture Radar (SAR, Sentinel-1) and optical remote sensing (Landsat-8, Sentinel-2) data to evaluate grassland biomass[68], which is still suitable for forest biomass estimation; Minh *et al*. estimated the forest biomass of Madagascar using the tree cover data generated by ALOS PALSAR and optical remote sensing[25]. Tang obtained ecological parameters such as forest canopy height and canopy density based on LiDAR and multispectral remote sensing data, and then established a forest AGB inversion model using multiple linear regression and BP neural network model[43]; Li *et al*. estimated the AGB of temperate forests through stratified sampling and geostatistical modeling, combined with airborne lidar data, SPOT images and field sampling data[69]; Chi *et al*. integrated GLAS data and Landsat/ETM+ data, and then carried out forest AGB estimation research[70].

4.2 Estimation of forest productivity

Vegetation productivity refers to the rate at which green plants accumulate or fix organic matter, mainly including Gross Primary Productivity (GPP) and Net Primary Productivity (NPP)[71]. Among them, forest NPP represents the remaining part after removing the organic matter consumed by plant autotrophic respiration from GPP, reflecting the intensity of forest carbon sink[71,72].

4.2.1 Influencing factors of NPP spatio-temporal pattern

The dominant factors that produce the temporal and spatial differences of forest NPP are different, mainly including environmental factors, forest age and forest disturbance.

The influence of climate (such as temperature, precipitation, light) on NPP is achieved by changing the length of the growing season and the rate of photosynthesis. Abundant rain and heat conditions have a significant impact on plant productivity. Fang *et al*. studied the NPP changes of Changbaishan pine and cypress on a long time scale and found that the lowest temperature in April and the precipitation in June and July are the main reasons for the NPP changes[73]. Other studies have found that the increase of temperature will stimulate the autotrophic respiration of plants, and different water and heat combinations have an important impact on the temporal and spatial differentiation of NPP in the study area[74,75]. Extreme climate (drought, extreme high temperature or low temperature, etc.) also have a profound impact on terrestrial ecosystems[73,76]. In addition, the increase of carbon dioxide concentration between green plant cells can improve the photosynthetic efficiency of vegetation and increase forest productivity; nitrogen deposition affects the absorption and utilization of nitrogen by vegetation, thus affecting the photosynthesis of vegetation. In addition, topography, soil and tree species will also affect the temporal and spatial pattern of NPP.

The relationship between forest age and NPP has attracted more and more attention, which is of great significance to improve the accuracy of NPP estimation. The photosynthetic utilization rate of young trees is higher, which improves the absorption of carbon by stems, branches and thick roots, and NPP increases rapidly; NPP of trees reached the maximum in the medium term; in the later stage, as the growth of aboveground biomass decreases, and NPP is mainly composed of leaf and fine root turnover organic matter, NPP will decline to a relatively stable state[77,78].

Human activities (such as logging), forest fires, forest diseases and insect pests and other disturbances can directly release carbon to the atmosphere and accelerate the respiratory process, which has a strong impact on the carbon cycle, and may even be the leading factor causing the mutation of forest ecosystem in a special period of time[79]. Disturbance activities can also change the age structure and tree species composition of forests, resulting in temporal and spatial differences in forest NPP[77].

4.2.2 Overview of forest NPP estimation research

Forest NPP can be composed of organic matter and litter accumulated in roots (thick roots, fine roots), stems and branches, food consumption, volatile organic matter, unobserved litter and dead tree organic matter[77,80].

The research on forest NPP has been carried out since the last century, and the commonly used research methods such as direct harvesting method and carbon flux observation method are suitable for the observation of forest NPP in a small range. With the development of remote sensing technology, using remote sensing images and forest inventory data to estimate forest NPP in a large area has become a hot spot. For example, using MODIS NPP data and downscaling methods to carry out multi-scale NPP research[81]; NPP was estimated using NDVI significantly correlated with leaf area index[82]. Summarize the NPP research models commonly used by scholars, mainly including empirical/statistical models, remote sensing models and process mechanism models (**Table 6**).

Table 6. Three main NPP estimation models

Model	Advantage	Shortcoming	Representative model	Application
Empirical/statistical model	Meteorological data are easy to obtain and the model is simple.	The actual surface vegetation types are ignored, reflecting a trend or potential NPP.	Miami model, Chikugo model; Comprehensive model, etc.	[83,84]
Remote sensing model	Use remote sensing technology to obtain relevant parameters.	The quality of remote sensing image affects the accuracy of the model; Input parameters of different forest types lack calibration.	CASA, GLO-PED model, InTECc model, etc.	[85,86]
Process mechanism model	Considering the ecological mechanism of vegetation, the estimation result is more accurate, which is usually applied to the productivity simulation of small areas.	There are many parameters, the model is more complex, it is difficult to correct, and some parameters are difficult to obtain, so it is difficult to promote.	BIOME-BGC model, etc.	[87]

In addition, the method of estimating forest NPP through the correlation between NPP and forest biomass has also been widely used and practiced[73,77,78,80,88,89]. Some studies have shown that some NPP estimation models lack consideration of forest age, and the spatial distribution of forest carbon sources/sinks is more dependent on forest age than environmental factors[72,80].

4.3 Remote sensing inversion of forest structural parameters

The forest structure reflects the structural elements of trees and the connection mode of their attributes. The structural parameters that reflect the forest status mainly include: tree height, diameter, forest age, tree species composition, canopy height, canopy density, forest origin, etc.[90].

Remote sensing technology is an effective way to extract forest structural parameters. Li *et al*. comprehensively use remote sensing data, terrain factors, land cover, and forest inventory data to retrieve the average age of forest stands in Jiangxi Province, and then analyze the impact of forest age on forest NPP[72]. Hansen *et al*. used regression tree algorithm combined with Landsat-7 and Landsat-8 comprehensive data to draw the tree height distribution map of sub Saharan region, with high inversion accuracy[91]. Qiu and Liao used glas waveform parameters to estimate the discrete forest maximum tree height, canopy height, forest canopy density, etc., and assisted GLAS in retrieving forest parameters on a regional scale with optical images and ground data[20,92].

LiDAR can accurately obtain forest vertical parameters (such as tree height), but its coverage in the horizontal direction is limited; optical remote sensing can obtain a wide range of forest canopy horizontal parameters, but it is relatively insensitive to the change of vertical height. Therefore, there are more and more studies on the combination of LiDAR and optical remote sensing to obtain forest structural parameters. Hudak *et al*. combined LiDAR, ETM data and five statistical methods to estimate canopy height[26]. Jin *et al*. used the small-scale vegetation canopy height extracted by LiDAR as the ground truth value data to train the

RF model, so as to realize the inversion of large-scale vegetation canopy height[93].

5. Existing problems and research prospects

5.1 Existing problems

Due to the multi-level, complexity, unity, dynamic change and other characteristics of forest, its ecological quality assessment may cover all aspects, which determines that there will be many problems in the assessment process.

5.1.1 Selection of evaluation indicators

The evaluation indicators of forest ecological quality are screened only by theory or experience, and insufficient consideration is given to the effectiveness and representativeness of the evaluation indicators, which may lead to the lack of comparability of research cases in different research areas or even the same region, so that the research results cannot be effectively used and referenced, and hinder the exchange of scientific research and academic activities.

5.1.2 High quality data problems

In the process of retrieving forest ecological parameters using remote sensing technology, accurate and representative ground measurement data are needed for algorithm training and product verification, so high-quality sample data set is the premise of forest ecological quality estimation. Generally speaking, the verification data obtained from field sampling and vorticity related flux observation are of high accuracy, but such methods take a long time and have a small application area, and the data cannot be synchronized, which reduces the inversion accuracy. In addition, the estimation of forest biophysical parameters is more based on model simulation. Different models will have differences in parameters, thresholds, operation conditions and accuracy, which increases the uncertainty factors. For example, the forest biomass of the sample plot cannot be measured directly, and some ecological parameters (such as tree height, DBH, and forest age) are needed to assist in the calculation. Different studies use different regression models to calculate the ground point biomass, even for the same region, the results will be different.

5.1.3 Environmental impact

The level of forest ecological quality is closely related to its living environment. Environmental factors such as soil, climate, atmospheric composition, hydrological conditions, terrain and interference factors such as biological activities and natural disasters will affect the forest. However, few studies have evaluated the relative impact of environmental factors and interference factors at the same time, resulting in insufficient analysis of the impact mechanism of forest ecological quality.

5.1.4 Remote sensing means application issues

Remote sensing is a feasible method to obtain regional forest ecological parameters and quantitatively assess the ecological quality of forests, but most studies choose easily accessible horizontal forest structure parameters and do not consider enough vertical forest structure factors to comprehensively assess the ecological quality of forests with complex structure characteristics.

5.2 Development prospect

According to the problems existing in the evaluation of forest ecological quality, the following discussions and prospects are made for its development prospects.

First of all, forest ecological quality assessment needs to develop a standardized and unified index system. Reasonable evaluation indexes will improve the accuracy and objectivity of the assessment. The selection of each index should follow the principles of scientificity, representativeness and comprehensiveness to avoid problems such as unclear meaning, index duplication and strong correlation. For example, when it is forest land, “vegetation coverage” and “canopy density” have certain repeatability. Under different regions, different tree species and different site conditions, the threshold value of the evaluation index can be adjusted according to local conditions to improve the promotion ability, so that the research results of scholars can be mutually verified and used for reference, and promote academic exchanges.

Secondly, high-level forest ecological quality estimation requires long-term dynamic observation, so strengthen the long-term network monitoring and management of ground forests, constantly update and improve the basic data, so as to obtain real-time and effective sample data. Integrating multi-source remote sensing data, sample survey data, field sampling data, machine learning models and other data and methods to estimate forest biophysical parameters to quantify forest ecological quality, this research idea can reduce the uncertainty of a single model, improve the estimation accuracy, and realize forest assessment at different scales. In addition, carrying out forest multi-scale research is not limited to the pixel scale of remote sensing data, but also using object-oriented methods for forest ecological parameter estimation and multi-scale transformation, so as to improve the accuracy and generalization ability of the estimation model.

Thirdly, environmental factors (climate, terrain, soil, etc.), interference factors (drought, flood, pest, fire, etc.) and human activities should be considered in the process of forest ecological quality assessment. These factors will cause forest changes, resulting in differences in ecological quality levels. In addition, the parameters of the same species with different age structures and the heterogeneous species with the same age structure are different. Considering the age and species structure of tree species when quantifying the evaluation parameters can improve the accuracy of inversion results and promote the refinement and systematization of forest resources mapping.

Finally, multi-source remote sensing data is expected to improve the inversion accuracy of large-scale forest biophysical parameters, mainly by fusing the bands of different remote sensing platforms and sensors with different spectra and resolutions, so as to give full play to the advantages of a variety of remote sensing images and obtain more accurate and comprehensive forest horizontal and vertical structure ecological parameters. In addition, the expansion of research scale and the diversification of data sources have increased the amount of data, and the use of appropriate and efficient computing methods is also worth exploring and studying.

It is worth mentioning that the quality of forest ecological quality will affect the exertion of forest ecological functions and benefits. With the deepening of forest development and utilization, its ecological functions will be damaged or even changed, which is bound to have an impact on the level of forest ecological quality. Therefore, the research on the relationship between forest ecological functions and their ecological quality should be paid attention to in the next work.

Conflict of interest

The authors declared no conflict of interest.

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Optimization strategy of national park resource utilization system—Take Bawangling Zone of Hainan Tropical Rain Forest National Park as an example

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ABSTRACT

The national park with Chinese characteristics is the highest level of protection of a kind of natural protection, its establishment marks the park will implement the strictest ecological protection means. It is of great value to construct the utilization system of national park resources under the new natural protected area system in the new era to avoid the misunderstanding of "ecological protection only" and explore how to carry out the sustainable utilization of resources in the reform of national park system and mechanism. According to the analytic hierarchy process (AHP) and Delphi method, the evaluation framework, indicators, reference standards and weights of resource utilization under the national park system were determined in combination with the requirements of constructing the protected natural area system and the total value of resource ecosystem services (including harvest value, existence value and future value). Based on the application research of Bawangling zone of Hainan Tropical Rainforest National Park, the optimal resource utilization system in the future was proposed, and two optimization strategies of ecological adjustment of resource utilization system and construction of suitable resource utilization system were put forward.

Keywords: National Park; Resources Utilization; Ecosystem Service Value; Industrial Structure; Sustainable Development

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1. Introduction

The national park with Chinese characteristics is a kind of natural protected area with the highest level of protection[1], and the establishment of the national park marks that the strictest ecological protection measures will be implemented in the park. Since 2013, China's national parks have started various protection modes, but there is little mention of resource utilization. Due to the uncertainty of the concept of "strictest", each pilot area administration dare not easily open up production activities and human activities. However, different from the large-scale high-quality wilderness with sparse population in the United States and Canada, China's national parks are often accompanied by human settlements, and it is necessary to preserve human settlements and corresponding livelihoods within the general control areas of national parks[2]. However, in the current pilot situation, the interest demands of all parties are not completely consistent with the ecological protection and management objectives of the national parks, among which the significant conflicts are the socio-economic development needs of community residents and concessionaires, the recreation needs of visitors, and the protection needs of the National Park Administration on the integrity and authenticity of the ecosystem[3,4]. Therefore, it is necessary for China's national parks to build an appropriate resource utilization system to maximize the value of ecosystem services, that is, resource protection, sustainable resource utilization and coordinated development of local society[5].

For the first time, since 2013, the third plenary session of the 18 proposed national park system, Chinese national park has been carrying on the relevant system pilot actively explore, in the top-level design and maintain the original true and completeness of the natural ecological system has achieved results stage, but there are still many underlying difficulties, including resource utilization and coordinated development between human and nature. At present, there are two main viewpoints on the utilization of national park resources in academia and national park builders: (1) national parks contain precious natural heritage, which should adhere to the strictest conservation concept and avoid exploitation as far as possible; (2) the view that conservation and utilization can develop in harmony is gradually dominating[6]. Under the high-pressure situation of "the strictest protection" in the national park policy of the central government, on the one hand, the legitimacy of the utilization of national park resources in China is questioned, falling into the misunderstanding of "ecological protection only"[7]. On the other hand, the destruction of ecological environment caused by the production and living of aborigines in national parks has been repeated, and the effect of ecological compensation and resource protection is not good[8]. It can be seen that the balance between conservation and utilization is the core issue of scientific development of national parks. Through combing the literature related to the construction of pilot areas of national parks in China, the author finds that the existing literature mainly focuses on the following aspects: (1) in view of the nature of national parks, it is necessary to prevent national parks from being simply transformed into country parks, tourist resorts or the most strictly protected nature reserves. The primary function of national parks is to protect the ecosystem, and at the same time, it should meet the restricted and standardized contact of citizens[9]. (2) according to the particularity of China's national parks, in order to guarantee the production and living conditions of indigenous people in China's national parks, the balance between traditional utilization and nature conservation should be found[10]. For example, resource users in the park are transformed into ecological conservators[11], community participation and interest sharing mechanism are implemented[12], and functional zoning is carried out to find differentiated resource utilization measures[13], etc. (3) in order to give full play to the comprehensive functions of scientific research, education, recreation and other functions of national parks, ecological tourism can be developed, the mechanism of paid utilization of resources can be innovated, and franchising can be explored[14], etc.

To sum up, there are still some problems in the protection and rational utilization of national parks in China, and a new resource utilization system is urgently needed to improve the relationship between man and nature in the region, so that both can benefit. This requires the pursuit of development on the premise of conservation, and the realization of human well-being while maintaining harmony with nature, in order to maintain the sustainable development of the entire ecosystem and society.

Bawangling area is the only gibbon habitat and typical tropical forest distribution area in Hainan Tropical Rainforest National Park. The present situation and problems of resource utilization are typical in the pilot exploration of national parks in China, including: (1) unclear nature positioning. Hainan tropical rain forest national park after the establishment, the Bawangling area management department—The Bawangling Management Branch also continues the forest resource management thinking of the original Bawangling State-owned Forest Farm. The Bawangling Management Branch and its subordinate Bawangling Forest Development Co., Ltd. have overlapping and dislocating the government and enterprise functions, and there is a phenomenon of arranging the social functions of the area. (2) Lack of top-level design. Due to the short period of establishment of national parks, more appropriate and detailed regulations on resource utilization have not been formulated. (3) contradiction between protection and development. Due to long-term economic underdevelopment, the core industries and community production activities in Bawangling, which is located in the core protection area of the national park, cannot be stopped immediately. In this context, resource utilization system will become an important management tool to solve the conflicts between resource protection and social and economic development in Bawangling area. Therefore, based on the application experience of the resource utilization system reconstruction in Bawangling area, this study constructed the resource utilization evaluation system under the new natural protected area system in the new era, and explored the optimal strategy of sustainable resource utilization under the multi-objective management of the entire national park ecosystem.

2. Overview of the study area

According to the GIS vector data of Bawangling Area provided by Bawangling Sub-Bureau of Hainan Tropical Rain Forest National Park in October 2020, Bawangling Area of Hainan Tropical Rain Forest National Park is located in the southwest of Hainan Province, straddling Baishan Li Autonomous County, Changjiang Li Autonomous County, Dongfang City and Ledong Li Autonomous County (**Figure 1–2**). The area covers a total area of 88,000 hm^2, including 69,000 hm^2 core protection area and 19,000 hm^2 general control area. Bawangling area is the best preserved of pristine tropical forest of Hainan Province, is a tropical rain forest in Hainan national park in the only gibbon habitat in seven area, important eco-function areas of Hainan Province, in the protection of regional ecological security, climate change, the construction of ecological province in Hainan international tourism island has an irreplaceable role.

Ecological construction has been the key work since the reform of Bawangling area. The implementation of ecological protection and sustainable utilization of resources has been the heavy experience of Bawangling area after nearly 40 years of predatory logging. Bawangling Area has undergone three historic reforms (see **Figure 3**) from the birth of Bawangling Forest Management Site in 1955 to the establishment of Bawangling Sub-Bureau under the vertical management of Hainan Tropical Rainforest National Park Administration in 2019. At this point, with the end of the second phase of Tianbao engineering (2020), Hainan tropical rain forest national park was set up will bring more strict ecological protection and top-down system update, prompting Bawangling area onto the road of a new stage of transformation, how to achieve the goal of national park ecosystem value maximization under construction suitability resource utilization system. It will be the key point of future transformation of Bawangling area.

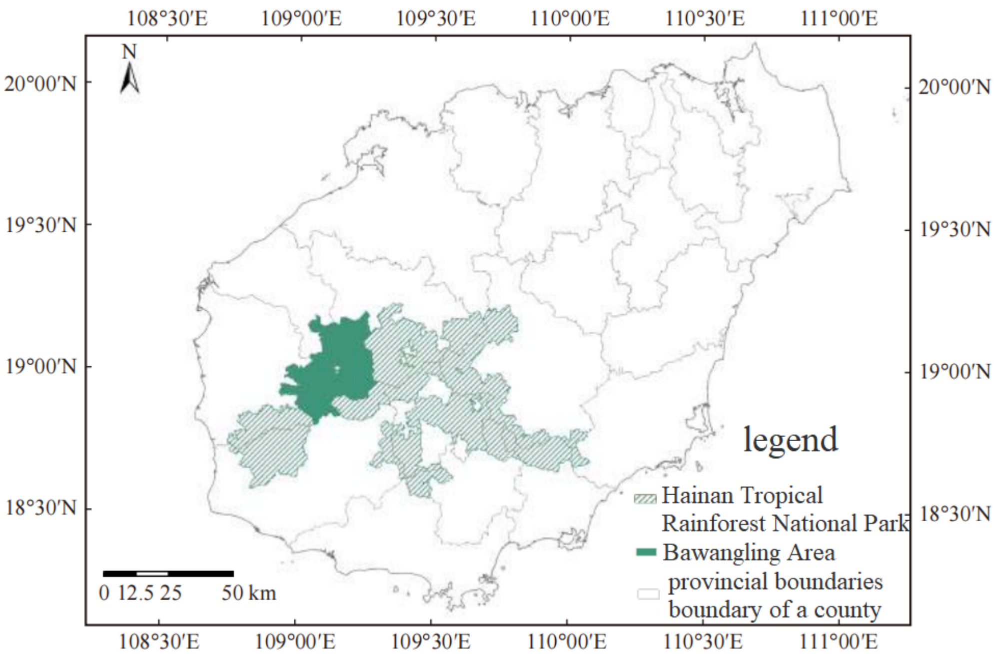

Figure 1. Location map of Bawangling Area.

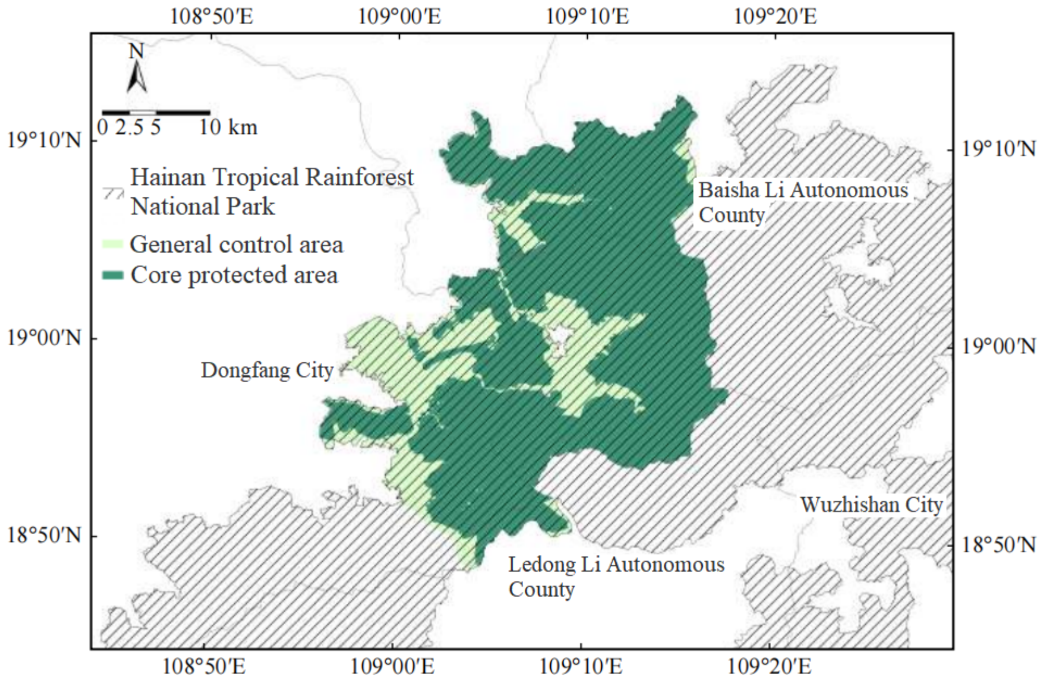

Figure 2. Zoning map of Bawangling Area.

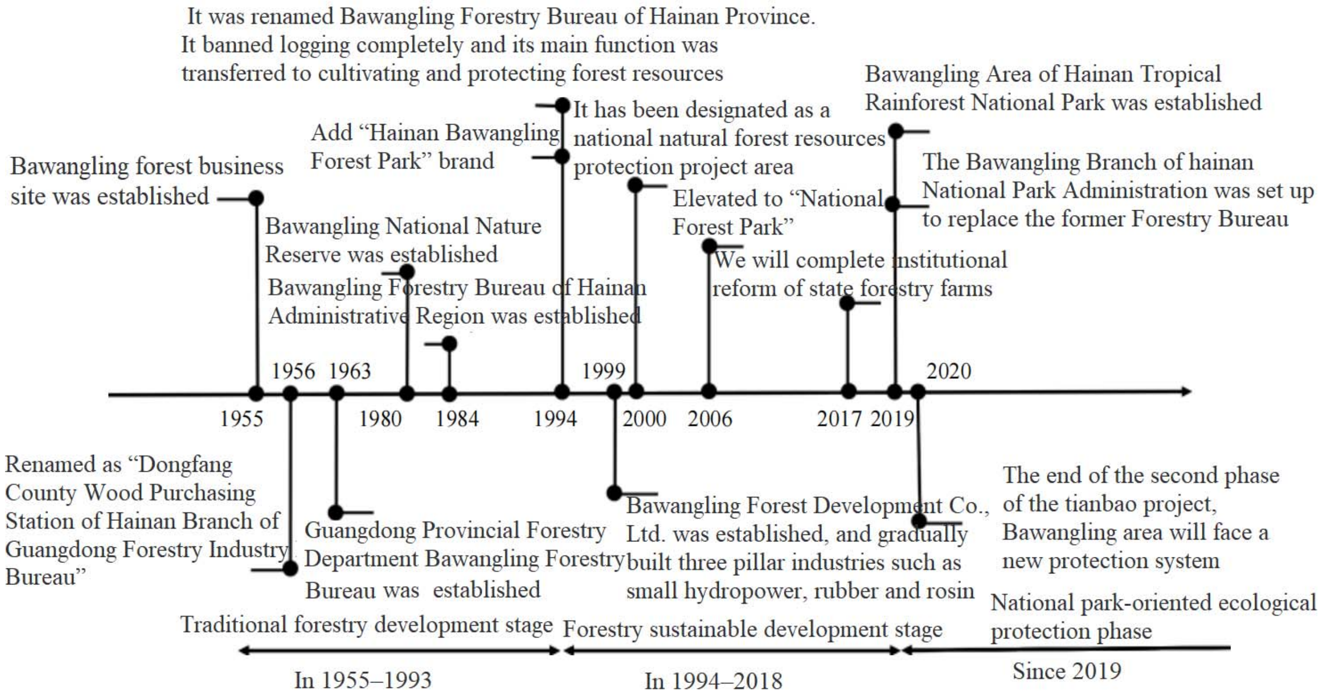

Figure 3. Timeline of historical development of Bawangling Area.

3. Research methods and index system

3.1 Research methods

As for the research on the choice of resource utilization methods, the commonly used methods can be divided into two categories: qualitative analysis, mainly SWOT analysis; quantitative analysis mainly includes entropy method, grey clustering method, deviation-share analysis method, principal component analysis and analytic hierarchy process. Among them, the analytic hierarchy process (AHP) is the most widely used method, which can extract the main value evaluation criteria of complex things and comprehensively evaluate the development value of each utilization mode by relying on the subjective weight of experts' discipline experience and the objective calculation of computer science algorithm. The most important thing is that the results are simple, clear and feasible in practice, which is conducive to the repeated use of the evaluation system by national park managers, and based on which the regional resource utilization methods are regularly investigated and evaluated.

At present, this evaluation method has been widely used in forest industry screening and has a mature evaluation system[15,16]. However, under the development goal of national parks, there are still some defects in the evaluation of direct use value of natural resources. In the stage of index establishment and weight assignment, this study, starting from the value of ecosystem services, uses protective indicators and weight allocation to guarantee the non-consumption use value and public benefit value of resource utilization[17,18], so as to achieve the transformation goal of priority protection and sustainable resource utilization in all pilot sites under the national park system. Combined with R 3.6.1 software package (R software for short) and hierarchy analysis software, the comprehensive evaluation and ranking of regional resource utilization development ability are carried out to provide data support for the establishment of resource utilization system.

3.2 Establishing an indicator system

3.2.1 Logical framework

According to the "Overall Plan for Establishing a National Park System" (2017), "Guiding Opinions on Establishing a Natural Reserve System with National Parks as the Main Body" (2019) and other documents, national parks can rationally use resources on the basis of protection, Therefore, the effective protection of natural resources, the maximization of ecosystem service value and the sustainable utilization of resources are the important evaluation criteria of national park resource utilization target and resource utilization index system. Ecological protection is always the core connotation of China's national parks, indicating that any resource utilization should be based on environmental carrying capacity and subject to strict regulations[19]. The maximization of ecosystem service value means that resource utilization mode must have ecological, economic and social functions, and shoulder the dual tasks of ecological product supply and ecological environment health protection[5]. Sustainable utilization of resources means promoting economic development, technological progress and highly green industrial structure, that is, enhancing the sustainable development capacity of the industries involved, while sustainable development represents the comprehensive response of the "development degree", "coordination degree" and "sustainability degree" of the complex system of "nature, society and economy" [17,20]. To sum up, the author divides the resource utilization evaluation system under the national park system into three levels: the market value of resources (harvest value), the value provided by unharvested resources in situ (existence value) and the future value of resources.

(1) Harvest value can be further divided into: a. economic value refers to the direct use value and economic benefits brought by harvested products, such as wood, fruit and medicinal materials; b. social value, that is, the social demand for livelihood welfare and products brought by the use of natural resources for community residents. In addition, due to the externality of natural resources, the market cannot fully reflect the costs and benefits of natural products, so the existence value and future value are further used to constrain the market failure of national park natural resources[21].

(2) The existence value includes the ecological benefits brought by the national park ecosystem, such as water purification, pollution control, natural pollination, pest control, soil and water conservation, climate regulation, etc.[22,23]; services or "potential benefits" that can be provided without consuming or destroying natural resources, including indirect use value of ecotourism, recreation, education and scientific research[22,24].

(3) Future value refers to the expected value of resources to human society in the future, such as research and development of new drugs, food and genetic resources, or the value that people are willing to pay in order to protect a species from extinction or an ecosystem from being destroyed and leave natural resources intact to future generations[25].

3.2.2 Screen evaluation indicators and determine the weight of indicators

The resource utilization index system is the formal expression of the industrial structure of national parks[15]. The rationality of industrial structure is the basis of whether the industry can better reflect the service value of regional ecosystem. A reasonable resource utilization system can not only maintain the ecological balance, but also make better use of natural resources. The selection of evaluation system indicators should firstly be based on the harvest value, existence value and future value of each industry to ensure that the effectiveness and potential of resource utilization are reflected from different aspects. Secondly, the index should not only quantitatively evaluate the contribution of the industries involved to the community economic development, but also dynamically reflect the industrial development potential and ecological benefits during the duration, and ensure the accuracy and reliability of the evaluation results. On the basis of listening to experts' opinions, this study first consulted literatures[25], papers[15,26-39], reports[40,41] and statistical yearbooks[42] related to the evaluation of ecosystem resource utilization and industry screening. Combined with the frequency statistical method, the evaluation indexes with high frequency were selected as candidate indexes. The index system of 3 levels is determined, which is composed of 3 dimensions and 23 indicators. Delphi method was adopted, which was scored and evaluated by 15 experts in related fields of national park and forestry research, and analyzed by MicroSilver AHP software. All indicators passed the consistency test. According to "2019 Bawangling Forest Development Co., Ltd. Production and Operation Management Plan", "2019 Bawangling Management Branch Financial Final Report", and "Bawangling Area Situation Report", combined with background information, interviews and field investigation of Bawangling Area, and speech materials for the sixth meeting of the 18th Workers' Congress of Bawangling Forestry Bureau of Hainan Province (now Bawangling Sub-Bureau), and specific evaluation of indicators, reference standards and corresponding weights (see **Table 1**).

Table 1. Evaluation indexes and reference standards of national park resources utilization

Destination layer	First-level indicator	Second-level indicator	Quantization method	Unit
Harvest value (0.2343)	Economic indicators (0.0879)	Gross industrial output value (0.1438)	Gross output value of the industry	Ten thousand yuan/year
		Local financial support (0.0823)	State or local financial support	Ten thousand yuan/year
		Ability to absorb investment (0.1079)	Social investment	Ten thousand yuan/year
		Market share (0.0619)	Industrial output value/total value of the industry in the province where the national park is located	%
	Social indicator (0.1464)	Average monthly salary of employees (0.0283)	Average monthly income of active employees	Yuan
		Number of employment (0.0344)	Industry annual employment	
		Technical training (0.0281)	Experts assign points, no development, only a little development, general development, more development, and a lot of development 1 to 5 points in order	
		Policy support (0.0250)	Experts assign points, none at all, only a little, average, many, many in order of 1 to 5 points	
Harvest value (0.2343)	Social indicator (0.1464)	Industry relevance (0.0196)	Experts assign points, no correlation, only a little correlation, general correlation, more correlation, strong correlation, 1 to 5 points in order	
		Regional competitiveness (0.0153)	Experts assign points, with no competitiveness, little competitiveness, general competitiveness, greater competitiveness, and strong competitiveness in the order of 1 to 5 points	
		Market demand (0.0190)	Experts assign points, no demand, only a little demand, general demand, more demand, and great demand 1 to 5	

Table 1. (Continued).

Existence value (0.4586)	Ecological indicators (0.4586)	Ecological integrity value (0.0270)	Experts assign points, industrial development has a serious negative impact on ecological integrity, a large impact, a general impact, only a little impact, and no impact on the order of 1 to 5 points	
		Carbon fixation and oxygen release value (0.0139)	Area area × carbon sequestration coefficient of ecosystem	T/year
		Protect biodiversity[40] (0.0309)	Experts assign points, no protection, only a little protection, general protection, more protection, and very good protection in order of 1 to 5 points	
		Protect local culture (0.0155)	Experts assign points, no protection, only a little protection, general protection, more protection, and very good protection in order of 1 to 5 points	
		Pleasant value (0.0199)	Experts assign points, unpleasant, somewhat pleasant, generally pleasant, somewhat pleasant, very pleasant, 1 to 5 points in order	
		Education and science value (0.0203)	Experts give points, no educational and scientific projects, only a little educational and scientific value, certain educational and scientific research significance, great educational and scientific value, and many educational and scientific projects, 1 to 5 points in order	
Future value (0.3071)	Potential evaluation index (0.3071)	Protected area (0.789)	Protect the area	hm^2
		Proportion of technical personnel (0.0405)	Total number of skilled persons/employed persons	%
		Industrial R&D density (0.0415)	Annual investment in R&D	Ten thousand yuan
		Ecological constraints[33] (0.0739)	Experts assign points, no constraints, only a little constraint, a certain constraint, a large constraint, and a large constraint, 1 to 5 points in turn	
		Management ability of industrial environmental protection (0.0446)	Experts assign points, none at all, only a little, with certain management, more management, and sound management in order of 1 to 5 points	

Note: the weights of indicators are in brackets.

4. Reconstruct the utilization system of National Park resources

4.1 Current situation of resource utilization in Bawangling Area

At present, the resource utilization in Bawangling Area covers primary, secondary and tertiary industries: the primary production mainly includes the planting industries of rosin, rubber, areca nut, oil tea, scented rosewood, phyllotrium, Agarwood and Shanlan rice, as well as the breeding industries of beekeeping, overking pheasant and black pig; the secondary production is mainly small hydropower stations (referred to as small hydropower); the three industries mainly include ecological resource management and conservation, forest cultivation and other nature conservation industries, forest tourism, ethnic village tourism and other tourism services, and property management services.

The revenue status of each industry is shown in **Figure 4**, and the specific analysis is as follows: (1) the financial revenue of ethnic village tourism and natural protection project in Wangxia Township is the main economic source of Bawangling Area, accounting for more than 90% of its total revenue. However, with the end of the second phase of the Tianbao Project (2020) and the establishment of the national park, the resources and structure of nature conservation of Bawangling will be greatly adjusted, and the restrictive development strategy of the national park will certainly affect the further development of rural tourism in the region. (2) The contract development of rubber and rosin is large in scale and involves many stakeholders. It is the main income source of Bawangling Forest Development Co., LTD. (the former Bawangling Forestry Bureau, now the wholly-owned operation company of Bawangling Management Sub-Bureau of Hainan Tropical Rainforest National Park). However, in recent years, with the continuous downturn of rubber and rosin market, the aging of pine and rubber in the region is serious, and most of rubber and pine are located in the core protection area of national parks, so the scale of operation and output will be

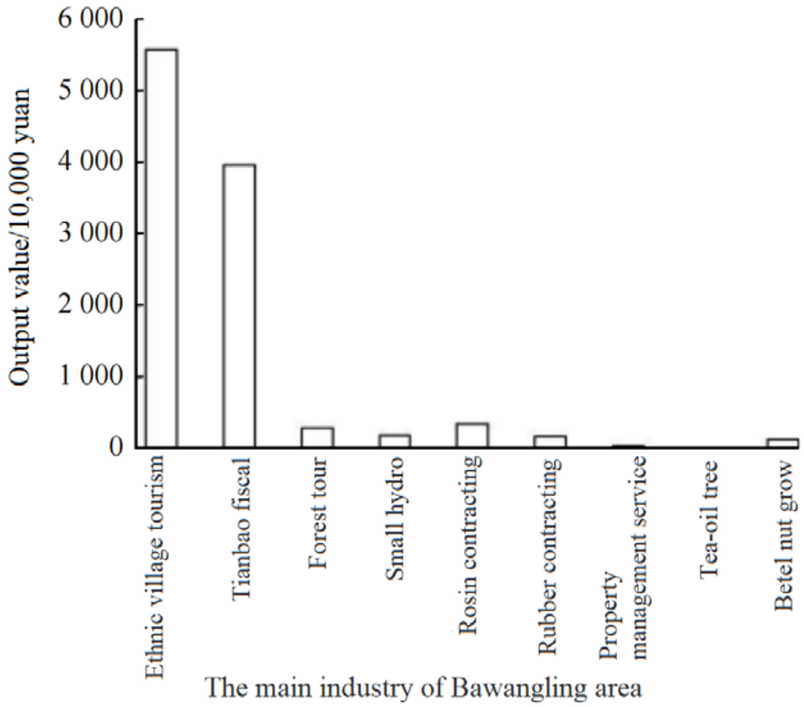

Figure 4. Output value of main industries in Bawangling Area in 2019.

greatly reduced in the future. Therefore, liquidated damages for early termination of the contract, resettlement of surplus employees after industrial reduction and ecological compensation for villagers are all arduous and important tasks for the transformation of national parks. (3) In terms of small hydropower and property management services, due to the withdrawal requirements of being located in the core reserves and the operating situation of losing money for years, they will face the risk of shutting down in the future. (4) Forest tourism in the region has begun to take shape, but the products are single, the facilities are obsolete, and the driving effect has not been brought into play. It is in urgent need of upgrading. Forest tourism, though not yet profitable, has the potential to become one of the main industries of Bawangling in the future.

4.2 Resource utilization score and comparative analysis in Bawangling Area

According to “2019 Bawangling Forest Development Co., Ltd. Production and Operation Management Plan”, “2019 Bawangling Management Branch Financial Final Report”, and the author’s field investigation records from August 20 to 22 and October 22 to 31, 2020, Sixteen industries with statistical data in Bawangling area were extracted as data sources for analysis, among which bee, pheasant and mountain pig farming industries were not included in the analysis due to the unstable benefits of COVID-19 and other uncontrollable factors. The index data of 16 industries in Bawangling Area were substituted into the resource utilization evaluation system, normalized by R software and multiplied by corresponding weights to obtain the industry evaluation results (see **Table 2**).

The results can be seen as follows: (1) nature conservation has the highest score, which is consistent with the main function of national parks to protect the authenticity and integrity of important natural ecosystems. Therefore, nature conservation can be regarded as the core industry of resource utilization in the area, and the development of forestry based on forest cultivation should be accelerated during the transition period from Bawangling area to national park. (2) The tertiary industry, mainly forest tourism and ethnic village tourism, scored second. This is the main way to realize the comprehensive functions of national parks such as scientific research, education and recreation, so it can be identified as a key industry in the transformation of the area to absorb the surplus labor force caused by the shutdown of the core protection areas. (3) The planting industries mainly featured flowers, rubber, mountain orchid rice, areca nut and puzzle were ranked from 4 to 8 in order. All the above industries were featured industries in Bawangling area, with mature planting and picking technology and relatively stable employment income. With the implementation of national park control measures such as restricting development and production projects and forbidding destructive human activities, the above characteristic industries can be used as auxiliary industries to restrict development in the general control areas. (4) Rosin, camellia, rubber, betel nut contracting and small hydropower are affected by market and policy, and the advantages are not obvious. With the contraction of production control in national parks, industries related to the core control areas can be phased out. (5) Housing rental and property management services are still at a disadvantage. After the responsibilities of Bawangling Management sub-bureau are gradually clear, the transfer of its relevant social function industries should be accelerated.

4.3 Reconstruction of the resource utilization system in Bawangling Area

To reconstruct the resource utilization system means to reconstruct the industrial structure based on the resource utilization status and evaluation results of Bawangling area, and form the future resource utilization system of Bawangling area under the national park system (see **Figure 5**). Specific analysis is as follows: (1) Bawangling Hainan tropical rain forest national park area resource utilization system should be in the forestry ecosystem services (conservation) as the core resources development direction, formulated to protect the gibbon and habitats for core resource management scheme, in order to ensure the safety Bawangling area to the survival and development of resources, the economic development of other tasks through franchising system transfer out, complete the separation of government (Bawangling Management Branch) enterprise (Bawangling Forest Development Co., LTD.) and the separation of resource management rights and management rights; (2) tourism and leisure services as the key resource utilization mode, as an important resettlement outlet for surplus workers to transfer jobs and community villagers to supplement livelihood under the restricted development of national parks; (3) in other places in a green economy for auxiliary industry, as the core national park reserve ban on the implementation of the productive activities, the core should be early to reserve resource utilization type industrial repel or migration work, for the rest of the general control area, based on regional environmental bearing capacity of resources, the development of upstream and downstream side and related industry, absorption of surplus labor force, maximize industrial benefits per unit area; (4) the brand of "national park" can also be used to integrate idle natural, cultural and industrial resources into assets for marketing or investment, so as to form good brand benefits and add value to these traditional characteristic products.

However, it should also be noted that in the initial stage of the transformation of Bawangling area into a national park, core industries should not be developed singly and all existing industries in the core protection area should be "cut into one size", resulting in capital chain fracture, unemployment of forest workers and antipathy of community villagers. Some resource utilization methods with the highest comprehensive score will be included in the ecological industry group of the area, and the disadvantaged industries will be restricted and gradually withdrawn, so as to set aside adjustment time for the affected enterprises, employees and community residents, and provide targeted and diversified compensation and resettlement measures. To promote the tourism service industry as the leader, realize the simultaneous development and integration and upgrading of multiple industries, avoid the risk of unbalanced industrial development, and help to adjust the industrial structure of the area, leaving room for the settlement of workers suspended and community residents.

In addition, because the resource utilization evaluation is limited to the current utilization status, Bawangling area should always pay attention to green frontier technology and forestry hot spots, take the national park as the support focus of the central and local financial system, the new development concept of the "14th Five-Year Plan" and the important practice base of the "Two Mountains theory". The pilot work of green industry development mechanism, such as smart culture and tourism promotion, green high-tech research and development, and green financial instrument innovation, is regarded as an important resource utilization content of its exemplary guiding role.

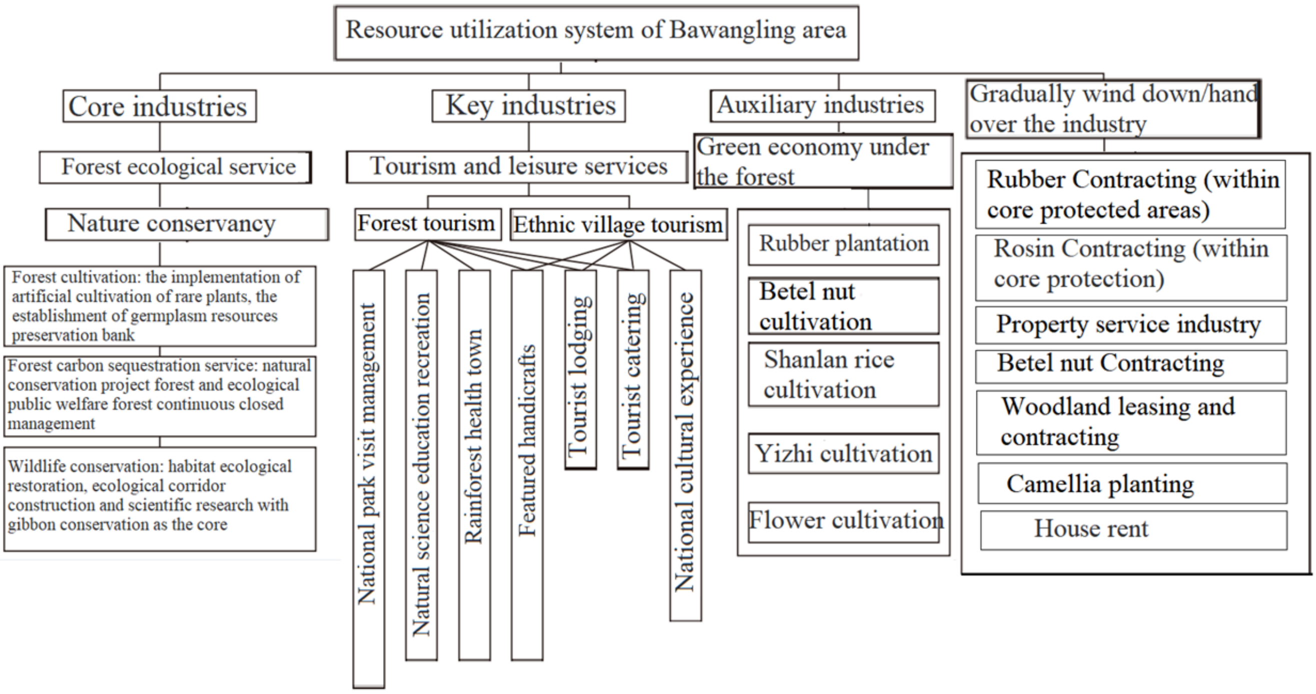

Figure 5. Future resource utilization system of Bawangling area under the national park system.

5. Optimization strategy of national park resource utilization system

5.1 Ecological adjustment of resource utilization system

As the reform of the management system and mechanism of the new nature reserve system is gradually advancing in the national parks, strengthening ecological protection has become the first priority for the transformation of each pilot area into a national park. However, from the practical experience of Bawangling area, the economic activities of national parks are also necessary to maintain the healthy development of the area, and the key is how to solve the conflict between the demands of natural resources, ecological environment protection and social and economic development.

First of all, it is necessary to ensure the core position of nature conservation, that is, to ensure resource supply and protect the ecological environment, and to strengthen the conservation activities of ecological assets such as management, conservation, cultivation and scientific research, which are the primary purpose of China's national park resource utilization system. Secondly, based on the interests of all parties, to ensure the realization of economic and social values, to find tourism, leisure or community green industries in line with the development goals of national parks. For reference, for example, is similar to the situation of our country, the national park also has complex stakeholders Japan home park's attitude toward the resource utilization. That is, while protecting beautiful landscapes and ecosystems, it contributes to citizens' health, entertainment and culture through resource utilization, divides protection levels through resource values, and uses control plans to regulate and control areas to achieve sustainable conservation of ecosystems and parks.

In conclusion, rather than a "one-size-fits-all" approach to conservation, an ecologically-oriented resource utilization system is an important tool to ensure the health, vitality and sustainable management of national parks. The modernization of "ecologicalization of economy" requires judging the total value provided by various resource utilization modes under the national park system from the perspective of ecosystem service value[43], which can be calculated by calculating the direct use value representing economic and social benefits and the existence value and future value of resources representing public welfare of the whole people. The resource utilization evaluation index system that is most suitable for national park protection priority, ecosystem service value maximization and sustainable concept is selected.

5.2 Constructing an appropriate resource utilization system

Suitability analysis is the process and procedure of determining the suitable use of a particular piece of land[44]. The difference in application depends on the actual or expected relationship between benefits and observed factors such as demand, preference, and environmental consequences[45]. In order to form a high-efficiency resource utilization system in national parks, constructing an appropriate resource utilization system is the fundamental way to accurately improve the value of ecosystem services in each pilot area under the dual constraints of land and functions of national parks. How to comprehensively consider the influence and constraint conditions of various resources utilization is the key to construct the appropriate resource utilization system according to the development goal and resource status of national parks.

5.2.1 Industrial suitability analysis

The analytic hierarchy process (AHP) used in this study to construct the evaluation index system of resource utilization is a commonly used item ranking method for suitability analysis[46], and the resource utilization evaluation system constructed based on this method can reflect the effect of all natural, social and economic functions of national parks. According to the industrial evaluation experience of Bawangling area, the industrial suitability analysis of national park should be based on the comprehensive analysis results of industrial resources, industrial scale, industrial structure and industrial subjects. For example, the evaluation index system of resource utilization used in this study can accurately optimize the industrial structure of Bawangling through quantitative comparison among industries. According to the results of the Bawangling area resource utilization system reconstruction can be found in similar Bawangling legacy industry and general control area is building the core reserves many national park, in the community should be in order to solve the problem, optimization of core area industrial repel and general control area industrial structure and resource utilization of the sustainable development path as its limited financial background of the development of new ideas; In addition, adaptive management methods can be combined, that is, dynamic management of strategies can be adjusted in time according to industrial development ideas and resource utilization system index changes, so as to achieve timely loss stop and minimize the destructive interference of human social system and economic system to the national park ecosystem[5].

5.2.2 Suitability analysis for development stage

Based on the application research of Bawangling area, the utilization mode of resources in the pilot area is closely related to the construction stage of national parks, which is also consistent with the conclusion analyzed by relevant scholars[2] that “the protection and utilization of national parks should be considered in the overall environment of social and economic development stage to determine the utilization intensity and sequence of national parks”. In the pilot stage of transforming into a national park, it is necessary to carry out resource utilization evaluation, actively guide the industry and population of the core protected areas to withdraw, and establish the green development concept of the area and surrounding communities. In the construction period of national parks, it is necessary to actively seek for projects close to nature, with nature conservation as the core industry, tourism and leisure services as the key industry, and green economy under forests as the auxiliary industry, and always pay attention to green frontier technology and forestry hot spots. In the completion period of the national park, local residents with good education background and stable income base can use the national park brand to build a benefit sharing system and further deepen the value co-creation concept and consciousness of stakeholders in pursuit of "maximizing the value of national park ecosystem services"[4]. Through the tourism association and driving effect generated by high-quality services such as recreation development, natural science and education, accommodation, catering and cultural experience of national parks, the linkage with green economy of other forests is realized, and the resource utilization pattern of "cross-regional linkage, productive integration and multi-participation" is basically formed.

5.2.3 Normative restriction suitability analysis

The utilization of resources in Bawangling area involves a huge ecosystem, especially the incoordination of stakeholders. In order to achieve the goals of effective protection of natural resources in national parks, maximizing the value of ecosystem services and sustainable utilization of resources, in addition to meeting the development needs of national parks and the interests of stakeholders, Managers, community residents, concessionaires and visitors should also be guided to conduct responsible and eco-friendly behaviors to regulate and restrict industrial activities and micro-subject behaviors in the utilization of national park resources[19].Good regulations on the utilization of national park resources need to be formulated in terms of laws, regulations and standards. Including management rules and regulations to protect the safety of ecological resources, monitoring of franchise regulation of the industry development, guarantee the attraction of tourists tourism and leisure resources negative behavior regulation, ensuring the sustainable livelihood of employees and residents welfare regulation, establish protection priority values of popular science education, etc., to ensure that industry development after the smallest negative impact ecosystem, the largest supply of social welfare.

To sum up, an appropriate resource utilization system needs to be comprehensively analyzed based on the industrial foundation of national parks, the construction stage of national parks and the normative mechanism (see **Figure 6**) to ensure that the resource utilization system supports the sustainable operation of national parks and monitors the resource utilization to meet the management requirements.

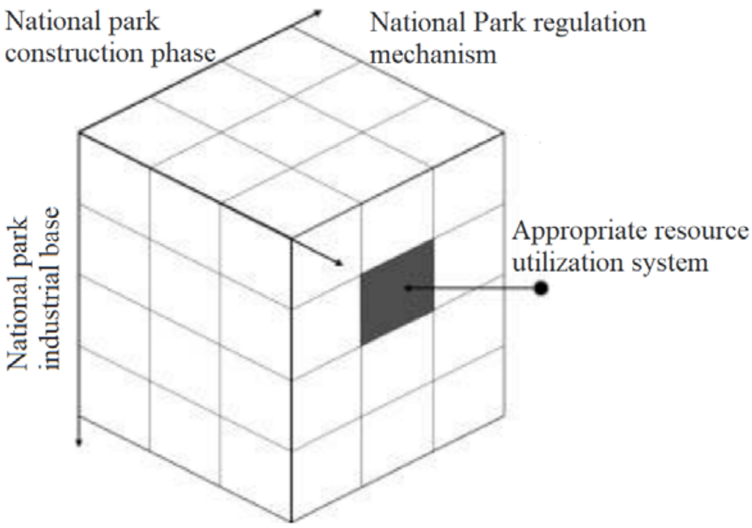

Figure 6. Appropriate observational factors for resource utilization.

6. Conclusion

The most typical problem in the pilot areas of national parks lies in the original contradiction between protection and utilization. The key to solve this problem is not only the priority of ecological protection, but also the new way of resource utilization. Rational resource utilization is not only an important channel to realize diversified investment and financing of national parks, but also an important guarantee to realize the goals including ecological protection, community co-management and public sharing. Resource utilization assessment is the basis for understanding the suitability of production activities in national parks. The ranking of resource use assessment can reflect an industry's contribution to natural harmony and human well-being. This study based on national park, ecological protection, ecosystem services value maximization and the target of sustainable development of resource utilization, puts forward the value of ecosystem services under the perspective of resource utilization index system, and combining the Hainan tropical rain forest national park Bawangling partition application analysis, put forward the new type of Bawangling nature reserve system for resource utilization system. On this basis, resource utilization is bound to be a long process of control, and its impact is unknown. In order to make resource utilization assessment an effective resource management tool for national parks, the following points should be done in resource utilization for future national parks like Bawangling area, which should guarantee the basic productive activities of community residents.

(1) Adhere to the road of modern development of "ecological economy", retain the value appeals of ecological, social and economic parties to maximize the value of the ecosystem; in order to promote the national park management department to make full use of the national park resource utilization evaluation index system, to quantitatively and systematically analyze the feasibility of the development of each industry, and judge the annual environmental impact trend of the industry, timely control.

(2) Based on the scientific analysis of industry suitability, development stage suitability and normative restriction suitability, and on the premise of assuming the responsibility of protecting the integrity and authenticity of the ecosystem, the adaptive management method should be used to release the maximum ecological, social and economic benefits of the region.

(3) The core position of nature conservation in the resource utilization system of national parks should be firmly established, the social needs of tourism and leisure service development should be met, and the system of green economy and technology under forests should be actively innovated to create a resource utilization pattern with the participation of relevant stakeholders.

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Conflict of interest

The authors declared no conflict of interest.

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REVIEW ARTICLE

Advances in forest transition theory research

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ABSTRACT

Forest transition is a trend change process from decreasing to increasing forest area in a country or region. Since the 1990s, ecological and environmental problems such as climate change and loss of biodiversity have received constant attention. The research theory and method of forest transformation has gradually become the frontier and hot topic pursued by international academic circle. With forest transformation as the theme, on the basis of introducing the origin of forest transformation research, along the development vein and internal logic of forest transformation research, this paper reviews the research progress of forest transition theory from the perspectives of Kuznets curve of forest environment and forest transition path, and summarizes the major issues in forest transformation research. The main direction of future research is proposed, including the impact of economic globalization on forest transition, the refinement of research units and the analysis of forest quality transition.

Keywords: Forest Transformation; Forest Area; Deforestation; Forest Restoration

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1. Introduction

The concept of forest transformation was first developed by Finnish geographers and historians A.S. Mather in 1992. Forest transformation, that is, the trend process of forest area of a country or region change from decreasing to increasing. On a global scale, the forest area has tended to decline in the last 20 years mostly in the Latin American, Caribbean region and Africa. Among them, Latin America and the Caribbean suffered the most net forest loss. The trend of deforestation in other areas has been curbed to varying degrees, and the forest area remains stable or growing.

Most of the existing forest transformation studies are carried out at the national level. Scotland was the first place where the forest transition took place. The transformation took place around the 1750s. At the time of transition, forest cover was 3%. France's forest area continued to decline until the 1830s. Until the forest cover drops to about 15% and stabilizes. From then, forest area began to grow continuously. The Irish forest transformation took place in 1920s. The forest coverage rate at the transition point was about 2%. The Danish's forest coverage rate was 4% at the time of forest transition. Forest transformation in the United States took place at the beginning of the 20th century' where forest coverage was around 27% at the time of the transition. Further research has plotted the timing of the transition in each state. The transformation of the eastern region is earlier, and the transformation of the western region is later. The time span is from 1907 to 2002. Korea's forest transition point has a high forest coverage rate of about 55%. Its forest transformation took place in the 1960s and 1970s. Forest transformation in Costa Rica took place in the end of the 20th century where the forest coverage at the transition point is 30%. In addition, China, India, Vietnam and other developing countries have gradually realized forest transformation after the 1980s[2-6].

The forest coverage rate at the time of forest transition in each country varies greatly: Developed countries precede developing countries. The forest area has been transformed from decreasing to rising, and the rich countries in transition generally have much lower forest cover than developing countries. The previous point suggests a link between forest transformation and economic growth. The developed economies that are the first to achieve economic development and also the first to achieve the trend of deforestation has been reversed. The latter point may indicate that the political, social and economic changes in modern times make developing countries face a different environment from the historical period of forest transition in developed countries in the past, and the driving factors behind forest transition may be different.

Mather[1] discussed the realization of forest transformation on the basis of summarizing the historical trend of forest area change in some European and American developed countries has opened the exploration process of forest transformation research. Later, the mechanism of forest transition and the trend of forest area change dynamic factors, theories and methods of forest transformation are developing rapid. The driving forces of forest transformation may vary in different countries and regions, and at different stages of economic development in a country or region, the same factor may play a different role. Existing research literature[7-10] believes that the factors that explain forest transition include: agricultural concentration, the price of wood and other forest products, policy intervention and system development, urban and rural labor transfer, and the change in the value concept of forest resources.

According to the basic context and logical relationship of forest transition literature development, this paper combs the theoretical changes and internal logic of forest transition research, and summarizes the mechanism of forest transition and the main problems in forest transition research. In view of the lack of research on forest transition in China, this paper aims to promote the development of research on forest transition in China, especially to enhance domestic and international academic discussion based on the empirical rules of forest transition in China.

2. Forest transition based on environmental Kuznets curve

Developed countries realize forest transition earlier than developing countries, suggesting that there may be a certain correlation between economic growth and forest transition. Forest transition describes the trend change process of forest area decreasing first and then rising over time, while the environmental Kuznets curve shows the trend change process of environmental conditions deteriorating first and then improving with economic growth[11]. Considering the environmental attribute of the forest, and the synchronization of economic growing with time of in most countries and regions in the world, is there a forest environmental Kuznets' curve (hereinafter referred to as the forest Kuznets curve), that is, with economic growth, forest area first decline and then rise, economic growth will eventually lead to an increase in forest area?

In the early stage of forest transition research, a large number of documents discussed the relationship between forest area change and economic growth, but no consensus was reached. Most of these studies use multiple country data across time (the main source of forest area change data is form the World Food and Agriculture Organization (FAO), taking the rate of forest area reduction as the dependent variable and the primary and quadratic terms of GDP per capita as the core independent variables. If the primary term coefficient of GDP per capita is positive and the quadratic term coefficient is negative, the forest Kuznets curve is considered to exist. However, with the differences in research period and model setting, researchers have drawn different research conclusions in different regions[12]. Some studies have shown that the inverted U–shaped forest Kuznets curve exists in Latin America and Africa, but does not exist in Asia[13-15]. Some studies also believe that there is an inverted U–shaped forest Kuznets curve in Asia and Latin America, but not in Africa[16]. Mather *et al.*[7] and Bhattarai *et al.*[13] further discussed forest area loss association between low rate and GDP per capita cubic term, that is to verify whether there is an S–shaped curve relationship between forest area and economic growth. In the early stage, the measurement methods used by Forest Kuznets curve Research Institute were mainly ordinary least square method[17-19], then panel data model[20,21], and feasible generalized least square method[13].

As the research data used by researchers are mostly multinational panel data, the definition of relevant concepts and statistical caliber of data will greatly affect the robustness and consistency of research conclusions. For example, as FAO, the international agency is responsible for compiling data on each country's forest area. In order to overcome the shortcomings of incomplete forest data for some countries and regions, the 1990 Global Forest Resources Assessment was prepared on the basis of population growth projections[22,23]. This means that the FAO data for at least some years are not suitable for analyzing forest transitions between countries using demographic factors as explanatory variables. The quality of data may be an important reason for the contradiction of research conclusions, which needs to be paid attention to in the future research.

Some scholars have discussed the forest Kuznets curve in China. Zhang *et al.*[24] used official statistics of China from 1990 to 2001. The relationship between economic growth and forest area change was studied at the national, regional and provincial levels respectively. Economic growth was the most important factor affecting the change of forest area in China, and China as a whole was in the later stage of inverted U–shaped forest Kuznets curve. However, Zhang *et al.* only considered the linear empirical relationship between the primary term of GDP per capita and economic growth, without considering the influence of the secondary term of GDP per capita. Wang *et al.*[25] made further expansion on the basis of Zhang *et al.* took 1984–2003 as the research interval, introduced the quadratic term of GDP per capita, and found that there was a non–linear relationship between economic growth and GDP per capita, but the research did not support the existence of inverted U–shaped forest Kuznets curve. Liu *et al.*[26] constructed a panel data set of China's forest area and socio–economic variables, and proved the existence of the forest Kuznets curve in China on the basis of controlling the influence of China's forestry system. In addition, Xu[27] compared and verified the relationship between forest area, forest stock and economic growth and they came to the conclusion that there is no forest Kuznets curve in China. Wang[28] added poverty reduction into the study and revised the analysis of forest Kuznets curve based on forest environmental attributes on the basis of considering the contribution of forests to development.

In conclusion, the forest Kuznets curve is not an empirical law, even if the study on the same site, the conclusion will be affected by the study period and research methods. On the one hand, the change of forest area is the result of political, social, economic and cultural factors and economic growth is probably one of the most important factors, but not the only one; on the other hand, forests have not only environmental attributes, but also development attributes. Forests not only provide environmental services, but also play an important role in livelihood, industrial development, and national economic development strategies. The analysis of forest Kuznets curve mainly considers the environmental properties of forest.

3. Forest transformation pathway analysis

In different countries or regions and different periods, the factors that affect the change of forest area are often different. Even the same factors have different effects in different countries or regions, and in different historical periods in the same country or region. In the case that forest Kuznets curve could not provide a scientific explanation for forest transition. Researchers began to analyze the driving factors behind forest transition from a broader perspective, analyze the mechanism of each driving force on forest transition, and develop the theory of forest transition path. Among them, Rudel *et al.*[5] and Lambin *et al.*[29] made the most outstanding contribution to the formation of this theory.

3.1 Forest scarcity path

In some countries, the scarcity of forest products or ecological services provided by forests will prompt the government or forestry departments to implement effective afforestation plans, that is, in response to the negative impact of forest area reduction. It will lead to policy and economic changes in the forestry sector and promote the growth of forest resources[5]. For example, in the 19th century in Europe, especially in the Alps, frequent floods caused by forest destruction in important watersheds forced the recovery and growth of forest resources in the region[30]. In India, the continuous decrease of forest area increases the price of forest products, which in turn promotes the investment in forestry and the growth of forest area[8]. A series of afforestation and ecological restoration projects implemented by the Chinese government to improve the ecological environment are an important driving force for the growth of China's forest area[9,31].

3.2 National forest policy path

The adjustment of forest policies in some countries has played an important role in the transformation of their forests. In addition to the implementation of forest restoration policy caused by forest scarcity, the national forest policy path also includes the adjustment of national land use policy caused by some factors other than the forestry sector, which objectively promotes the restoration and protection of forest resources in the country. Such as policies to modernize the country's economy and land use, and to unite minorities in remote areas of ethnic groups, policies to promote tourism and attract foreign investment through enhancing national image[29] and so on. Bhutan's forest transition occurred during a period of high forest coverage, which increased from 60% in 1990 to 68% in 2005[10]. Bhutan pursues the development model of ecological-centered rather than economic-centered. And environmental protection and sustainable utilization is one of the key goals of Bhutan's development[29]. *The Forest and Nature Protection Act* issued in 1995 established the principles of sustainable forest management, biodiversity conservation and social forestry in Bhutan in legal form[32]. The Bhutanese culture of harmony with nature is reflected in policy implementation, which has contributed to sustainable forest management and forest area growth in Bhutan.

3.3 Economic development path

Economic growth can create non–agricultural employment opportunities and transfer labor force from the primary industry to the second and third industries, and from the countryside to the city. It can reduce the labor force attached to the land, and the pressure on forest resources and promote the recovery of forests[5]. Increased investment in the manufacturing sector has boosted urban wages and reduced the rural workforce. Therefore, in the path of economic development, it is the scarcity of labor rather than the scarcity of forest products or forest services that leads to the recovery of forest resources[29]. In addition, technological progress triggered by economic development may also have a positive impact on forest transformation. For example, the application of agricultural technologies with higher productivity can obtain higher agricultural output with less land, reduce the demand for cultivated land, facilitate the withdrawal of cultivated land with low productivity, and provide conditions for the recovery of forest resources[9]. Conversion from traditional energy sources (fuelwood) to modern energy technologies (electricity, liquefied gas, etc.) will also have a positive impact on forest transformation[29]. Nagendra[33] discussed the positive impact of the application of new technologies on reducing the pressure on forest resources on the change of forest area in Nepal.

3.4 The path of globalization

Compared with the European and North American countries that achieved forest transition in history, the management and change of forest resources in developing countries are deeply influenced by globalization. The increasingly integrated goods, labor and capital markets are the most important international economic environments facing all countries today. Studies on the impact of globalization on forest transformation mainly focus on agricultural and forestry product trade[34], foreign remittance[35], immigration[36], foreign direct investment in primary industry[37,38], neoliberal economic reform and global diffusion of environmental protection concepts[39]. Under the influence of globalization, the destination of population mobility has expanded from the domestic cities to the economically developed foreign countries, and the labor force pursuing high income can remit money from abroad to its backward rural hometown, thus reducing the pressure of livelihood on local land and resources. The development of global tourism also contributes to the spread of ecological protection concepts[34]. Spillover effect is one of the focuses of research, that is, a country or region can transfer its pressure on forest resource development to other countries or regions through immigration or trade of agricultural and forestry products, so as to realize the protection and recovery of its own forest resources[40-42]. For example, during 1987–2006, 39% of Vietnam's forest area recovery was achieved through imports of agricultural and forestry products[43]. The existence of spillover benefits makes it necessary to evaluate the ecological effects of forest transformation in a country with a more cautious attitude.

3.5 Intensification of peasant household land use

In areas dominated by smallholder farmers, the increase in forest coverage may be associated with the expansion of orchards, patches of woodland, agroforestry systems, gardens, hedgerows, and secondary forests on abandoned land[35]. This staggered land use pattern has existed for thousands of years, often formed and maintained at the edges of forests. The ecosystem is multi–functional, connecting the natural forest and the plantation ecosystem[44]. Farmers' motivation may be to reduce their vulnerability to economic and ecological shocks and to maintain their livelihoods by diversifying their ecological and economic sources. This land use intensive approach requires a high level of labor input and traditional environmental management knowledge, which is of great value in protecting native tree species and maintaining biodiversity, but the formed ecosystem value is easy to be ignored in forest resource statistics[34]. Mather *et al.*[4], based on the experience of European national forest transformation, proposed a theoretical explanation for forest transition from the perspective of long–term land use adjustment. It meant that agricultural production will constantly adjust to land quality, farmers and will gradually concentrate their agricultural production on better quality plot through a learning process, even in the absence of technological progress, it is possible to produce equal or even greater yields from less land area, and more poor land can be slowly removed from agricultural production, which can be used for natural regeneration of forests or afforestation.

4. Conclusion and prospect

The concept of forest transformation has only been put forward for more than 20 years, and its theory is still under development. The forest transition theory is mostly based on the experience of developed countries. However, nowadays, developing countries are facing different social, economic and political backgrounds from developed countries in realizing the transition in history. Therefore, more studies on developing countries are needed to supplement the forest transition theory. It is found in this paper that forest transition studies based on environmental Kuznets curve are mostly based on transnational panel data, and the quality and consistency of data need to be paid attention to. In addition, there is still a lack of theoretical innovation on the dual attributes of forest environment and development in this field. In the study of forest transition path, researchers have concluded different forest transition path theories based on the practical development experience of various countries, but the logic and scientific interpretation of the theories need to be improved through further research. Following the development trajectory of forest transformation theory, this paper proposes the following three research directions.

One is the impact of globalization on forest transformation. Existing studies mainly study the impact of globalization on forest transition from the perspective of trade in agricultural and forestry products. However, trade in agricultural and forestry products is only the tip of the iceberg in the process of globalization, and the existing studies have not clearly and profoundly demonstrated the mechanism of globalization on forest transition. Therefore, future studies can try to combine globalization with economic and social changes such as economic restructuring and labor mobility in developing countries, and explore the internal correlation and mechanism between globalization and forest transformation.

Second, in terms of research units, previous studies mostly took the country as the research unit, and research at sub–national levels such as province, county and village need to be further strengthened. National studies mostly use macro social economic statistics and use statistical and econometric methods to explore the important variables affecting the forest transformation process. However, it is difficult to reveal the internal correlation between variables in macro social economic data. The study on forest transition at the meso and micro-levels can make up for this deficiency, and help to reveal the action mode and micro mechanism of various factors on forest transition, so as to have a deeper understanding of the relationship between variables.

The third is the extension of forest transition research to forest quality analysis. Forest transition studies used to focus on the process of forest area change, and it will be of great significance if forest quality analysis can be included in future studies. Forest quality determines the performance of forest ecological functions. The transformation of forest quality and forest quantity into a unified analysis framework for comparative study can reveal the similarities and differences of driving factors of forest area and forest quality change, and better grasp the law of forest resources change.

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Conflict of interest

The authors declare that they have no conflict of interest.

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METHODS

Discussion on the construction of a standard system for forestry cultivation

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ABSTRACT

Based on the analysis of the development and present situation of the standardization of forest cultivation in China and combined with the characteristics of forest cultivation, the main basis, principles and methods of establishing forest cultivation standard system were discussed and put forward. A standard system of forest cultivation was established, which included six sub-systems, namely, forest cultivation foundation, prenatal planning, artificial afforestation, tending management, harvest renewal etc. The ideas and management suggestions for standardization of forest cultivation in China in the future were put forward, such as to establish an authoritative and complete database and a supporting management system.

Keywords: Forest Cultivation; Standard System; Artificial Afforestation

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1. Introduction

With the rapid development of the revolution of IT worldwide and the economic globalization marked by the WTO, standardization permeates almost every area in human activity. Applicable, advanced, scientific and reasonable standard system is the basis of standardization, and most developed countries have formed a relatively perfect agricultural standard system[1–3]. China's forest cultivation standards were basically equivalent to the technical standards of the former Soviet Union before the reform and opening up. Since the 1990s, there has been many progresses in forestry standardization, and many industry standards for forest cultivation have been formulated. With the continuous enrichment of the quantity and content of forest cultivation standards, there are also some problems, such as non-standard writing and outdated content, so it is difficult to form a system. Moreover, the existing forest cultivation standards are repetitive, chaotic and lack of systematization. Therefore, in order to improve the quality and level of forestry production, it is very necessary to construct the systematic and scientific forest cultivation system.

2. The significance of constructing the forest cultivation standard system

Standard system refers to the organic whole of science formed by standards within a certain range according to its internal connection[4]. Standard is the element of the standard system, and also the core of standardization. Scientific and reasonable standard system are conducive to the efficient formulation of standards and standardization activities[5–7]. Forest cultivation standard system refers to related standards in the forest cultivation, and according to its internal connection form the scientific organic whole[7], which is one of the bases for the formulation and revision of relevant standards of forest cultivation, it is the basis to promote the clear hierarchy and reasonable structure of forest cultivation standards, and it is the blueprint covering the existing and expected development standards of forest cultivation. It constantly develops and updates with the development of the technology of forest cultivation.

For a long time, China's forest resources have insufficient total quantity, low quality, uneven distribution and other problems. For a long time in the future, forest cultivation is still the core content of forestry construction. At present, there are some problems in the forest cultivation, such as the non-standard management, the low forest quality and the low survival rate of afforestation. By April 2013, China had promulgated 1,386 forest cultivation standards for seed production, seedling cultivation, afforestation and tending management[8]. Many standards are repeated and crossed, the overall revision of forest cultivation standards is relatively low, and the number of revised standards is less than 10% of the total standards. Standards update slowly, with more than half of the standards used more than five years. Therefore, it is urgent to carry out the standardization research of forest cultivation[7,9,10].

The significance of constructing the standard system of forest cultivation in China lies in: (1) From the macro perspective, it can provide a general outline for standardization of forest cultivation. Under the guidance of this outline, standardization of forest cultivation can be carried out scientifically and orderly; (2) it can provide important technical basis and guarantee for forest cultivation in China, so that each link of forest cultivation can be followed with standards, which can promote the application and popularization of scientific and technological achievements of forest cultivation, improve the quality and benefit of forest cultivation and is also beneficial to establish the trade order of wood products at home and abroad; (3) it is helpful to grasp the status quo and problems of standardization of forest cultivation in China and makes up of the vacancy of the formation and revision of forest cultivation standard system; (4) as the basic research of standardization, the establishment of forest cultivation standard system provide a basis for standardization, such as standard formulation, revision and planning, making it more proactive, forward-looking, being able to drive the development of specific standards, and conducive to occupy the initiative of the global forest cultivation standard system.

3. The present situation and main problems of forest cultivation standardization

3.1 Composition and quantity of forest cultivation standard

Forest cultivation is mainly composed of seed production, seedling cultivation, afforestation and tending management. As of April 2013, the domestic standards for forest cultivation such as seed harvesting, seedling raising, planting and tending issued were 1,386 in total, including 58 national standards, 164 industry standards and 1,164 local standards. Local standards are far more than industry standards and national standards. Among these standards, the number of standards involving seedling cultivation is the largest, reaching 966, including 231 afforestation and camp forest, 109 tending and management, and 80 seed production. Among the 58 national standards, most are the seed production standards, with 24. The others are 13 standards of tending and management, 11 of seedling cultivation and 10 of afforestation[8].

3.2 Revision and standard age of forest cultivation standards

Standards have a certain timeliness. With time passing by and the developed science and technology and practical experience, the original standards may lag behind the current actual situation, and the standard may lose its effectiveness. The validity of China standard is 3–5 years[6]. The overall revision level of China's forest cultivation standards is relatively low, and the number of revised standards is less than 10% of the total. Six of the 58 national standards have been revised, 23 for 164 industrial standards, and 108 for 1,164 local standards.

In terms of the age of the standards, there are 303 forest cultivation standards of more than 10 years, 589 from 5 to 10 years, and 494 less than 5 years. In the 58 national standards, that is 39, 10 and 9 respectively; in the 164 industry standards, that is 44, 16 and 104 respectively; and in the 1,164 local standards, that is 220, 536 and 381 respectively. In China's forest cultivation standard, less than half of the standards have an age that is less than 5 years.

3.3 The main problem of the standardization of forest cultivation

At present, there are very few foreign literatures on forestry standardization, and the forestry standard system is mostly included in the agricultural standard system. Most developed countries have formed a relatively perfect agricultural standard system. For example, implement the standardization of the whole process of agricultural production, and product quality standard becomes the barrier of product import and export; form a standardization system with strong operability and advanced inspection and testing means, and make standardization has legal guarantee. Compared with developed countries, the standardization of forest cultivation in China mainly has the following problems.

3.3.1 The standard system for forest cultivation has not yet been established

Before the reform and opening up, China's forest cultivation standardization borrowed more from the former Soviet Union. The real development started in the 1990s, but there is little basic research on the forest cultivation standard system, and a scientific forest cultivation standard system has not been established. Gu[11] has studied the development and existing problems of forest cultivation standards in China, and put forward the revision plan of forest cultivation technical standards, but it has not risen to the level of guiding standardization from the perspective of the construction of standard system. Standardization itself is a complex and systematic engineering, and forest cultivation has characteristics of public welfare, economic inefficiency and wide area, etc. Li *et al.*[1] pointed out the importance of the construction and basic research of forestry standard system in China by analyzing forestry standardization at home and abroad. Under the guidance of scientific and perfect forest cultivation standard system with the reasonable structure, the standard formulation can be more proactive and forward-looking, the advantages and role of standardization can show out. Therefore, it is urgent to establish a scientific forest cultivation standard system in China.

3.3.2 Standards are not coordinated and unified

The lack of coordination and unity among the existing forest cultivation standards is mainly reflected in the following aspects: Firstly, the standards with the same name consisted of the repeated content is common. Relevant local standards have still been formulated under the situation that the national standards or industrial standards have already been formulated. For example, in the *Afforestation Technical Planning, Tree Seed Inspection Regulations, Tree Seed Quality Classification* and *Main Afforestation Tree Quality Classification*, 5–8 standards with the same name can be retrieved. Secondly, some technical requirements among local standards, national standards, and industry standards are not unified, and there is a phenomenon of repeated definition. Too many standards are easy to make content crossed and repetitive. Therefore, the relevant state departments should establish a standardized and scientific standard system as soon as possible, control the number of similar standards, and guide the formulation of standards.

3.3.3 The standard content is old and poorly written

From the perspective of the revision of forest cultivation standards and standard age, China's forest cultivation standards are seriously old, and especially "aging" phenomenon of the national standard is the most serious, with more than 10 years of standard age accounting for 68.42%. Some of the standards were renumbered, but they were not revised. Poor revision and low bid acquisition rate are the direct causes of standard aging.

Most of the standard texts of forest cultivation with a standard age of more than 10 years do not meet the provisions of GB/T 1.1–2009 *Directives for Standardization Part 1: Rules for the Structure and Drafting of Standards.* Most of these standards do not have covers or their cover are incomplete, the number is not standard, the basic format is not specified, such as preface and note are reversed [12].

Through the above study of the forest cultivation standard system, we can conclude that the forest cultivation standards have features of large quantity, low quality, untimely revision, low bid acquisition rate and uncoordinated standards. Therefore, it is very urgent to build the existing forest cultivation standard system and integrate the existing forest cultivation standards in China.

4. The idea of constructing the forest cultivation standard system

To introduce the whole process of forest cultivation into the standardization, we should focus on the development of forest cultivation and the construction of modern forestry, follow the basic principle of standardization of "unification, simplification, coordination and optimization", and "scientific, systematic, coordinated, advanced, compatible, advanced and scalable" principle[5,6]. The author believes that the construction of the forest cultivation standard system in line with the market demand in China, as the technical guarantee to guide forest cultivation, should follow the following points in addition to the compilation requirements of the general standard system.

4.1 Construction principles

4.1.1 The principle of comprehensiveness

The standard system of forest cultivation should include the various technologies and concepts involved in the whole process of forest cultivation and those that need to be coordinated and unified in their management, so that each link can be based on standards.

4.1.2 Coordination principle

The standards among the forest cultivation standard systems, within the standard system and outside should be coordinated to avoid the inconsistency of terms and technical parameters and disharmony of standards, such as the duplication, crossover and contradiction,.

4.1.3 Hierarchy principle

On the one hand, the standard system consists of different levels of national standards, industry standards, local standards and enterprise standards. On the other hand, the level reflects the scope of application of the standards. The standards with a large scope of application are at the top level of the standard system, while they are at the lower level when opposite is the case, and the specific custom-made standards are at the lowest level. Forest cultivation can be divided into different stages according to the timeline, and the corresponding standards are formulated for each stage. Different stages constitute different levels of the standard system. The standard system with clear framework and reasonable structure divides each standard into the appropriate level, so that each standard can restrict and complement each other, and they can be coordinated and unified.

4.1.4 Principles of sustainable development

The standard system of forest cultivation should have a mechanism to gradually develop over time. The forest cultivation standard system should be comprehensive, dynamic, prospective, and has timeliness. It should reflect the current level of science and technology and industry development, and fully consider the future development, especially forest cultivation technology and management methods, leaving enough space for the new standard.

4.2 Building basis

(1) Standardization Law of the People's Republic of China, Regulations for the Implementation of the Standardization Law of the People's Republic of China, Interpretation of the Provisions of Standardization Law of the People's Republic of China, Measures for the Administration of National Standards, GB/T 13016–2009 Principles and Requirements for Preparing Diagrams of Standard System, GB/T 1.1–2009 Directives for Standardiza-

tion, Part 1: Rules for the Structure and Drafting of Standards etc.

(2) Existing domestic and foreign forest cultivation standards. This is the basis of the systematic construction of the standard system of forest cultivation in China.

(3) The development status of forest cultivation technology in China. The standard system constructed should cover the different stages of the current forest cultivation and development, and the specific standards should meet the needs of practice.

(4) Research results of forest cultivation technology in China. Promot the application of high and new technology through standardization, and grasp its development direction which is conducive to construct a standard system with more room for development.

(5) Principles and methods for the construction of standard systems of relevant forestry and other industries.

4.3 Construction method

The construction of the standard system is generally first to regard the research object as a system, and then use specific methods according to the characteristics of the system to build the standard system. The whole process reflects the ideas and views of the system engineering. Common methods of building standard system include hierarchical analysis method, classification method, 3-dimensional coordinate method, modular method, and framework construction method, etc. Refer to domestic research on other standard systems, especially on the forestry industry standard system, combined with the complexity and systematization of forest cultivation itself, the author thinks that building forest cultivation standard system can use the system engineering method. By analysis of every standard of forest cultivation technology system and the forest cultivation process, we carry out systematic analysis of standard elements of forest cultivation, establishing a scientific and reasonable forest cultivation standard system combined with classification, hierarchy and process method[13–18].

5. Establish a standard system for forest cultivation

5.1 Composition and structure of the forest cultivation standard system

According to the above methods, after all the standards of forest cultivation are analyzed and reasonably sorted according to the forest cultivation, the author designs the forest cultivation standard system in China based with hierarchical and process analysis (see **Figure 1**). **Figure 2** shows the hierarchical framework of the structure of the forest cultivation standard system. The forest cultivation standard system is divided into six sub-systems: basic subsystem, prenatal planning subsystem, artificial afforestation subsystem, tending management subsystem, harvest update subsystem and other, Under the subsystem, it is divided into several subsystems, and then according to the characteristics and actual situation of the subsystem, the subsystem can be further classified, and the subsystems and classes are specific standards[3].

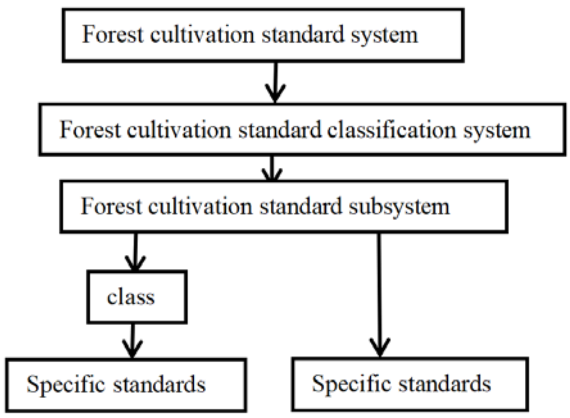

Figure 1. The hierarchy diagram of forest cultivation standard system.

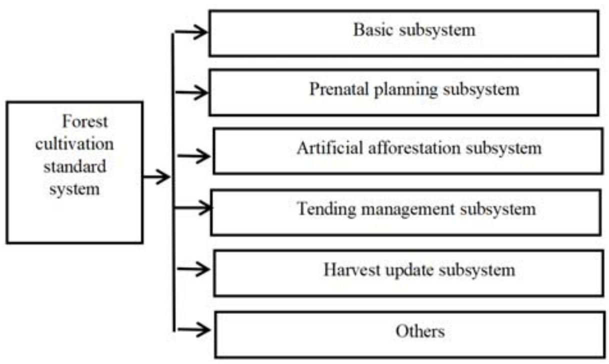

Figure 2. Hierarchical framework diagram of forest cultivation standard architecture system.

5.2 Hierarchical framework of each subsystem

The basic subsystem framework is shown in **Figure 3**. The subsystem of codes and terms should include specific standards, such as the basic terms of forest cultivation and the code of forest resources. The subsystem of the method should include the specific standards, such as forest site classification and type, forest site quality evaluation, forest classification, forest division, forest industry division system and nomenclature, determination of stand density and its relationship with forest formation, afforestation planning, design and construction, individual growth of forest trees, growth of forest groups, etc. The subsystems such as digitalization, management system and information dissemination system etc. should also formulate corresponding specific standards to regulate the contemporary forest cultivation under the background of informationization and economic globalization.

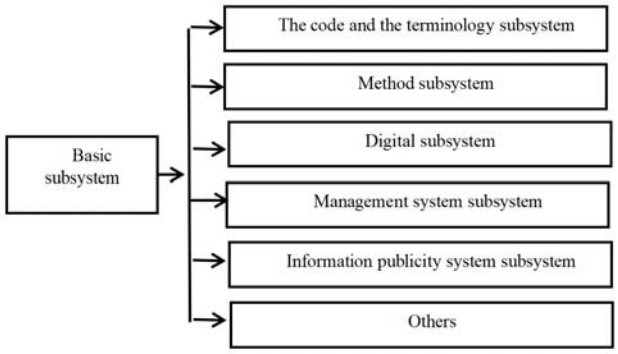

Figure 3. Tomographic frame diagram of the basic subsystem structure.

Prenatal planning in forest cultivation standard system is an important stage of forest cultivation, whose main technology includes site survey, tree species selection, forest species planning, seed production and seedling cultivation. The hierarchical framework of the subsystem structure of prenatal planning is shown in **Figure 4**. The subsystem of site investigation and selection evaluation mainly includes specific standards, such as site quality evaluation, afforestation species selection and forest species planning, etc. The seed production subsystem includes specific standards, such as seed division, classification, grading, inspection, seed processing, storage, transportation, collection, dormancy and bud promotion, improved seed base, improved seed breeding, etc. The nursery cultivation subsystem includes standards, such as nursery construction, sowing seedling, cutting seedling, container seedling, seedling nursery, seedling quality evaluation, etc. Each subsystem also contains specification standards in technical processes.

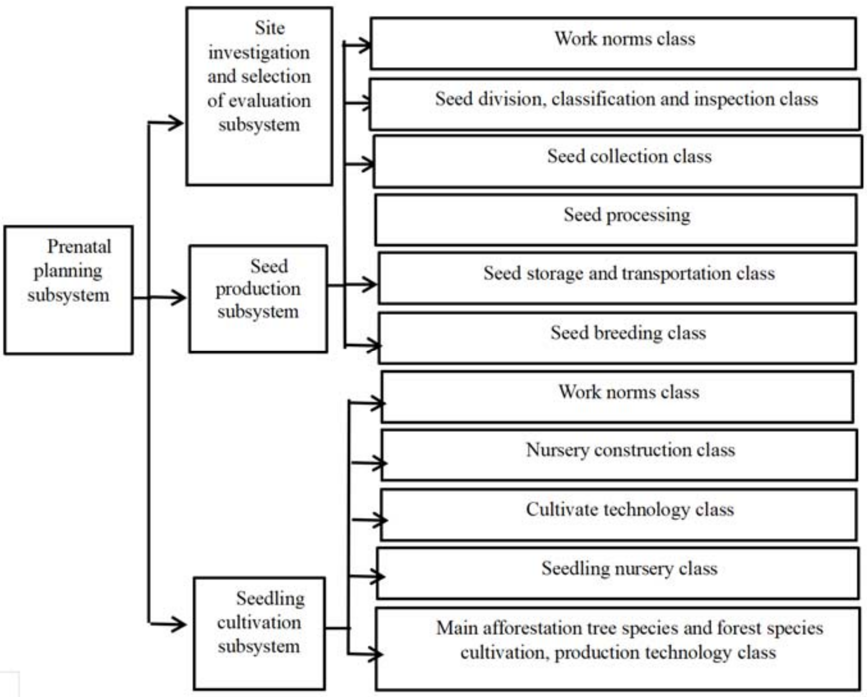

Figure 4. Frame diagram of subsystem hierarchy of prenatal planning.

The main technical work of artificial afforestation is natural enclosure, afforestation land cleaning and soil preparation, planting site allocation, seedling planting or planting and afforestation technology. The standard subsystem of artificial afforestation is mainly composed of four sub-systems: work norms, forest group structure regulation, forest land growth environment control and afforestation method (see **Figure 5**). The control subsystem of forest community structure includes artificial forest afforestation technology and mixed forest cultivation technology; forest growth environment control subsystems are mainly forest growth environment standard, etc.; afforestation subsystem includes specific standards, such as live afforestation technology, afforestation technology and subdivision afforestation technology.

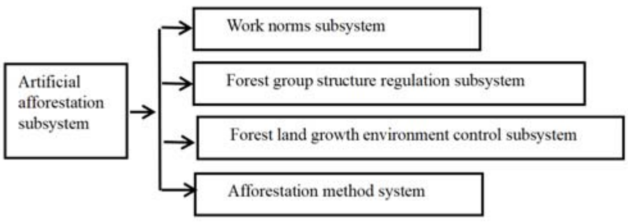

Figure 5. Frame diagram of subsystem structure of artificial afforestation.

Forest cultivation and management should constantly adjust the relationship among trees and between trees and the environment to ensure the growth of young trees according to the expected requirements. Therefore, the forest cultivation and tending management system includes six subsystems: work norms, forest land management, forest tending management, tending and felling (intermission), forest division transformation and management model (see **Figure 6**). Woodland management subsystem includes specific standards, such as forest fertilization, forest land reclamation and planned burning, etc.; forest tending management subsystem includes tree pruning, cutting of tree buds and tillers; tending and felling (intermission) subsystem includes light tending, growth tending and tending and felling (intermission) period; forest reform subsystem includes low-value plantation transformation technology, secondary forest management and transformation technology; management model subsystem includes various forest management model standards.

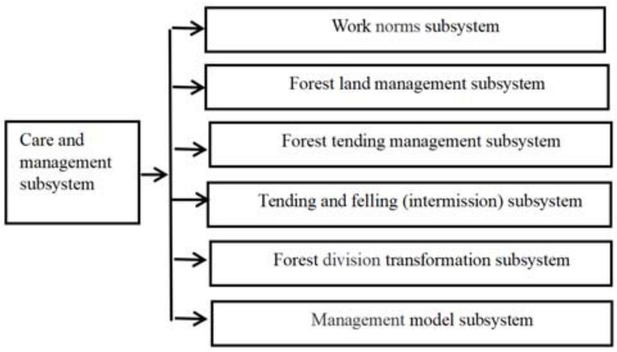

Figure 6. Framework of care and management subsystem structure.

The harvest renewal of the forest directly affects the renewal of the next generation and the sustainable development of the forest. Therefore, the forest harvest renewal is also a subsystem of the forest cultivation standard system, mainly including two subsystems of working norms and harvest methods. The harvest method subsystem includes the specific standards of different-age trees selective felling, complete felling of same-age trees, gradual felling of trees of relative same-age, updating felling of overmature old trees, dwarf trees operation method, middle trees operation method and post-disaster forest rescue, etc.

In addition to the forest cultivation standards mentioned above, some established forest cultivation standards cover the main process of forest cultivation, with different technical regulations of forest species for afforestation and engineering standards, which cannot be classified into the above 5 categories. There are also some forestry engineering standards, such as natural forest protection project, grain for green project, mountain closure and forest conservation project, and nature reserve project, etc., which are put into the sixth forest cultivation standard subsystem (see **Figure 7**).

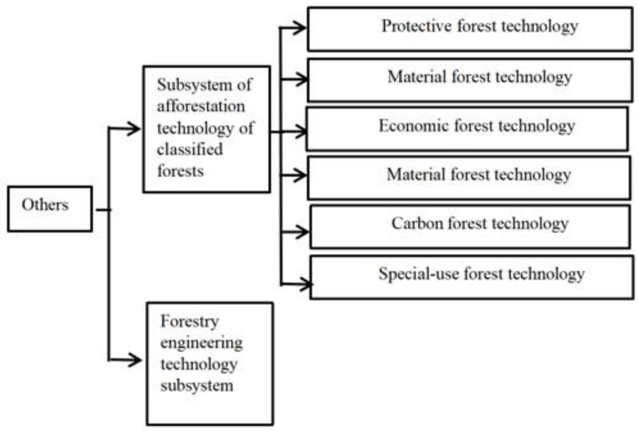

Figure 7. Other sub–architecture hierarchies.

6. Suggestions on the implementation of forest cultivation standard system

The standard system of forest cultivation established in this paper basically covers every link of forest cultivation production, which accords with the current development of forest cultivation and the trend of standard development. On the implementation of the standard system, some suggestions were put forward below.

6.1 Extensively carry out basic research, establish an authoritative and complete database

Timely include standard texts, and establish an authoritative and complete forest cultivation database for readers to use. The establishment of the database should be based on evidence, so as to facilitate information inquiry, duplicate check, etc. Standardization is a continuous and spiraling movement including the formulation of standards, the issuance of standards, the implementation of standards and the supervision of the implementation of standards, of which the core is the standard, the key link is the implementation of standards[4]. The authoritative and transparent standard database is helpful for the standard users to implement the standard and promote the standard. At the same time, it will digitize the standard information of forest cultivation in China, and more directly reflect the development and status quo of the current standard system of forest cultivation, which is beneficial to improve the standard system of forest cultivation and enhance the level of standardization.

6.2 Through the research of the standard system, drive the formulation and revision of specific standards

According to the forest cultivation standard system, rectify the existing national standards, industrial standards and local standards, merge or abolish some overlapping or conflicting standards, and revise the outdated standards. On the basis of the standard system of forest cultivation, we should check and fill in the gaps of the existing standards, accelerate the formulation and revision of specific standards, such as the basic standards and forestry ecological construction, forest tending management, forest harvesting and utilization, energy forests, etc. and realize the standardized production of all links in the whole process of forest cultivation as soon as possible. At the same time, we should adopt international standards and foreign advanced standards to formulate and revise our forest cultivation standards, and constantly improve the standard system to make the levels of the standard system clearer and the structure more balanced and reasonable.

6.3 Establish a supporting management system

On the one hand, the forest cultivation standard system not only includes the forest cultivation technology standards, but also should cover various things and concepts that need to be coordinated and unified in the forest cultivation technology and its management. A complete forest cultivation standard system should include the standards of management system and work norms. On the other hand, standardization is a complex system. To make the system operate orderly, we must establish an effective management system and operation mechanism. First, establish a full-time forestry standardization management organization; second, it should be clear to avoid the phenomenon of multiple forestry standards and separate governance; third, establish a standardized promotion system, increase the distribution and allocation of standards, and conduct extensive publicity and guidance through various news media, such as the network, radio, television, newspapers, etc.

As the core of forestry construction, forest cultivation is a complex and systematic engineering. This paper uses the thought of standardized system engineering to study and construct the forest cultivation standard system. On the basis of studying and analyzing forest cultivation technology system and each standard of forest cultivation, the framework of forest cultivation standard system designed basically covers the whole process of forest cultivation. As the research of forest cultivation standard system involves a wide range of areas, complex content and large workload, there are still many problems and contents to be studied. In the future, we should also pay attention to the research of forest cultivation standard system, forest cultivation specific standard and forest cultivation standard system model, etc.

Conflict of interest

The authors declare that they have no conflict of interest.

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REVIEW ARTICLE

Rethinking forest management issues in China in the context of the new era

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ABSTRACT

The contradiction between the ability of forestry that provides high-quality and abundant forestry products and good ecological services, and the demand for high-quality and diversified forestry products and service in order to meet the people's rapid growing, has become the main contradiction faced by forestry development in new era. Since the area of forest resources in China is restricted by the expansion space, expanding the effective supply of forestry must mainly depends on the improvement of the quality and structure of forestry resources. Therefore, the focus of promoting forestry development is to comprehensively improve the level of forest management in the new era. Based on the analysis of the causes for the low level of forest management, it is proposed that forestry development in the new era should focus on the positively stimulating and strengthening the human capital development, etc., which come from the current following aspects: innovating forest management theory and model, clarifying the relationship between government and market.

Keywords: New Era; Forestry Development; Forest Management

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1. Introduction

Since the reform and opening up, China's forestry development once fallen into the dilemma of resources and economy. After years of afforestation and large-scale construction projects, the area of forestland and the total scale of forest resources in China have grown rapidly, and the forest resources have stepped into the track of sound development. Data from the Ninth National Forest Inventory (2014–2018) showed that China's forest area increased from 122 million hm2 to 220 million hm2 in the early days of reform and opening-up, and the forest coverage rate increased from less than 13 % to 22.96%[1].

The report of the 19th CPC National Congress indicated clearly that socialism with Chinese characteristics has entered into a new era, which is the new historic orientation in China's development. As the largest green industry in the national economy, forestry shoulders the dual tasks of guaranteeing the supply of basic forest products and ecological services. The new features of socialism with Chinese characteristics in the new era put forward new problems and requirements for forestry, which will definitely affect and determine the direction of forestry development in the future. On the contrary, forestry development must meet the requirements of building a strong, democratic, civilized, harmonious and beautiful modern socialist country on the basis of comprehensively winning the well-off society.

For forestry, the connotation and extension of its concept are closely related to the changes of social and economic development level and people's living needs. In the past, forest was mainly regarded as a source of wood. At present time, society gets down to paying attention to a series of ecological benefits and social services provided by forest[2]. The report of the 19th CPC National Congress clearly pointed out that the modernization we want to build is one in which human beings and nature live together peacefully. In 2019, China's GDP reached 99.1 trillion yuan, and its per GDP has exceeded 10,000 dollars[3]. The level of people's income has significantly improved, and the economy has stepped into a stage of high-quality development from high-speed growth. Income growth has motivated the transformation and upgrading of the consumption level and structure, and people's living requirements have changed from satisfying the average quantity in the past to pursuing a better life with higher standard and quality. The way of economic improvement requires to concentrate on harmonious development of human beings and nature. Therefore, forest, the largest terrestrial ecosystem on earth, is an important force to realize harmonious symbiosis between man and nature. It should not only meet people's demand for material products such as high-quality wood and other green non-wood forest products provided by forests, but also create and provide ecological and spiritual services such as good ecological environment, recreation and entertainment, health preservation, culture and technology and other ecological and spiritual services, so as to adapt to the transformation of the principal contradiction facing Chinese society into the contradiction between unbalanced and inadequate development and the people's ever-growing needs for a better life.

After decades of ecological forestry construction, the total amount and quality of China's forest resources have increased, but there is still a big gap from the requirements of building a beautiful China with sufficient quantity, reasonable distribution and ecological stability of forest ecological system[4]. Therefore, the main contradiction facing forestry will also turn into the contradiction between forestry's ability to provide high-quality and abundant forest products and good ecological services, and meeting people's rapidly growing demand for high-quality and diversified forestry products and services. On the basis of maintaining the steady growth of the total amount of forest resources, we should pay more attention to improving the quality and structure of forest resources, excavating and effectively bringing into play the various functions and benefits of forest ecosystem, which are supposed to become a new economic growth point of forestry.

2. Forest management level is the key to the development of forestry in the new era

Having a stable, healthy and sustainable forest resource system is the fundamental guarantee for increasing effective supply, improving supply quality, improving supply structure and enhancing comprehensive benefit. The fundamental task of forestry supply side structural reform under the guidance of market demand is to expand the effective supply of products, the main direction is to improve the quality of product supply, and the core link is to optimize the product supply structure[5]. However, it is undeniable that the realization of all these above must be based on the forest ecology and production system with rich resources, stable quality and optimized structure. Improving the quantity and quality of forest resources is the fundamental and key to ensure the effective supply of forestry. National Forest Management Plan (2016–2050) clearly points out that the problems of insufficient total amount of forest resources and low quality and weak function of forest resources are the shortcomings of China's modern forestry construction, among which the low quality, low efficiency and fragile function of forest resources are the most prominent problems of China's forestry[6].

The shortage of total forest resources will be an objective long-term problem. China's per capita forest area is only 1/4 of the world's average level, and the quantity of forest resources is relatively insufficient. On the one hand, due to the limitation of land resources, the expansion capacity of forest resources is strictly restricted, and there is not much room for growth. On the other hand, based on the analysis of population growth and forest area growth potential, even if forest coverage increases by 2050 and stable above 26%, China's per capita forest area will still be at a low level. Therefore, the relative shortage of total forest resources is determined by our country's actual national conditions and forest conditions, and it is difficult to change significantly in the short and medium term.

Since the area of forest resources is restricted by the expansion space, the expansion of effective forestry supply must depend on the improvement of forest resources quality and structure. Since the reform and opening up, the growth rate of China's forest resources is fast. However, it is undeniable that while pursuing the increase of the number of resources, the quality improvement and structure improvement of forest resources have not attracted the corresponding attention. The data from the Ninth National Forest Inventory and the National Forest Management Plan (2016–2050) shows that the forest stock in China is 89.79 m^3/hm^2, which is 69% of the world average. The average annual growth of the forest was 4.23 m^3/hm^2, which is only 53% of the average level of forestry developed countries. The value of forest ecological services has not been fully exploited. The annual value of main ecological services provided by each hectare of forest is only 61,000 yuan, only equivalent to 40% of that in Japan and other countries. In the actual stands, only 31% of the total forest yield per hectare reached 50% or more, while 43% of the total forest yield per hectare did not reach 20%. Although China has the largest area of plantation forest in the world, there is still a big gap in the quality of plantation forest management and a large space for structural optimization. Sheng[7] studied the quality of artificial forests in China and pointed out that the most prominent problem of forest quality in China was productivity. The stock per hectare of main artificial afforestation tree species in China is far lower than that of similar tree species in Japan. Chinese fir is less than a quarter of that in Japan, larch is less than a third, and their actual annual growth is only 1/4 and 1/2 of the standard of fast growing and high yield forest in China respectively. At the same time, the problems of planted forest exist as followings: coniferization and pure forestry issues, mixed forests account for only 15% of plantation area, and serious continuous cropping and lack of scientific management after forest.

It can be seen that there is still a big gap in the overall quality and structure of China's forest resources, whether it is the ecological service value provided by forests or the timber supply capacity, and there is a huge space for improvement. Improving the quality and structure of forest resources is closely related to the level of forest management. The main reason for the low quality and structure of forest resources in China is the low level of forest management. "The forest quality is not high, which is the most prominent problem of our country forestry. To improve forest quality, the key lies in strengthening forest management[6]." It can be seen that the low level of forest management is the biggest shortcoming that restricts the effective supply, quality improvement and structure optimization of forestry in China. It should become the most important task of forestry development in the new era to strengthen forest management. Only good forest management can accurately enhance and improve the quality and structure of forest resources, improve the effective supply capacity of forest products and services, and effectively meet people's growing demand for forest goods and services.

3. Analysis of the reasons for the low level of forest management in China

Generally speaking, the poor quality and structure of forest resources in China is the result of not paying attention to forest management for a long time, and the enthusiasm and creativity of forestry management subjects having not been brought into full play. The restrictive factors that cause the low level of forest management are mainly reflected in the supply side of forestry. Some scholars mostly put forward from the technical level how to strengthen forest management[7-9]. In fact, forest managers should also seriously reflect on and break through the constraints of institutional and policy arrangements.

3.1 Long-term "harvesting and planting but not management" policy guidance

Since the establishment of the New China, the transformation of China's forestry supply structure can be approximately divided into two stages: The first stage is from the establishment of the new China to the end of the 20th century. The main purpose of the forestry is to pursue wood production and attach importance to the economic value, with emphasis on harvesting rather than manufacturing as the main policy feature. The second stage is that since the 21st century, the main purposes of forestry are to focus on ecological construction and to attach importance to ecological value. The main policy features of forestry are forbidding cutting and encouraging afforestation. The forestry policy orientation of these stages is too biased towards the two extremes of "harvesting" or "planting", while ignoring the key intermediate links in the supply of effective forest products and services–forest management and maintenance, making the technology of this link backward and investment insufficient. Although the formulation of the policy was influenced by the historical and social economic conditions at that time, as well as the shortage of capital and talents, the long-term "harvesting and planting but not management" mode of forestry production and management has resulted in the overall poor quality and structure of China's forest resources.

3.2 Forest management guidelines that do not attach importance to the micro practical level

Developing and strengthening forest scientific management needs modern advanced forest management theory and management technology as guidance. However, the research on this aspect in our country is relatively insufficient. Many researches focus on tracking foreign forest management theories and management models, such as forest multi-function theory, forestry division theory and near-natural forestry management theory, etc. However, the construction of forest management theory and technology system based on the national conditions of China's forest is relatively lagging behind, and the theoretical guidance often fluctuates. *National Forest Management Plan (2016–2050)* put forward the multi-functional forest management technology system on the basis of establishing multi-functional forest management theory as the guiding management thought. However, there is still a lack of planning and management guidelines at the regional and specific forest level, which makes it difficult forestry micro-managers to operate in practice. Technical guidelines and standards for the practical operation of specific forest are still in need of construction and improvement.

3.3 Forestry science and technology promotion ability is seriously inadequate

The key to weak ability of forestry science and technology promotion lies in the lack of a perfect forestry science and technology promotion system. The weakest link of forestry science and technology extension system is the serious shortage of talents in forestry departments at the grassroots level. Extensive operation with low benefits for a long time, rigid system and mechanism, changeable policies and the poor working condition of grassroot level unit of forestry have led to a serious brain drain and difficulties in bringing in professionals in the forestry field, especially in the grassroots forestry sector. Scientific and efficient forest management cannot be achieved without the professional personnel according to the national macroscopic forestry management goal and related standards, guidelines and so on, taking into account the local or the unit's forest resources status, geographical location, vegetation characteristics, operating status and management objectives, such as formulating scientific and reasonable forest management strategies, planning, and technical operating procedures at the forest level, and provide classification guidance for specific implementation. However, in reality, there are many problems such as serious aging of employee's age structure, generally low cultural quality and shortage of professional and management talents in forestry departments and forestry management units at the grassroots level. This leads to a serious break in the link of extension system of forestry science and technology. It is difficult to promote and implement the new mode and technology of modern forest management, and it is hard to form and develop new ideas, new formats, new technologies and new modes of forest management within the forestry.

3.4 Ineffective market incentives, lack of enthusiasm of forestry business entity

It is very important to clarify and definite the relationship between government and market, and to encourage the voluntary behavior of ry business entity and the active participation of social capital. Forest management cannot merely rely on government investment and coercion. Under the new situation of economic development, it is very difficult to significantly increase financial input, and forestry input must depend on the market[5]. It has been proved that government support and financial investment alone cannot meet the demand for capital and human resources in intensive forest management. Therefore, it is necessary to pay attention to the decisive role of the market in realizing the efficient allocation of forest resources, good quality, reasonable structure and coordinated function of forest supply pattern. The transformation of forest management from extensive management to scientific intensive management requires more energy, material and financial resources, and continuous investment of human and capital from forestry business entity. Only forest intensive management can bring more substantial income, can forestry management subjects be motivated and attracted to voluntarily change the management patterns, actively absorb social investment and talents, and successfully realize the upgrading and transformation of forest management. However, in practice, too much emphasis is placed on the attributes of public goods and public welfare of forestry, while the attributes of private products and economic characteristics of forestry are ignored. The government gives too much administrative control and direct intervention to forestry production and management, making it difficult for the automatic adjustment function of market resource allocation to full play its role, and inhibiting the initiative and enthusiasm of forestry business entity to carry out forest management.

4. Focus of comprehensively improving the level of forest management

The development of forestry in the new era requires comprehensive improvement of forest quality and systematic optimization of forest structure. There is still a great potential for the development of forest resource quality in China[10,11], and forest management is the fundamental method to improve forest quality[7]. Cultivating a healthy, stable and well-functioning forest ecosystem is the fundamental purpose of modern forest management, as well as the basic way to improve the effective supply of forest products and services and meet people's demand for a high-quality life. This needs to start from the in-depth improvement of forest management level and capacity, and lead and promote the development of forestry in the new era.

4.1 Re-examine and establish the forest management theory and model with Chinese characteristics

Effective forest management practice must be guided by the advanced forest management theory in line with national conditions and forest conditions. At present, China's forest management is basically guided by the forest classification management theory established in the early 1990s, which is of basic guiding significance from the overall situation. However, as China has a vast territory, plus there are huge differences in natural conditions and social and economic conditions across the country, so this inevitably results in distinction in distribution, growth status, abundance of forest resources and diversification of management objectives. The practice of classified management should not fall into the "two extremes" of single pursuit of economic benefit or ecological benefit for a certain forest. Generally, China is a country lacking of forests, and the per capita water level of forest resources is low. If the classified management mode is strictly followed which means the forest is cultivated solely for wood or protected purely for forest ecological benefits, it is not conducive to the full play and utilization of the multifunctional benefits of the forest in the whole growth period. At the same time, with the improvement of people's income and living standards, the demand for forest recreation, health care, culture and other close-to-nature activities is increasing. Therefore, on the basis of overall classified management, it is necessary to emphasize the ecological principle of forest resource cultivation and close-to-nature management, and pay attention to the full utilization of all functions and values of the whole growth cycle of forest. This should be the adjustment direction of the theory and mode of forest management in China.

4.2 Deepening the reform of forestry system and mechanism and giving full play to the role of market resource allocation

The key to effective system supply lies in straightening out and handling the relationship between the "decisive role" of market and the "better role" of government. It has to be said that compared with other industries, forestry has a long operation cycle and has its particularity in the reasonable positioning of the relationship between government and market, which is mainly reflected in the public welfare characteristics of forestry and has significant positive externalities. According to economic theory, the market mechanism has "failure" in forest resource allocation, but it cannot deny the key role of the market in forest resource allocation, and be completely handled by the government.

The reform and innovation of forestry management system and management mechanism must first make clear the position and function of market in forestry resource allocation. "Government action" is a necessary condition for "efficient market". The key of the government action is to intervene moderately, prevent and dissolve the "market failure", guide and standardize the market behavior, stimulate the enthusiasm and innovation vitality of the market entities to invest and manage forestry. Secondly, the "action" of the government should be reflected in the scientific planning and formulation of forest resources quantity growth, quality improvement and related ecological protection standards and targets for each forest management unit, and strict monitoring and supervision. Specific forest management behavior can be carried out by introducing strategic investors and professional operators into the market through exploring various effective forms. Finally, as rational units, forestry management and investment subjects pursue the maximization of forest management income. Therefore, only when there are sufficient economic benefits to be derived from improved forest management, will there be a real incentive for investors and operators to participate voluntarily and take corresponding positive actions. It is necessary to scientifically determine and clarify the best meeting point of forest protection and utilization in forest management, and apply it in the forest protection, protect the forest in the utilization, accelerate the integrated development of primary, secondary and tertiary industries, and promote the protection and utilization of forest resources to complement each other and grow together.

4.3 Perfect positive incentive policies and measures to stimulate the enthusiasm of forestry business entity to carry out forest management

Fundamentally, advanced forest management concept, modern forest management technology and good forest management measures are inseparable from the effective allocation of human resources and capital and other elements. The "market failure" of forestry comes from its positive external effect. The principle of the internalization of external demand and the policy thinking of solving the "market failure" of forestry should be adjusted to the afforestation or good forest management behavior such as positive incentives like subsidies, tax (or cost) reduction or cancellation, rewards, rather than just emphasize the negative incentives such as the use of administrative controls and imposing of punitive taxes and fees. The government should deepen the reform of system and mechanism, perfect the positive incentive policies and measures, encourage the enthusiasm and creativity of forestry management subjects and investment subjects, and guide them with the goal and direction of decision-making in line with government policy objectives.

On the one hand, for commercial forest and private-operated forest management, it is necessary to clarify the scope of government control and the method for controlling it in place. In addition, intensive efforts should be made to reduce or eliminate some unnecessary forestry policies, regulations, taxes fees etc., which may influence the enthusiasm of the market entity to invest and manage forestry. More positive incentives should be adopted, such as fiscal subsidies, incentives, government purchase or compensation for forest ecological service and strengthening of social services. At the same time, the entity of forestry operation should be guided and encouraged to take measures such as cooperation, forestland circulation, and strengthening the integration of primary, secondary and tertiary industries, to expand the scale of operation, extend the industrial chain, and effectively expand the profit space of forestry operation. On the other hand, we should pay attention to the efficiency and effect of positive incentive measures. In reality, there are market actors who adjust their decision-making goals and behavior directions to obtain as much government subsidies as possible, regardless of whether they can achieve the policy goal expected by the government[12]. This may lead to some forestry management departments, local governments and state-owned forest farms and other forestry operators to generate inert ideas, i.e., "waiting, depending and demanding", not thinking about progress and innovation, but focusing on how to get more government subsidies and preferential policies. Deepening the reform of forestry management system and operation mechanism should not only emphasize and stay at the level of increasing financial support. "The government" has to take action according to objectives management as the policy guidance, strict forest management standards and management objectives, clear responsibility parties, strengthen the dynamic monitoring and regulation of resources.

4.4 Strengthen the cultivation and development of human and capital resources and enhance the new driving force of forestry economic growth

Forestry development in the new era must adapt to the change of social demand and accelerate the adjustment of forestry supply structure with new industries, new technologies, new business forms and new economic growth drivers, for which talent is the key. In view of the shortage of forestry grass-roots professional and management personnel, the government should make great efforts to further improve the cultivation and development of human capital. Firstly, establishing a special training funds and cooperate closely with universities and research institutes to develop a detailed training plan and re-education for forestry management and technical staff, including those from state-owned forestry farms and grassroots forestry bureaus. Secondly, establishing a publicly-funded targeted training program in conjunction with forestry universities or other forestry-related majors in other universities for forestry students to prepare and deliver technical extension personnel to the grassroots level in state-owned forest farms or townships. Thirdly, improving and perfecting forestry technology popularization system. This should not only intensify cultivation and introduction of forestry professionals at the grass-roots level to strengthen the construction of practical platform, but also should use the modern communication technologies such as internet to build technology service network. Fourth, the establishment of a regular system of science and technology services to the countryside. Researchers from research institutes and universities at all levels are encouraged to go down to the forest, go to the countryside, regularly or as needed from time to time to carry out scientific and technological guidance and advisory services.

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Conflict of interest

The author declares no conflict of interest.

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REVIEW ARTICLE

Characterization of a forest in the center west of the province of Chaco, Argentina

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ABSTRACT

This work was carried out with the purpose of generating ecological and silvicultural information oriented to sustainable management. The horizontal structure was evaluated using the importance value index of Curtis and Macintosh, the vertical structure using Finol's methodology. Through the sociological position index, the percentage natural regeneration and the extended importance value index were estimated in order to infer the permanence of the forest ecosystem. The floristic composition was represented by species of the families *Anacardiaceae*, *Apocynaceae*, *Fabaceae*, *Santalaceae*, *Rhamnaceae*, *Sapotaceae*, *Simarubaceae*, *Ulmaceae*, *Zygophyllaceae*, *Capparidaceae*, *Borraginaceae* and *Achatocarpaceae*. In the horizontal structure, the species with the highest rank was *Acacia praecox*, followed in order of importance by *Schinopsis balansae*, *Aspidosperma quebracho blanco* and *Prosopis kuntzei*. According to sociological position, Acacia praecox was the most representative species, followed by *Patagonula americana*, *Schinus longifolius*, *Proposis kuntzei* and *Aspidosperma quebracho blanco*. The species with the best regeneration values were *Achatocarpus nigricans* and *Acacia praecox* in the shrub layer and *Patagonula americana* in the tree layer. The extended importance index consolidated the category of *Acacia praecox* in the community and gave a better category to *Schinopsis balansae*, *Aspidosperma quebracho blanco*, *Prosopis kuntzei* and *Patagonula americana*.

Keywords: Chaco Park; Native Forest; Vertical and Horizontal Structure; Regeneration

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1. Introduction

In recent times, the characterization of the Chaqueño Park has been profoundly challenged, while numerous ecological studies have recently been generated. Although the floristic, diversity and dynamics knowledge base is increasing, it is still fragmentary and too regionally concentrated[1]. Among the physiognomic formations of the Argentine Chaco Region, different types of forests characterized by the dominance of Schinopsis species stand out, such as the quebracho colorado chaqueño (*Schinopsis balansae*) and the quebracho colorado santiagueño (*Schinopsis lorentzii*), characteristic of the Humid Chaco and the Semiarid respectively. The distribution area of these two species overlaps in a SO-NE direction from the SE of the Province of Santiago del Estero and NO of Santa Fe towards the center of Formosa. However, their coexistence in a strict sense is rare[2] and it is likely that this is the case since when following the route of National Route No. 16, the quebracho colorado chaqueño is no longer observed near the town of Los Frentones. There is a clear need to gather detailed information on these ecosystems, unique on the planet, which are modified by the constant action of man, increasing the degree of fractionation or subjecting the forest to continuous pressure as a result of exploitation without criteria.

As Giménez *et al.*[3] state, the growing interest in biodiversity is in the first place, due to the abundance of plants and animals, which is of incalculable value. It is the natural heritage of a country, the result of a long process of evolution that has occurred over time and is unrepeatable. Franklin and Armesto[4] add that the productivity and biological diversity of forest ecosystems depend to a large extent on the structural complexity of forests. Based on these arguments, it is logical to think that it is necessary to know the structure of the forest under study and its ability to regenerate in order to have better information that will help facilitate decision-making for the responsible management of native forest stands.

The fact that Argentina's native forests have been subjected to severe degradation processes does not mean that they have lost their potential; on the contrary, they are forests that can be recovered under silvicultural practices aimed at sustainable management[5]. It is an arduous task to turn the vision of effective regeneration of forest parts into reality, which requires systematizing the existing information and guiding research to find what is lacking. Gadow *et al.*[6] affirms that forest resources fulfill various functions for society and consequently it should be a condition that management is carried out on a scientific basis, which is a difficult challenge. In this perspective, Giménez *et al.*[3] believe that sustainable management is a pillar for the conservation of biological diversity. There are publications aimed at providing a basis for the sustainable management of forests in the Chaco park, such as that of Araujo[7], Araujo *et al.*[8], Araujo *et al.*[9], Brassiolo[10], Giménez *et al.*[3], Hampel[11], Tálamo *et al.*[12], Torrela *et al.*[2] and Wenzel and Hampel[13], although information regarding forest structure in the central western Chaco province is scarce and data regarding regeneration are uncertain.

Early descriptions of the three quebracho forest highlighted the agricultural potential of its soils and warned about this implicit threat to its conservation[2,14], Torrella *et al.*[2] conclude that this forest is not represented in the system of protected areas and is distributed exclusively on private lands. Contributions of this nature are a way to prevent these pristine environments from continuing to be modified without taking the minimum precautions through the application of prudent criteria derived from knowledge translated into terms of sustainability.

The objectives of this work are: to know the floristic composition and the natural order of the trees expressed in numerical data that will provide feasible information to be used to base technical norms oriented to the sensible management of the forest. It is also useful to quantitatively specify the regeneration of the species, since it will orient the capacity of the forest to remain and to react if it is disturbed by any external cause.

2. Material and methods

The study area, located approximately 4 kilometers north of the town of Concepción del Bermejo, is a rectangle defined by picadas and country roads that facilitate access and is defined by the following geographic coordinates: S 26°21'17.83" W 61°01'49.64"; S 26°31'13.47" W 60°48'5.76"; S 26°37'23.27" W 60°50'53.14" and S 26°32'21.04" W 61°04'35.91" (**Figure 1**).

According to Ledesma[15], the original material of the soil, referring to the C horizon and the materials above the C from which the soils develop, corresponds to loess and local fossil loess-alluvial and is located within the climatic subtype cfw'a(h) of the Koppen climatic classification[14]; consequently, humid mesothermal with temperatures of the warmest month higher than 22 °C and the mean annual temperature higher than 18 °C, with rainfall that is markedly scarce in winter, according to Ledesma[15] it can be specified that the area studied is located between the isohyets of 800 to 850 mm per year.

The design of a forest inventory requires the assembly of a series of different techniques, including photogrammetry and photointerpretation techniques, biometric or statistical techniques, dendrometric techniques, data processing techniques, and operational programming and analysis tech-

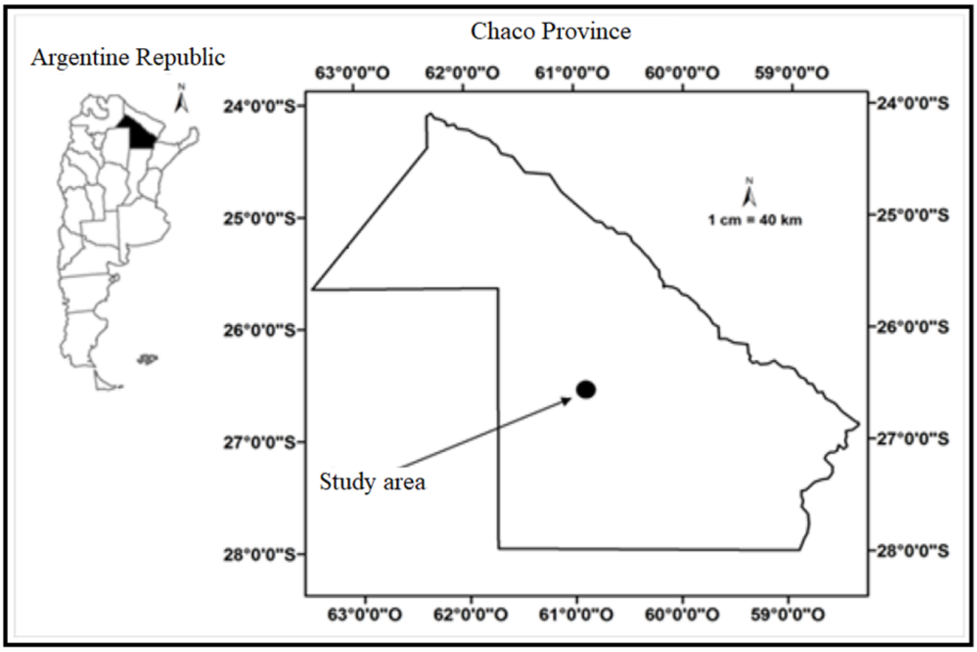

Figure 1. Location of the study area.

niques[16]. A 2012 satellite image was used for the study area, which according to the LANDSAT global path-row reference system corresponds to 228–078. After classifying the satellite image, the surface corresponding to the study area could be differentiated into surface with forest cover and surface without forest cover. Three types or strata were differentiated in the area covered by forest. In order to differentiate these strata, the methodology described by Reuter and Tévez[17] was used due to the heterogeneity and fragmentation of the study area. The study area has a surface area of 30.059 hectares, of which 16.071 hectares belong to forest cover areas. The distribution of the surfaces according to the three identified strata was 1.539, 4.327 and 10.205 hectares.

Within each stratum, five control points were selected, which are located close to local roads and located with the help of a global positioning system. The difference between the strata was visually corroborated, estimating that the stratum of 1,539 hectares corresponds to a high open forest. Following the methodology proposed by Zevallos and Matthei[18], a sampling unit of 1,000 m^2 was determined, consisting of a 10 × 100 m rectangle. The 10 sampling units have the characteristics of continuity, so they together form an area of 1 hectare. The starting point of the first sampling unit was selected in such a way that the integrity of the sample was installed within a fragment of the forest identified as high open forest. Within each sampling unit, a 10 × 5 m subplot was defined at the beginning and at the end. The variables surveyed in each sampling unit were normal diameter (DN) and total height (AT). All woody specimens with DN equal to or greater than 0.10 m were surveyed. In the 50 m^2 subplots the natural regeneration of woody species was surveyed, classifying them into 3 categories: specimens between 0.1 and 0.99 meters in height (I); specimens between 1 and 2 meters in height (II) and specimens greater than 2 meters in height and less than 0.10 meters in normal diameter (III).

The total number of trees and the basal area (AB) discriminated by species were calculated for each sampling unit. Basal area was compared among the ten sampling units by analysis of variance (ANAVA) and Tukey's test was used to determine the homogeneity of the total sample. Each sampling unit was processed. The number of trees and basal area per hectare and per species were then determined.

The specimens of woody species surveyed were identified at the species level using existing flora books: Cáceres[19], Cabral and Core[20], Giménez and Moglia[21] and the species of the herbaceous tapestry were identified by the working group of the natural resources research area. The identified species were grouped into woody and herbaceous.

Horizontal structure was evaluated using the importance value index (IVI). Its magnitude is an excellent indicator of the importance of the vegetation of a species within a stand, since it is sensitive to variables such as aggregation or basal area[22]. Its main advantage is that it is quantitative and precise and does not resign itself to subjective interpretations[23], the same author defines it as an indicator of the phytosociological importance of a species within a community. It is calculated using the following equation:

$$IVI = A\% + D\% + F\%$$

Then:

$$IVI\% = (A\% + D\% + F\%) * 3^{-1}$$

Where:

A% = relative abundance

D% = relative dominance

F% = relative frequency

The abundance index refers to the number of individuals per species and per hectare[24]. The frequency index of each species was calculated based on the presence of the species in each of 10 sampling units that make up the final sample[25], the dominance index of each species was calculated by adding the normal section of all specimens of the species and relating it by quotient with the surface area of the sample[26]. The percentages of relative abundance, frequency and dominance accounting for each of the above indices were calculated for each species.

To define the vegetation floors, the rule known as 20/30/50 was applied[9]. In order to evaluate the vertical structure, the methodology proposed by Finol[27] was used through the Sociological Position Index (PS). First, the phytosociological value of each stratum (Vfe_i) was calculated by relating the number of trees of stratum i (Ne_i) to the total number of trees (N):

$$Vfe_i = Ne_i^{*}N^{-1}$$

The phytosociological value ($Vfe_i\%$) percentage of each stratum was calculated according to the following expression:

$$Vfe_i\% = (Ne_i^{*}N^{-1})^{*}100$$

In order to simplify the calculations, the simplified phytosociological value (Vfe_is) was calculated according to the following equation:

$$Vfe_is = Vfe_i\%^{*}10^{-1}$$

Then the phytosociological value of a given species per stratum ($Vfes_i$) was deduced according to:

$$Vfes_i = Vfe_i^{*}Ne_i$$

The absolute value of sociological position (Ps_{abs}) was calculated based on:

$$Ps_{sabs} = \sum Vfes_i$$

Finally, the value of the relative sociological position ($P_s\%$) was defined by:

$$P_s\% = P_{sabs}^{*}100*N^{-1}$$

Natural regeneration was evaluated by relative natural regeneration (Rn%), a parameter proposed by Finol[27]:

$$Rn\% = (A\% + F\% + C\%) * 3^{-1}$$

The values of abundance and absolute and relative frequency of regeneration were calculated in a similar way to the procedure used in the calculations of the horizontal structure.

The regeneration size category was calculated using the same criteria as that used for the calculation of the sociological position index. Regeneration size classes C1, C2 and C3 correspond to categories I, II and III surveyed during the inventory. The relative (VP%) and simplified (VPs) phytosociological values for each regeneration size category and the absolute (Ct) and relative (Ct%) size categories were calculated similarly to the sociological position indices.

The Expanded Importance Value Index (IVIA), an index introduced by Finol[27] takes into account both the horizontal and vertical structure and according to Ramos and Plonczak[28] allows synthesizing the phytosociological contribution of each species in the horizontal and vertical structure of each community. It was calculated according to the following equation:

$$IVIA = A\% + F\% + D\% + Ps\% + Rn\%$$

The program Info Stat version 2013[29] free version was used for data systematization and processing.

3. Results

Tree, shrub and herb species were identified by their scientific and common names. Indices and parameters were calculated to describe the horizontal and vertical structure of the high open forest studied as well as to express the viability of natural regeneration in the forest typology. The data and results were grouped in tables.

Description of the floristic composition. Nineteen woody species of trees and shrubs from 12 different families were recorded (**Table 1**).

Also included in the description were those species that were observed in the study area although they were not surveyed in the sampling units and those species that were not surveyed because their DN was less than 10 cm.

In the herb stratum, 11 species of 7 different families were identified (**Table 2**).

Table 1. Species of the arboreal and shrub stratum

Family	Scientific name	Common name
Achatocarpaceae	*Achatocarpus nigricans* Triana, Ann.	Ink stick
Anacardiaceae	*Schinopsis balansae* Engl.	Chaco red Quebracho
	Schinopsis quebracho colorado (Schlecht) Barkl. et Meyer	Quebracho colorado santiagueño
	Schinus longifolius (Lindl.) Speg.	Molle
Apocynaceae	*Aspidosperma quebracho blanco* Schlecht.	White Quebracho
Borraginaceae	*Patagonula americana* L.	Guayaibí
Capparidaceae	*Capparis retusa* Gris.	Sacha bean
Fabaceae	*Acacia praecox* Griseb.	Doodle
	Caesalpinia paraguarienses (D. Parodi) Burk.	Guayacán
	Prosopis kuntzei Harms Kuntze	Itín
	Prosopis alba Griseb	White carob
Santalaceae	*Acanthosyris falcata* Griseb.	Saucillo
	Jodina rhombifolia Hook et Arn.	Bull shadow
Rhamnaceae	*Condalia microphylla* Cav.	Piquillin
	Ziziphus mistol Griseb.	Mistol
Sapotaceae	*Bumelia obtusifolia* Roem. & Schult.	Guaraniná
Simaroubaceae	*Castela coccinea* Griseb.	Peach
Ulmaceae	*Celtis tala Gillies* ex Planchon	Tala
Zygophyllaceae	*Porlieria microphylla* (Baill.) Descole, O' Donell & Lourteig	Ladle

Table 2. Species of the herb stratum

Family	Scientific name	Common name
Bromeliaceae	*Bromelia hieronymi* Mez	Chaguar
	Bromelia serra Griseb.	Chaguar
Cyperacea	*Carex sp*	-
Cactaceae	*Cereus aethiops* Haw.	Cardón
	Opuntia quiscaloro	Quiscaloro
Fabaceae	*Chaetotylax umbrosus?*	Sachalfalfa
Grasses	*Panicum sp.*	-
	Setaria sp	-
Poaceae	*Setaria fiebrigii?*	Pastured cow
Pteridocea	*Pteridium aquillinum* (L.) Kuhn.	Fern
	Thelypteris dentata (Forssk) E.P. StJohn	Fern

Homogeneity of the sample. The ANAVA using the AB of all specimens in the sample units showed that the sample is internally homogeneous (**Table 3**).

Since the p value was greater than alpha equal to 0.05, it was found that there were no differences between treatments. Tukey's test (alpha equal to 0.05) was used to determine the differences between the arithmetic means of the AB. The comparisons between the arithmetic means indicated the existence of internal homogeneity within the final sample, as shown in **Table 4**, since equal letters confirm that there are no differences between the different sample units.

Calculation of indices and parameters. We counted 275 specimens with a diameter greater than 10 cm and seven old stumps of quebracho colorado, 6 of which had diameters between 20 and 22 cm and the remaining 41 cm in diameter. It was not possible to differentiate whether these stumps belonged to specimens cut from quebracho colorado chaqueño or quebracho colorado santiagueño. The stumps were not included in the calculations.

Table 3. ANAVA table

FV	SC	CM	gl	F	p-value
Model	0.05	9	0.01	1.08	0.3757
Treatment	0.05	9	0.01	1.08	0.3757
Error	1.45	272	0.01	-	-
Total	1.5	281		-	-

Horizontal structure. The importance value index (IVI) was calculated for each of the species of

Table 4. Comparison of arithmetic means of AB

Treatment	Means	N	E. E	F
6	0.03	33	0.01	A
2	0.04	34	0.01	A
8	0.04	26	0.01	A
9	0.04	29	0.01	A
5	0.05	29	0.01	A
7	0.05	22	0.02	A
4	0.06	25	0.01	A
10	0.06	28	0.01	A
1	0.07	34	0.01	A
3	0.08	22	0.02	A

the tree and shrub stratum; it synthesizes the hierarchy of each of them in a dimensionless number and reflects the importance of the species in the community. **Table 5** shows the results of the calculation of each of the indices. The highest ranking species within the community was *Acacia praecox*, followed in order of importance by *Schinopsis balansae*, *Aspidosperma quebracho blanco* and *Prosopis kuntzei*. *Acacia praecox* reached a preponderant place due to its abundance and the fact that it was present in all sample units. *Schinopsis balansae*, Aspidosperma quebracho blanco and *Prosopis kuntzei* justified their hierarchy by their frequency and basal area, to the extent that they had an IVI% value of 39% with abundance values of only 26% adding the three species together. *Schinopsis* quebracho colorado santiagueño was represented by only four specimens in the final sample, although it reached a relative dominance of 10% due to the diameters of the specimens.

Vertical structure. The total heights of the largest specimens reached 23 meters. The vegetation floors were distributed as follows: a) lower floor: specimens < 11.5 meters; b) intermediate floor: specimens ≥ 11.5 meters and < 18.5 meters; c) upper floor: specimens ≥ 18.5 meters.

The results of the calculation of PS and PS% are specified in **Table 6**. The shrub layer included those species that were only in the lower vegetation floor.

In terms of sociological position within the community, Acacia praecox was the most representative species. It was followed in order of importance by *Patagonula americana*, *Schinus longifolius*, *Proposis kuntzei* and *Aspidosperma quebracho blanco*. Both *Acacia praecox* and *Schinus longifolius* belong to the shrub layer, while *Patagonula americana*, *Prosopis kuntzei* and *Aspidosperma quebracho blanco* belong to the tree layer. These three species together with *Schinopsis balansae* and *Schinopsis quebracho colorado* were present in the three vegetation strata.

Table 5. Calculations of horizontal structure indices

Species	A	A%	F	F%	D	D%	IVI	IVI%
Acacia praecox	114	41	10	13	2.30	17	71	24
Acanthosyris falcata	8	3	5	6	0.23	2	11	4
Aspidosperma quebracho blanco	27	10	9	12	2.24	16	38	13
Caesalpinia paraguariensis	13	5	6	8	0.88	6	19	6
Celtis tala	1	0	1	1	0.01	0	2	1
Jodina rhombifolia	6	2	4	5	0.17	1	9	3
Patagonula americana	30	11	9	12	0.50	4	26	9
Prosopis kuntzei	18	7	9	12	1.82	13	31	10
Schinopsis balansae	24	9	10	13	3.64	26	48	16
Schinopsis quebracho colorado	4	1	4	5	1.44	10	17	6
Schinus longifolius	25	9	8	10	0.50	4	23	8
Ziziphus mistol	5	2	3	4	0.11	1	6	2

Note: A = Relative abundance, F=Relative frequency, D = Relative dominance, IVI = Importance Value Index

Table 6. Calculation of vertical structure indexes

Species	Pi	Pm	Ps	PS	PS%
Acacia praecox	113	0	0	919	51
Acanthosyris falcata	5	3	0	45	3
Aspidosperma quebracho blanco	11	14	2	112	6
Caesalpinia paraguariensis	5	8	0	53	3
Celtis tala	1	0	0	8	0
Jodina rhombifolia	5	0	0	41	2
Patagonula americana	25	6	0	213	12
Prosopis kuntzei	15	5	0	130	7
Schinopsis balansae	4	4	4	40	2
Schinopsis quebracho colorado	1	2	1	12	1
Schinus longifolius	25	0	0	203	11
Ziziphus mistol	4	0	0	33	2
Number of trees in each stratum	214	42	7	-	-
Phytosociological value of each stratum	8.14	1.60	0.27	-	-

Note: Pi = Lower Floor, Pm = Intermediate Floor; Ps = Upper Floor, PS = Sociological Position, PS% = Relative Sociological Position.

Natural regeneration. **Table 7** shows the values of the indexes calculated for the natural regeneration of the forest under study. While the results of the calculation of relative natural regeneration (Rn%) are simplified in **Table 8**.

The species with the best regeneration valuescorresponded to the shrub stratum, among which *Achatocarpus nigricans* and *Acacia praecox* stood out. Among the species that make up the arboreal stratum, *Patagonula americana* was rescued. Regarding the "three quebrachos": *Aspidosperma quebracho blanco* and *Schinopsis quebracho colorado* presented very low values of absolute

Table 7. Calculation of natural regeneration indexes

Species	C_1	C_2	C_3	Ct	Ct%	A	A%	F	F%
Acacia praecox	1,070	370	250	6,314	25	1,690	24	20	100
Acanthosyris falcata	30	60	70	498	2	160	2	7	35
Achatocarpus nigricans	990	1,540	520	10,968	43	3,050	43	20	100
Aspidosperma quebracho blanco	10	20	20	159	1	50	1	4	20
Bumelia obtusifolia	0	0	10	21	0	10	0	1	5
Capparis retusa	180	260	170	2,080	8	610	9	19	95
Celtis tala	120	180	100	1,383	5	400	6	18	90
Condalia microphylla	0	20	0	75	0	20	0	1	5
Patagonula americana	480	210	360	3,527	14	1,050	15	20	100
Schinopsis quebracho colorado	10	0	0	41	0	10	0	1	5
Schinus longifolius	40	20	30	303	1	90	1	6	30
Ziziphus mistol	10	20	0	116	0	30	0	2	10
Number of renewals	2,940	2,700	1,530	25,487	100	7,170	100	-	-
Phytosociological value of each stratum	4.10	3.80	2.10	-	-	-	-	-	-

Note: C_1 = Class I, C_2 = Class II, C_3 = Class III, Ct = Absolute size category; Ct% = Relative size category, A = Abundance, A% = Relative abundance, F = Frequency, F% = Relative frequency.

Table 8. Relative natural regeneration of the different species

Species	F%	A%	Ct%	Rn%
Acacia praecox	17	24	25	22
Acanthosyris falcata	6	2	2	3
Achatocarpus nigricans	17	43	43	34
Aspidosperma quebracho blanco	3	1	1	2
Bumelia obtusifolia	1	0	0	0
Capparis retusa	16	9	8	11
Celtis tala	15	6	5	9
Condalia microphylla	1	0	0	0
Patagonula americana	17	15	14	15
Schinopsis quebracho colorado	1	0	0	0
Schinus longifolius	5	1	1	2
Ziziphus mistol	2	0	0	1

Notes: F% = Relative frequency, A% = Relative abundance, Ct% = Relative size category, RN% = Relative natural regeneration.

Table 9. Calculation of IVIA

Species	A%	F%	D%	RN%	PS%	IVIA
Acacia praecox	41	13	17	22	51	143
Acanthosyris falcata	3	6	2	3	3	17
Achatocarpus nigricans	0	0	0	34	0	34
Aspidosperma quebracho blanco	10	12	16	2	6	45
Bumelia obtusifolia	0	0	0	0	0	0
Caesalpinia paraguariensis	5	8	6	0	3	22
Capparis retusa	0	0	0	11	0	11
Celtis tala	0	1	0	4	0	5
Condalia microphylla	0	0	0	5	0	6
Jodina rhombifolia	2	5	1	0	0	9
Patagonula americana	11	12	4	9	2	38
Porlieria microphylla	0	0	0	6	12	17
Prosopis kuntzei	7	12	13	0	7	38
Schinopsis balansae	9	13	26	0	2	50
Schinopsis quebracho colorado	1	5	10	0	1	18
Schinus longifolius	9	10	4	2	11	37
Ziziphus mistol	2	4	1	1	2	9

Note: A% = Relative abundance, F% = Relative frequency, D% = Relative dominance, RN% = Relative natural regeneration, PS% = Relative sociological position, IVIA = Index of value of importance amplified.

abundance, about 50 to 10 specimens per hectare, while no regeneration of *Schinopsis balansae* and *Prosopis kuntzei* was recorded.

The expanded importance index includes the relative natural renewal values of horizontal and vertical structures (**Table 9**).

In the hierarchy defined by the IVIA, the rank represented by Acacia praecox in the community was consolidated. This index gave a new hierarchy to *Schinopsis balansae*, *Aspidosperma quebracho blanco*, *Prosopis kuntzei* and *Patagonula americana* due to their participation in the horizontal and vertical structure, although in all cases the species cited in the first term practically triples the remaining species.

4. Discussion

Cabrera[30] states that in the Chaco Province, *Schinopsis balansae* characterizes the Eastern Chaco District and *Schinopsis lorentzii* characterizes the Western Chaco District. Ragonese and Castiglioni[31] indicate a transition zone where *Schinopsis* quebracho colorado and *Schinopsis balansae* grow in association. Morello and Adámoli[14] speak of large masses of quebrachal of three quebrachos, settled in apparently eolian cords, with a clear NNE-SSO direction. The study area presents a similar woody characterization, although currently it is highly fragmented due to the promotion of agricultural boundaries and the continuous development of timber harvesting forests, and finally only the vegetation patches that retain their intangible characteristics are left. The quantity of stumps found compared to the absolute abundance of *Schinopsis balansae* and *Schinopsis* quebracho colorado indicates that this is a scarcely intervened forest.

In the present work, common families and species were found, even with the same hierarchy in the community with respect to studies conducted by Araujo *et al.*[9] in a representative forest of the Western Chaco Park, and Giménez *et al.*[3] cites some common species in a region identified as Semiarid Argentine Chaco in the province of Santiago del Estero, although in those communities *Schinopsis balansae* is not mentioned. Again Giménez *et al.*[32] refer to a floristic composition similar to the study area in research carried out in an area identified as a transition area and locate them in Miramar (Chaco) and algarrobal (Formosa). Torrela *et al.*[2] proposed a similar situation in an area identified as the central sub humid Chaco in the southeast of Chaco Province, which eventually became a common species in the study area. Finally, as species common to the study region, Hampel[33] mentions *Schinopsis balansae* and *Patagonula americana* in the forested region of the eastern Chaco.

The importance value index represents an objective way to determine the plant species that characterize an association[34] and allows comparing the ecological weight of the species within the plant community[24]. Taking into account this index, Acacia praecox is the most prominent species in the community. Kunst[35] states that shrublands and low forests in the Chaco region are ubiquitous and generally result from the overcutting and overgrazing of savannas and forests, if so, the secondary forest would be ensured by the abundance of Acacia praecox. *Schinopsis balansae*, *Aspidosperma* quebracho blanco, *Prosopis kuntzei* and *Patagonula americana*, the first three identified as heliophilous and the fourth as umbrophilous by Hampel[33] are the most important among the arboreal species, which consolidates the argument that this is a high open forest with practically no anthropic intervention. This argument is supported by the opinion of Araujo *et al.*[9], stating that the fact that *Aspidosperma* quebracho blanco constitutes more than 50% of the stand is typical of exploited forests, while Araujo *et al.*[9] refer to Gaillard de Benitez *et al.* who verified that the form of exploitation produces this type of change in species composition. In addition, Humano *et al.*[36] state that the different species have low ecological importance when they present an IVI% lower than 5, medium importance when the IVI% is between 5 and 14 and high importance when it is equal to or higher than 15. According to this criterion, Acacia praecox and *Schinopsis balansae* are species of high ecological importance, *Aspidosperma* quebracho blanco, *Prosopis kuntzei*, *Patagonula americana*, Schinus longifolius and Schinopsis quebracho colorado are species of medium ecological importance and the rest of the species are of low ecological importance.

The results of the investigation of the vertical structure indicated that three species were present in all vegetation floors: *Aspidosperma* quebracho blanco, *Schinopsis balansae* and *Schinopsis* quebracho Colorado. And according to the criteria established by Finol[27], they ensure their place in the structure and composition of the forest formation. Again, Finol states that the more regular the distribution of the individuals of a species in the vertical structure of a forest (the number of feet decreases gradually as one moves up from the lower stratum), the greater its value in the relative sociological position. In the aforementioned association, the opposite occurs, so it is difficult to infer whether it is indeed stable, especially considering that they grow in a region considered as a transition region by Ragonese and Castiglioni[31], Morello and Adámoli[14], Torrella *et al.*[2] and Morello[37].

The low potential for natural regeneration of tree species that emerges from this study is confirmed by the opinions of some authors, such as Tálamo *et al.*[12] who mentioned that the regeneration of species of forest value, referring to *Aspidosperma* quebracho blanco and *Schinopsis lorentzii*, was low compared to that of other species in the semi-arid Argentine Chaco in the province of Chaco to the north and east of Copo National Park. In turn, Wenzel and Hampel[13] refer to the lower proportion of *Schinopsis balansae* and *Aspidosperma* quebracho blanco in the total regeneration of the Argentine humid Chaco in the province of Chaco and add that the first species cited did not regenerate in the closed high forest and there was little regeneration in open high forests, as was the case with the second species. Grulke[38] also cites a low density of quebracho colorado (6 young trees per hectare) in high-density quebrachales and none in low-density quebrachales for the semi-arid Salta Chaco in the province of Salta. Although other authors such as Araujo *et al.*[9] indicate that the regeneration of *Schinopsis* quebracho colorado is more abundant than that of *Aspidosperma* quebracho blanco in the semi-arid Chaco and cite Brassiolo, who counted up to 835 quebracho colorado regeneration per hectare in a forest exposed to cattle. The same authors again cite Brassiolo indicating that in a site under silvopastoral management, the number of red quebracho individuals (1,857/hectare) was also higher than that of white quebracho (862/hectare). Finally, Araujo *et al.*[9] refer to Brassiolo *et al.*, stating that a minimum of 100 seedlings/hectare of class III red quebracho colorado is needed to consider that there is an established and assured regeneration.

5. Conclusions

It is evident that the three quebrachos cohabit the study site and that the area can be described as a transition area, which makes this community attractive for the implementation of conservation and sustainable management strategies.

The dominant association of the tree community is composed of *Schinopsis balansae* and *Aspidosperma* quebracho blanco.

There was little or no regeneration of the main species. These species gain importance when IVIA is applied, although the values contrast sharply with those of RN%.

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Original Research Article

Calculation of ecological compensation standard in a small watershed—Based on the ecological service function value method

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ABSTRACT

Small watershed ecological compensation is an important economic means to solve the contradiction between protecting the ecological environment and developing the economy. Taking the Changtian small watershed in the Xixiu District of Anshun City as an example, this paper uses the ecological service function value method to roughly calculate the ecological service function value of the small watershed ecosystem: the ecological service function value of the Changtian small watershed is 913.586 million yuan, and the total amount of ecological compensation is 11.6245 million yuan, of which the farmland system compensation is 1.3194 million yuan, the forest system compensation is 7.5336 million yuan, and the water system compensation is 256,000 yuan, The compensation for the fruit forest system is 2,515,500 yuan. Based on the value of ecosystem service function, the compensated and non-compensated ecosystem service functions are distinguished, and the equivalent factors that different ecosystems can provide compensated ecosystem functions are expressed, so that the determination of ecological compensation amount is scientific and more accurate, and then provides a basis for the determination of ecological compensation standard of the small watershed.

Keywords: Changtian Small Watershed; Ecological Compensation; Ecological Service Function Value Method; Equivalence Factor

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1. Introduction

Ecological compensation is a common means to coordinate the contradiction between economic development and ecological protection. It uses economic means to stimulate and convert the externality and nonmarket value of the ecosystem into monetary value, so as to better measure the external value of the ecosystem, and protect the ecosystem more effectively. It is an economic means that can effectively coordinate the contradiction between economic development and ecological environment protection in the region, it is also a macro means that can adjust the relationship between interests in different sections of the whole basin[1]. Ecological compensation involves key areas such as nature reserves, important ecological function areas, watershed water ecosystems, and resource development areas[2]. In ecological compensation, the ecological compensation standard is its core issue, and it is also one of the focus issues of current research in this field. At present, there are three main ways of compensation for the ecological compensation of small watersheds: social-ecological compensation, economic value ecological compensation, and natural compensation. Among them social-ecological compensation is mainly to determine the compensation willingness of the compensation subject, including the acceptable maximum and minimum willingness to pay; economic value ecological compensation is a way to calculate the value of ecological services that can be provided by the small watershed ecosystem, so as to further determine the standard of ecological compensation; natural compensation is a way to determine the compensation standard after calculating the input cost.

In academic circles, the estimation methods of small watershed ecological compensation standards are widely used, such as the ecological service value method, conditional value method (CVM), opportunity cost method, etc. The externality theory in environmental economics clearly states that when the external marginal cost is equal to the external benefit, the environmental benefit can be maximized. Therefore, theoretically, the ecological value provided by the ecosystem can be used as the upper limit of ecological compensation[3]. Zhang Leqin and Rong Huifang[4] in their research on the ecological compensation value of the Qiupu River Basin, using the ecological service value method, took the ecological service function value of the ecosystem as the upper limit of the ecological compensation amount of the Qiupu river small watershed, which provided a reference for the ecological compensation value of the small watershed, but their research ignored the scope of benefits involved in the service function provided by the ecosystem, At the same time, it ignores whether the ecological service function provided by the ecosystem can increase the ecological marginal utility, which leads to a new problem: not all the ecological service function value provided by the ecosystem can be compensated in the basin. On the other hand, for the issue of opportunity cost, academia believes that opportunity cost is "the income given up when making a decision without making another decision". In the application of ecological compensation, opportunity cost is the economic income and development cost given up to protect the ecological environment, which can generally be used as the lower limit of the amount of ecological compensation[5]. From the perspective of opportunity cost, the conditional value method is widely used in the study of ecological compensation standards. This method was first proposed in 1947[3] and was first applied by economist Davis in 1963 when studying the recreational value of forest land in the United States[6]. Many economists in developing countries believe that this method is feasible[7]. The conditional value method simplifies the costs and expectations of the beneficiaries and the victims of ecological interests related to ecological compensation into wishes, and then visits and investigates the compensators or recipients in the form of questionnaires or interviews to obtain the corresponding willingness to pay or receive compensation[8], which is one of the common methods to determine the ecological compensation standard of small watersheds at this stage. However, the conditional value method is an investigation of the wishes of stakeholders, and there are many subjective factors, which may lead to deviations in the final results, so it can not accurately reflect the inner true wishes of the compensators and the indemnitees. In addition, both the compensators and the recipients are based on the study of the compensation subject, and the overall value standard of ecological compensation in small watershed areas has not been clearly defined. In its 2006 policy report, the China Council for international cooperation on environment and development said, “if the market value of ecosystem services can be accurately assessed and quantified, it should be the best basis for measuring the standard of ecological compensation”.

To sum up, in the existing research on the ecological compensation standard of the small watershed by using the ecological service function value method, there are still the following deficiencies: first, most of the compensation amount is measured by the ecological service function value, and all the ecological service functions of the ecosystem in the watershed are included in the scope of ecological compensation, and the boundary and scope of compensable ecological service functions are not clear; second, the calculation of ecosystem service function value is not aimed at the ecological function within the compensable range that the system can provide. The boundary between theory and practice is relatively vague, and there is also a lack of clear definition. Based on the existing literature results, this paper attempts to make contributions to the study of small watershed ecological compensation standards. Therefore, based on the value of ecosystem service functions, utility factor and equivalent factor models are introduced to distinguish the compensated and non-compensated ecosystem service functions, and the equivalent factors that different ecosystems can provide compensated ecological functions are expressed so that the determination of ecological compensation amount is scientific More accurate, and then provide a basis for the determination of ecological compensation standards in small watersheds.

2. Overview of the study area and data sources

Changtian small watershed is located in Xixiu District, Anshun City, 105°08'–106º26'E and 25º04'–25º20'N. The climate belongs to the north subtropical humid monsoon climate, which is characterized by rainy and hot seasons, warm and wet seasons, with an average annual temperature of 14 ℃ and an average rainfall of 1,300 mm for many years. The landform of the basin is mainly a peak cluster depression landform, with an average altitude of about 1,310.65 m and a total area of 13.43 km², the area of water and soil loss is 7.17 km^2. The agricultural industrial structure in the basin is dominated by agricultural production, and the economic income of local residents is dominated by planting rice and flue-cured tobacco. According to statistical data, the total GDP of the small watershed of Laotian in 2018 was 29.8615 million yuan, and the total agricultural output value was 6.2392 million yuan, of which the output value of the planting industry was 3.5432 million yuan, the output value of animal husbandry was 881,000 yuan, and the output value of sideline industry was 1.815 million yuan. The disposable income of rural residents was 2,132 yuan, and the total grain output was 1.468 million kg.

The total land area of this watershed is 13.43 km^2. Before the water and soil control project, the cultivated land area is 4.78 km^2, accounting for 35.60% of the total watershed area, the forest land area is 5.92 km^2, accounting for 44.00% of the watershed area, and the unused land (barren mountains and slopes) in other lands is 2.37 km^2, accounting for 17.00% of the watershed area. Due to a large number of sparse and young woodlands, barren mountains and slopes account for a certain proportion, and most of the existing cultivated land depends on the mountains, as well as some unreasonable agricultural cultivation and production and construction activities, the water and soil loss in Changtian small watershed began to become a more and more serious, mainly moderate and intensive loss, accounting for 54.81% of the loss area. Through the detailed investigation and statistics of water and soil loss in the watershed, the water and soil loss area of this small watershed is 7.17 km^2, it accounts for 53.00% of the total drainage area, of which the slight loss area is 3.28 km^2, accounting for 46.00% of the loss area. The moderate loss area is 2 km^2, accounting for 28.00% of the loss area. The intensity loss area is 1.88 km^2, accounting for 26.00% of the loss area. The average annual soil erosion modulus is 3600 t (/km^2 a), and the annual erosion is as high as 25,800 tons. Since December 2010, the Changtian small watershed in Xixiu District, Anshun City has begun to carry out soil erosion control with the goal of improving agricultural production conditions and ecological environment, improving people's living standards, and promoting the adjustment of rural industrial structure and the sustainable development of regional economy and society in the Changtian small watershed. Among them, the designed treatment area is 6.90 km^2, and the treatment degree is more than 86.00%. At present, the ecosystem of Changtian small watershed can be divided into five ecosystems: farmland, forest, water area, fruit forest land, and unused land, of which the farmland area is 4.78 km^2, the forest area is 5.92 km^2, the fruit forest area is 2.37 km^2, the water area is 0.09 km^2 and the unused land area is 0.28 km^2. The data sources of this paper include the data of the study area, from the statistical data released by the Guizhou Provincial Forestry Department and the Provincial Bureau of statistics, as well as the report data of the soil erosion control project of the Anshun Forestry Bureau and the Changtian small watershed in Xixiu District, and the local data provided by the village committees of local villages;

the social public data comes from the social public data and the relevant data of the National Statistical Yearbook published in the code for the evaluation of forest ecosystem functions (LY/T1721-2008).

3. Research methods

3.1 Calculation method of the ecological value of Changtian small watershed

3.1.1 Calculation method of the ecological value of forest land system

The fruit forest planted in Changtian small watershed to improve the ecosystem has a good market prospect. Planting Rosa roxburghii for several years at a time can harvest. Because trees and forests have similar ecological functions, the same method is used to calculate the ecosystem value of fruit forest and forest ecosystem. The forest area in Changtian small watershed is 5.92 km^2, and the planting area of fruit forest is 2.37 km^2. According to the LY/T1721-2008 evaluation specification established by the Chinese Academy of Forestry Based on its long-term observation data, the evaluation index system of forest ecosystem service function in Changtian small watershed is determined after improvement, and the formula is as follows:

$$P_k = \frac{P_f}{a_k} \times A_k \tag{1}$$

$$P_f = \sum A_k \times P_k \tag{2}$$

In formulas (1) and (2): k represents the specific type of evaluation index, P_f is the total ecological value of forest land ecosystem in Changtian small watershed (10,000 yuan /km^2), A_k is the unit area of the kth evaluation index in Changtian small watershed (km^2), P_k is the unit ecological value of the kth evaluation index, and P_f is the total ecological value of forest land ecosystem in Guizhou Province (10,000 yuan /km^2), A_k is the unit area (km^2) of the kth evaluation index in Guizhou Province.

3.1.2 Calculation method of the ecological value of farmland system

The farmland ecosystem in Changtian small watershed is mainly planted with rice and flue-cured tobacco, and the land type belongs to cultivated land. After consulting the sowing area, single grain yield, and the national average price of grain crops in Anshun, this paper uses the research of Xie *et al.*[9] on the value of equivalent factors and the calculation model method of farmland (cultivated land) ecological service value proposed by Liu *et al.*[10] for reference. The formula is as follows:

$$P_a = E_a \times A \tag{3}$$

Where: P_a represents the total ecological value of the farmland system in Changtian small watershed (10,000 yuan), E_a represents the value of unit equivalent factor (yuan /km^2), and A represents the total area of farmland in the region.

$$E_a = \sum \frac{m_i \times p_i \times q_i}{M} \tag{4}$$

Where: m_i refers to the planting area of the i-th food crop (km), p_i refers to the domestic average price of the i-th food crop (yuan /kg), q_i refers to the output of the i-th food crop (kg/km^2), and M refers to the total area of farmland.

3.1.3 Calculation method of the ecological value of water area system

The ecological value of the water area system in Changtian small watershed is measured by taking the water ecological service function as the index. The water ecological service function refers to a series of utilities that the water area ecosystem can bring to maintain the ecological environment while providing the natural environment for our human survival. The water ecological service functions of Changtian small watershed mainly include water resource accumulation, river sediment transport, soil conservation, carbon fixation, and biodiversity protection. This paper, combined with the water ecological value evaluation method proposed by Ouyang Zhiyun *et al.*[11] and the actual situation of the water system in Changtian small watershed, the formula for calculating the ecological value of the water system is as follows:

$$P_w = \sum P_n \times W_n \quad (5)$$

Where: n refers to different types of ecological service functions provided by the water system; P_n is the unit market price of the nth ecological service function; W_n is the material quality provided by Changtian small watershed in the nth function; P_2 refers to the total ecological value provided by the water system of Changtian small watershed.

3.2 Equivalent factor model of ecological compensation standard in Changtian small watershed

The value of ecological services provided by the ecosystem in the small watershed is provided through its ecological functions, and the value of ecological services provided is also the upper limit of ecological compensation. The classification of its ecological functions is specifically reflected in the services provided for ecology. According to the actual situation of the Changtian small watershed, the functions can be divided into four primary functions: supply function, regulation function, support function, and cultural function, Further subdivision can divide the four primary functions into 10 secondary functions, such as providing food, providing raw materials, supplying water resources, regulating gas, regulating climate, conserving water sources, purifying the environment, maintaining soil, protecting biodiversity, and providing landscape appreciation.

3.2.1 Determine the compensation scope of the small watershed ecological service function

As an equivalent factor, the service function provided by the ecosystem is an important factor to determine the standard of ecological compensation. However, from the perspective of compensation, ecological compensation is an economic means to adjust the relationship between interests and damage between regions in the basin. The specific implementation process needs to convert the value of ecological services provided by the ecosystem into the market monetary value. Therefore, in these equivalent factors, it is necessary to consider the spillover scope of each function and whether it can really improve the ecosystem. Among them, because the overflow range is too large, and the ecological function radiates to the whole country and even the world, it is impossible to determine the specific subject of ecological compensation, so the function of gas regulation and biodiversity protection cannot carry out the final ecological compensation. On the other hand, since the functions of providing food and raw materials are the natural characteristics of the ecosystem, they cannot increase the marginal benefits of the ecological value of small watersheds, so they cannot be included in the ecological compensation standard. See **Table 1** for the specific scope of compensation.

3.2.2 Determination of ecological compensation standard model

The five systems in Changtian small watershed have different ecological service functions, so the proportion of ecological compensation is also different, resulting in different final ecological compensation standards. The formula of ecological compensation standard is established by using the ecological value provided by the five systems:

$$P = \sum P_j \times e_{jg} \quad (6)$$

Where: P represents the total ecological compensation standard (10,000 yuan), P_j represents the total ecological value of the j^{th} ecosystem (10,000 yuan), and e_{jg} represents the equivalent factor value of the j^{th} ecosystem in the GTH compensable function.

3.2.3 Correction of equivalence factor table

When using the ecological value provided by the ecosystem to determine the ecological compensation standard in small watersheds, it is necessary to build an equivalent factor table. However, the equivalent factor table of ecosystem service value in China was established by Xie *et al.*[17] cannot be targeted at all small watersheds. Therefore, when determining the equivalent factor table in Changtian small watershed, it needs to be modified. This paper is based on the economic and natural environment of Changtian small watershed, combined with the actual ecological service functions and ecological resources brought about by the basin and its surrounding areas, the relevant ecological data provided by Anshun ecological environment bureau are selected, and corrected in combination with the table of equivalent factors of China's ecological service value. The correction principle is: for the ecological service functions of a specific ecosystem, the average value is selected if the difference is small in the measurement standard, and for those with a large difference, the average value is selected through the ecosystem. The correction formula is Formula (6). After correction, the compensated equivalent factors of the Changtian small watershed are shown in **Table 2**.

$$\bar{e}_{jg}=\frac{1}{l}\frac{S_k}{F_k}P_{jg}\,e_{0jg} \tag{7}$$

$$e_{jg}=\begin{cases} e_{0jg} & \left|\bar{e}_{jg}-e_{0jg}\right| \leqslant 0.5 \\ \bar{e}_{jg} & \left|\bar{e}_{jg}-e_{0jg}\right| > 0.5 \end{cases} \tag{8}$$

In formula (7) and formula (8): e_{jg} is the equivalent factor value of the jth ecosystem in the gth compensable function of Changtian small watershed; e_{0jg} is the equivalent factor value of the j^{th} ecosystem in the g^{th} compensable function in China; S_k is the value of ecosystem; F_k is the total area of the ecosystem; P_{jg} is the proportion of the g^{th} compensable function of the j^{th} ecosystem in the Changtian small watershed in the value of ecosystem services in China.

Table 1. Compensation scope of ecological service function in Changtian small watershed

Primary function	Secondary function	Beneficiary			Whether to improve the ecology		Whether it is included in the scope of compensation
		Within the basin	Whole country	Global	Yes	No	
Supply function	Provide food	√				√	
	Provide raw materials	√				√	
	Water supply	√			√		√
Adjustment function	Regulating gas			√	√		
	Regulate the climate	√			√		√
	Water conservation	√			√		√
	Environmental purification	√			√		√
Support functions	Maintain soil	√			√		√
	Protect biodiversity			√	√		
Cultural function	Provide appreciative landscape		√		√		√

Table 2. Compensated equivalent factors of Changtian small watershed (Unit: $\times 10^{-3}$)

Compensable function	Farmland	Forest	Waters	Fruit forest	Unused land
Water supply	-1.68	0.40	23.09	0.35	-0.72
Regulate the climate	0.83	2.52	5.33	2.40	0.05
Water conservation	2.69	6.74	18.08	5.21	0.03
Clean the situation	1.64	2.14	10.09	1.26	0.01
Maintain soil	1.34	3.91	0.65	3.68	0.08
Provide appreciative landscape	0.02	0.86	2.11	0.92	0.32
Total	4.84	16.57	59.35	13.82	-0.23

4. Results and analysis

4.1 Comprehensive evaluation of ecological service function value of Changtian small watershed

4.1.1 Ecological service function value of forest land system

According to **Table 3**, the total ecological value of the forest ecosystem in Changtian small watershed is 454.656 million yuan. Among them, the forest ecosystem has the highest ecological value in water conservation and air purification, which are 130.24 million yuan and 126.688 million yuan respectively. It can be seen that water conservation and air purification are the two service functions that provide the highest service value for the ecosystem, and the ecological value per square kilometer is 22 million yuan and 21.4 million yuan respectively; biodiversity protection and carbon sequestration and oxygen release take the second place, with the ecological value of 14.7 million yuan and 12 million yuan per square kilometer respectively; then there is the function of soil conservation and nutrient accumulation. The biological value per square kilometer is 4.7 million yuan and 1.4 million yuan respectively; the unit value provided by forest recreation is the least, only 600,000 yuan per square kilometer, and the ecological value provided by the forest ecosystem in Changtian small watershed in the forest recreation function is 3.552 million yuan.

Table 3. Evaluation index and ecological value of forest ecosystem in Changtian small watershed

Evaluating indicator	A_k/km^2	P_k/10,000 Yuan	Ecological value/10,000 Yuan
Water conservation	5.92	2,200	13,024
Purify the atmosphere	5.92	2,140	12,668.80
Biodiversity conservation	5.92	1,470	8,702.40
Carbon fixation and oxygen release	5.92	1,200	7,104
Soil conservation	5.92	470	2,782.40
Accumulate nutrients	5.92	140	828.80
Forest Recreation	5.92	60	355.20
Total	—	—	45,465.60

The ecological service function value provided by the fruit forest ecosystem in Changtian small watershed is 182.016 million yuan (**Table 4**). Like the forest ecosystem, it provides the most value in water conservation and air purification, with 52.14 million yuan and 50.718 million yuan respectively; biodiversity conservation and carbon sequestration and oxygen release followed, with 34.839 million yuan and 28.44 million yuan respectively; the value of forest recreation function is the least, only 1.422 million yuan. The forest and fruit forest ecosystem account for the largest proportion of the process of ecological compensation. The government can compensate in the future compensation process by putting fruit seedlings, building forest farms, and other capital investment methods. At the same time, it can also use technical support to carry out technical training for fruit farmers, so as to promote economic prosperity in the basin while the environment is beautiful.

4.1.2 Ecosystem service function value of water area system

The ecological value provided by Changtian small watershed in terms of water ecosystem is 4.314 million yuan (**Table 5**). The ecological service functions provided by the water ecosystem mainly include water resource accumulation, river sediment transport, soil conservation, carbon fixation, biodiversity protection, etc. Among them, the value provided in soil conservation is the largest, which is 3.6606 million yuan; carbon fixation takes second place, with 564,000 yuan. Although the value provided is the second, compared with the soil conservation function ranking first, the gap is large, with a difference of 3,096,600 yuan; the value provided by water resources accumulation, river sediment transport function, and biodiversity protection is relatively small, which are 44,200 yuan, 13,600 yuan, and 31,600 yuan, respectively.

Table 4. Evaluation index and ecological value of fruit and tree forest ecosystem in Changtian small watershed

Evaluating indicator	A_k/km^2	P_k/10,000 Yuan	Ecological value/10,000 Yuan
Water conservation	2.37	2,200	5,214
Purify the atmosphere	2.37	2,140	5,071.80
Biodiversity conservation	2.37	1,470	3,483.90
Carbon fixation and oxygen release	2.37	1,200	2,844
Soil conservation	2.37	470	1,113.90
Accumulate nutrients	2.37	140	331.80
Forest Recreation	2.37	60	142.20
Total	—	—	18,201.60

Table 5. Ecosystem service function and ecological value of waters in Changtian small watershed

Function type	W_n	P_n	Ecological value/10,000 Yuan
Water resources accumulation	6.60/10^4 m^3	0.67/(yuan/m^3)	4.42
River sediment transport function	4.40/10^6 kg	3.10/(yuan/kg)	1.36
Maintain soil	405.79/km^2	9,020.87/(yuan/km^2)	366.06
Carbon fixation	3.34/10^7 kg	168.85/(yuan/kgc)	56.40
Protect biodiversity	8.72/km^2	3,633.60/(yuan/km^2)	3.16
Total	—	—	431.40

Changtian small watershed has a small ecological area, but it accounts for a significant proportion of the four primary functions of supply function, regulation function, support function, and cultural function. The ecological significance of the water system is quite significant. Therefore, in terms of water compensation, we can make reasonable planning through the form of capital investment, such as building reservoirs, and building and beautifying rivers and lakes, so as to maximize the ecological value of the water ecosystem.

4.1.3 Total value of ecological service function in Changtian small watershed

The ecological value provided by the ecosystem of Changtian small watershed totals 913.586 million yuan. Among them, the forest system provides the most ecological value, reaching 454.656 million yuan. This is because the forest system has more ecological functions, so it can provide higher external value; the calculation model of the ecological value of fruit forest is consistent with that of the forest, but because the planting area of fruit forest is less than that of the forest, 5 conclusions and policy enlightenment unit: 10,000 yuan, so the ecological value of fruit forest is lower than that of the forest system. Due to the small area of the water system in Changtian small watershed, the ecological value provided is also small, only 4,314,000 yuan. However, the equivalent factor of the water system in providing ecological services, especially in the compensable function, is very high, as high as 59.35. It can be seen that the water system is the optimal system to purify the environment and maintain a good ecosystem. In addition, most of the unused land is the residence of farmers and the land for construction and development, which cannot provide services for improving the ecological environment and does not have the value of ecological externality.

4.2 Comprehensive evaluation of ecological compensation standards in Changtian small watershed

Through the calculation of the ecological value of five ecosystems, the equivalent factor model is established, and the ecological compensation amount of Changtian small watershed is 11.624 5 million yuan. Among them, the compensation amount for the farmland system is 1,319,400 yuan, the compensation amount for the forest system is 7,533,600 yuan, the compensation amount for the water area system is 256,000 yuan (accounting for 2.20% of the total compensation), and the compensation amount of fruit forest system is 2,515,500 yuan. Because the ecological value of unused land is 0 yuan, no compensation measures are taken for the unused land system. The current ecological value of the Changtian small watershed in the Xixiu District of Anshun City is the result of the local government's soil erosion control. The total investment in the implementation of the project is 2.53 million yuan, of which the cost of engineering measures is 1.011 million yuan, the cost of plant measures is 1.2562 million yuan, and the cost of ecological restoration measures is 60,200 yuan, and the independent cost is 202,500 yuan. As the water and soil loss control project has improved the ecology and belongs to the scope of compensation, the project funds invested by the government should be removed in the compensation process, and the final ecological compensation standard of Changtian small watershed is 9.0945 million yuan.

From **Table 6** and the above description, it can be seen that the area of farmland ecosystem in Changtian small watershed accounts for 35.60%, and the compensation accounts for 11.35%; the proportion of forest ecosystem area is 44.00%, and the proportion of compensation is 64.80%; the area of fruit forest ecosystem accounts for 17.70%, and the compensation accounts for 21.64%; the area of water ecosystem accounts for 0.05%, and the compensation accounts for 2.20%; the proportion of the unused land area is 2.10%, and the compensation proportion is 0. From the balanced proportion of area and compensation, it can be seen that the water area system is not only the best system to provide ecological services but also the highest proportion of compensation, followed by the forest and fruit tree forest ecosystem. Therefore, the Changtian small watershed can develop more in the water area and fruit tree forest system in the future, especially in terms of aquaculture and planting fruit trees in the water area, which not only provides ecological services but also is conducive to the expansion of economic scale. The total ecological compensation of Changtian small watershed accounts for 38.93%

of the local GDP, and the compensation method supported by funds is a good choice. Of course, the ways of ecological compensation are diversified, and the diversified combination of financial compensation, technical compensation, and policy compensation has more practical and long-term significance than simple financial compensation.

Table 6. Results of ecological compensation in Changtian small watershed (Unit: ten thousand yuan)

Farmland	Forest	Waters	Fruit forest	Unused land	Total
131.94	753.36	25.60	251.55	0	1,162.45

5. Conclusions and policy implications

Taking the ecological value provided by the ecosystem service function as the standard of ecological compensation has a theoretical basis and practical operability. The positive external utility of the ecosystem itself cannot be measured by real money, but the development opportunities sacrificed for protecting and improving the ecosystem need to be balanced through external compensation. Based on the previous research on the ecological compensation standard of the small watershed, considering the value of ecological service function brought by the ecosystem to the environment, and its ecological value, the corresponding ecological service functions of different ecosystems have different utility factors, this paper proposes an equivalent factor model and determines the amount of ecological compensation of Changtian small watershed in combination with the actual resource utilization and development of Xixiu District, Anshun City. The result is 11.6245 million yuan, excluding the project funds, the compensation standard amount is 9.0945 million yuan. This data is the upper limit of ecological compensation. The lower limit of ecological compensation also needs to take into account the subjective will of the compensation object and the willingness to pay off the compensation subject. When calculating the lower limit of ecological compensation, the commonly used methods are the opportunity cost method, willingness survey method, etc. Because each method has its limitations, it is recommended to combine them for better calculation. This problem is also the main research direction for small watershed ecological compensation in the future.

When implementing compensation measures, the local government can consider both macro and micro levels. At the macro level, corresponding policies and funds can be introduced to the whole small watershed for ecological engineering construction and technical training. From the micro level, taking into account the local actual situation, the ecological fruit forest resources such as *Rosa roxburghii* fruit trees can be invested in batches to protect the ecology and promote the local economic development at the same time. In addition, considering the small area of the water system in the Changtian small watershed, reservoirs can be built here to ensure the normal daily water use of residents. When determining the ecological compensation standard, this paper fully considers the actual development of Changtian small watershed and the current relevant market prices in China, which has reference value and significance for the local government in the implementation of compensation measures.

Conflict of interest

The authors declare that they have no conflict of interest.

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ORIGINAL RESEARCH ARTICLE

Forest dynamics in different scenarios: Selective logging in the middle Magdalena (Colombia)

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ABSTRACT

Selective logging is a frequently used forest use activity that has been shown to have less impact on biodiversity than clear-cutting. However, both the magnitude and direction of ecological change after logging depend on its intensity and subsequent forest dynamics. Therefore, it is important to conduct studies to understand the functioning of different ecosystems after selective logging. This study analyzed forest dynamics in the El Paujil reserve (Middle Magdalena, Colombia) in terms of demography, regeneration, clear-cutting dynamics, biomass accumulation and floristic composition by comparing two one-hectare plots in a fragment of the little disturbed (primary) forest and two one-hectare plots in a fragment of the forest that was selectively logged in the past. As expected, forest structure and biomass accumulation are altered by selective logging, but it did not have a significant impact on the other aspects mentioned, since it seems that the steep slopes of the area cause high mortality and promote the formation of clearings in both logged and lightly disturbed forests.

Keywords: Aerial Biomass; Primary Forest; Floristic Composition; Demography; Serranía de las Quinchas

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1. Introduction

Selective logging in tropical forests is a growing activity that has been shown to produce less soil and canopy damage than generalized deforestation. It is also the forest use activity with the least impact on diversity, as selectively logged forests have high mature forest species richness[1,2]. However, both the magnitude and direction of ecological change after logging depend strongly on its intensity and the subsequent spatial and temporal dynamics of the affected forest[3].

Among the most important consequences of selective logging in forests is the loss of biomass, not only during the logging period, but also in the time after the activity. In studies conducted in the Brazilian Amazon, Figueira *et al*.[4] found that during the four years following logging activities the forest lost biomass. Mortality was higher than predicted for this forest type, possibly due to the effects of mechanical damage, given the increased wind exposure of trees adjacent to logging sites[4]. However, long-term studies such as that of Gourlet-Fleury *et al*.[5] have found that selective logging favors increases in biomass, growth and survival of trees in all diameter classes below 70 cm, as well as recruitment of fast-growing tree species (pioneers), which increases rates of aboveground biomass gain in the forest. Another important effect of selective logging on forests is the formation of clearings, which allow more light to enter the understory, benefiting lianas and pioneer species, as these are plants that mostly grow rapidly when there is high light availability[6]. Subsequent dynamics are variable, pioneer trees can reach canopy height and become established or die from lack of light when the canopy forms above them again[6]. Lianas, if they manage to grow into the canopy and establish on mature forest trees, may even topple them with their weight, encouraging the formation of new clearings[7]. Thus, Schnitzer & Bongers[7] show that there is a negative relationship between the density of lianas and the density of mature forest trees, while the density of lianas is positively related to the density of pioneer species.

In neotropical countries such as Colombia, with its diverse climate and relief, it is even more difficult to predict the direction of recovery of selectively logged forests. Despite having 52.6% (60 million hectares) of the national territory occupied by forests[8], Colombia presents high deforestation rates, with losses of 5.4 million hectares of forest in the last 20 years[9]. The Magdalena basin is the most deforested in South America and the tenth most deforested in the world[9], but it presents regions such as the Serranía de las Quinchas, in the middle Magdalena, where some areas of continuous forest are preserved. For example, the El Paujil bird reserve includes 3419 hectares protected as a private civil society reserve[10] and has at least four forest types identified by Aldana *et al*.[11]: forest with a moderate level of selective logging (logged forest), floodplain forest, young secondary forest (secondary forest) and forest with subsistence logging (primary forest).

The objective of this study is to analyze the effect of selective logging on the dynamics of the tree community in the forest of the El Paujil reserve in the middle Magdalena region of Colombia. These dynamics are evaluated in terms of biomass accumulation capacity, clear-cutting dynamics, regeneration, demography and floristic composition. Given the effects of increased light availability and exposure to wind after logging, it is expected that logged forests will have a higher recruitment and mortality rate, a negative rate of population change and a lower capacity to accumulate biomass. Likewise, due to the direct effects of logging, it is expected to find a lower density of large individuals and a lower canopy cover, which will also allow for a higher density of seedlings and juveniles in the logged forest. In addition, given that selective logging has not been considered to have a great impact on forest diversity, we expect to find similarities in plant species composition and turnover between the two forest types, but a greater abundance of pioneer plants in the logged forest.

2. Materials and methods

2.1 Study area

This study was conducted in the El Paujil bird reserve, in the departments of Santander and Boyacá (74°11'W, 5°56'N) with a geographic altitude ranging from 150 m to 1,200 m and an average annual temperature of 27.8 °C[11]. There are two rainy periods during the year, the first one between April and May and the last one between September and November. Relative humidity ranges between 85% and 89%[11,12].

The reserve was created in November 2003 to conserve the blue-billed curassow (Crax alberti)[10] and its tropical rainforest habitat. Prior to the establishment of the reserve, the reforestation company Bosques del Futuro practiced selective logging for timber for five years in part of the forest. Silva-Herrera[13] reported that the reforestation company planned to harvest 50 m^3 of standing timber from the forest per hectare per year, distributed as follows: 15 m^3 of fine woods and 35 m^3 of ordinary woods. Accordingly, the reforestation company harvested approximately five trees per hectare, which could be verified by the researchers at the time of establishing the plots in 2006. This forest is located in the department of Boyacá, in the village of Puerto Pinzón in the municipality of Puerto Boyacá. The primary forest was exploited by the owners of the property for subsistence, which corresponds to at least one tree per hectare per year, as could be evidenced by the researchers during the establishment of the plots. This forest is located in the department of Santander, in the municipality of Bolivar. The distance between the two forest types (the sampling sites) is approximately 8 km. The forests sampled present a topography with slopes of up to 40°, and a geographic altitude from 194 masl to 471 masl.

2.2 Data collection

For each forest type, two one-hectare plots were sampled, established in 2006 by Aldana *et al*.[11] They measured diameter at breast height (DAP) for all individuals with DAP greater than 5 cm and identified them to species (or morphospecies if this was not possible). Decision to include individuals from 5 cm DAP but not from 10 cm as it is usually done, it is due to the presence of a large number of tree species that do not reach this size (**Annex 1**). Therefore would be left out of the sampling, which would lead to an underestimation of the diversity and accumulated biomass of the site[14]. In 2013, they were censused again, measuring DAP for individuals sampled in 2006, reporting dead or missing individuals and noting the causes of mortality where possible, following the protocol of Phillips *et al*.[15]. All individuals that entered the size category greater than 5 cm DAP were included as new recruits. Wood samples were collected to determine their density, using a borer and taking samples of at least five individuals of the most abundant species of the two forest types.

For regeneration estimates, the number of seedlings and juveniles present in the two forest types was compared by taking data from 100 plots of 2 × 2 m for seedlings and 100 plots of 5 × 5 m for juveniles[16]. This sampling was carried out systematically, within the 1 ha plots. To quantify the entry of light into the forest understory, 50 subplots of 20 × 20 m per forest type, located within the 1 ha plots, were used. Two photos of the canopy were taken at the central point of each of the subplots with the camera parallel to the ground at 1 m height. A fisheye lens was used and the camera was programmed to take the photos in black and white, with a constant 22 cm aperture and variable speed.

2.3 Data analysis

The information obtained in 2006 was compared with that of 2013 to establish the annual rates of growth, mortality and recruitment of the tree community for each plot using the formulas presented by Sherman *et al*.[17]. Then, in order to statistically compare these behaviors and make them comparable with the information obtained on clear-cutting and regeneration dynamics, comparisons were made at a scale of 20 × 20 m, with 50 subplots for each forest type. Using the statistical program Rversion 3.0.1[18] one-tailed t-tests were performed for two samples, with Welch's approximation when variances were not similar.

For the analysis of clearings, photos taken at the center point of each of the 20 × 20 m subplots were used, choosing one per subplot to determine the gray value per pixel (where 0 means black and 255 means white) with the Image J program[19]. This value represents the light intensity in the understory and is compared with a one-tailed *t*-test for two samples between the two forest types using the statistical program R version 3.0.1, Vegan library[18]. Additionally, as indicators of the regeneration process of the forests after the disturbance, the number of seedlings and juveniles present in the two forest types were compared with one-tailed two-sample t-tests with Welch's approximation when variances were not similar in the statistical program R version 3.0.1[18].

The density of wood samples obtained in the field was determined as the specific gravity (dry weight/green volume) following the wood density protocol of Chavé[20]. For species for which no wood sample was taken, the wood density data of Casas *et al*. (unpublished data) and Zanne *et al*.[21] were used. Subsequently, the height of each tree was estimated using the allometric equation derived from the Weibull function adapted for South America presented by Feldpausch *et al*[22]. The cumulative biomass of each tree was calculated using equation I.3 of Alvarez *et al*.[23] for tropical rainforest in Colombia, which takes into account that diameter at breast height, tree height and wood density. According to Alvarez *et al*.[23], it is the best equation for estimating carbon in Colombia, given the low uncertainty and variability with respect to the other equations generated by them. With the initial and final biomass values, the annual biomass change in Mg ha^{-1} $year^{-1}$ was determined.

Finally, the four most important species in each plot were identified with the importance value index determined by the density, frequency and relative basal area of each species. We looked for whether these species are exploited for their timber and timber quality[24] to relate any possible changes in the dominant species with logging. The conservation status of these species in Colombia was also sought[25] to investigate the vulnerability of the timber trees present in this forest. Additionally, a comparison of the species present and their abundance in the plots was made with a cluster represented in a dendrogram. Since pioneer species play an important role as indicators of disturbances (logging or tree fall), the individuals sampled were categorized into three groups depending on their wood density, as this is one of the most important functional traits in the determination of primary forest species and pioneer species[6]. Tree species with low wood density were considered those with values between 0.10 g/cm^3 and 0.39 g/cm^3, medium with wood between 0.40 g/cm^3 and 0.59 g/cm^3 and high those with wood between 0.70 g/cm^3 and 0.90 g/cm^3. Subsequently, the proportion of trees in each category was compared between forest types with a G-test in R version 3.0.1[18].

3. Results

3.1 Demographics

The logged and primary forests in the El Paujil reserve did not show significant differences in the annual mortality rate (t = 0.13, gl = 98, p = 0.45; **Figure 1a**), despite the variation found when analyzing by 20 × 20 m subplots. It can be seen that when comparing between 1 ha plots, the average is equal for the two types of forest, with an average annual mortality rate equal to 2% (**Table 1**). Recruitment was higher for the primary forest (t = 2.91, gl = 98, p < 0.01; **Figure 1b**), and, as in the case of mortality at the 1 ha scale, the result is corroborated (**Table 1**). The population change was zero for primary forest and negative for clear-cutting. At the 20 × 20 m scale, significant differences were found between forest types (t = 2.16, gl = 98, p = 0.02; **Figure 1c**).

Table 1. Annual mortality rate (m), recruitment (r) and population change (λ) in 2 one-hectare plots established in primary forests (P3 and P4) and 2 one-hectare plots in logged forests (P1 and P5) in the El Paujil reserve (Colombia)

Forest type	Plot	m	r	λ
Primary	P3	2.0	1.8	-0.2
	P4	2.0	2.2	0.2
	P1	1.7	0.6	-1.1
Logging	P5	2.3	2.2	-0.1

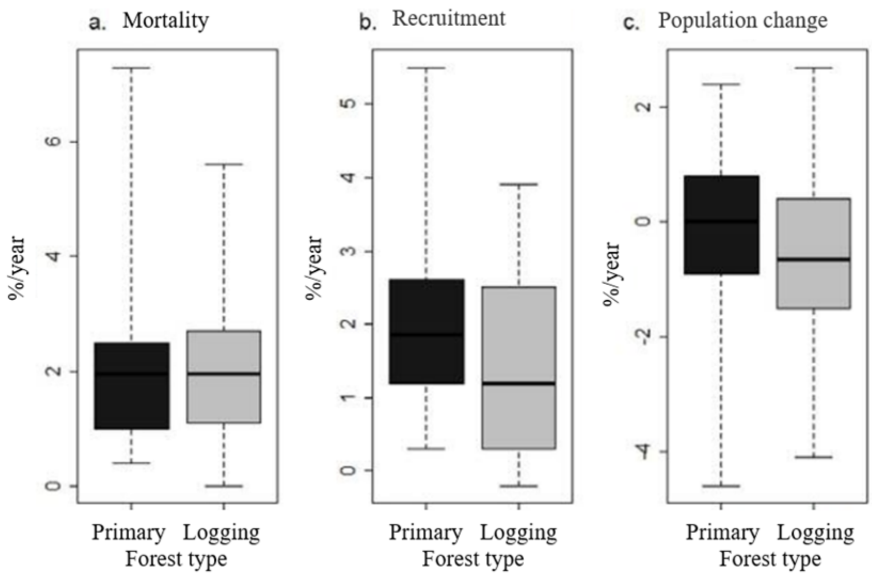

Figure 1. Comparison of annual demographic rates in 50 subplots of 20 × 20 m for primary forest and 50 subplots of 20 × 20 m for logged forest in the forests of the Paujil reserve (Colombia). **(a)** mortality, **(b)** recruitment and **(c)** population change. Mortality showed no significant differences, recruitment was higher for primary forest *(t = 2.91, gl = 98, p *<0.01*) and population change was zero for primary forest and negative for logged forest, with significant differences bn *(t = 2.16, gl = 98, p = 0.02).

3.2 Analysis of clearings and regeneration.

The amount of light reaching the understory in the forests of the El Paujil reserve is similar in both forest types (t = 0.32, gl = 98, p = 0.63; **Figure 2a**). Likewise, both the amount of seedlings and juveniles do not show significant differences between forest types (Welch's t = -2.18, gl = 197, p = 0.98; welch's t = -4.09, gl = 155, p = 1, respectively; **Figures 2b** and **2c**).

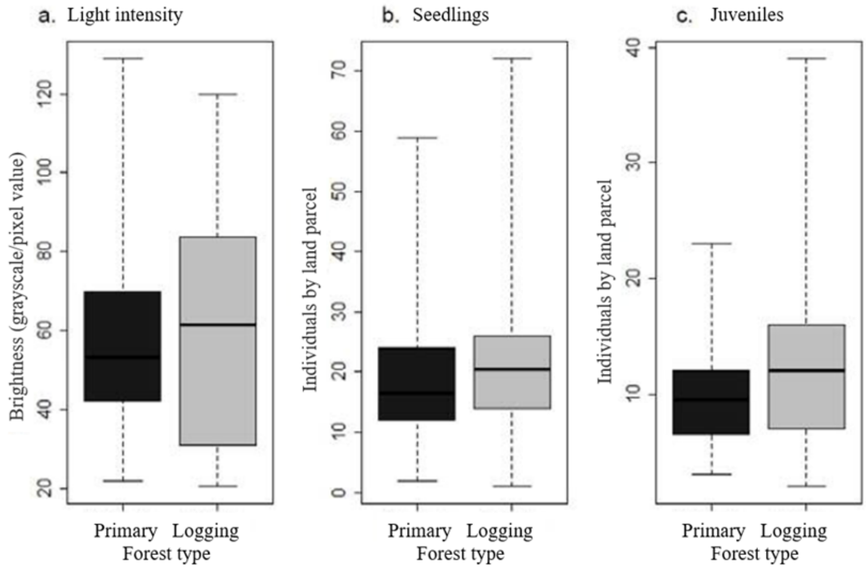

Figure 2. Analysis of the amount of light in the understory and plant density regenerating 50 subplots of 20 × 20 m for primary forests and 50 subplots of 20 × 20 m for logged forests in the El Paujil reserve (Colombia). **(a)** Light intensity. **(b)** Seedlings. **(c)** Juveniles.

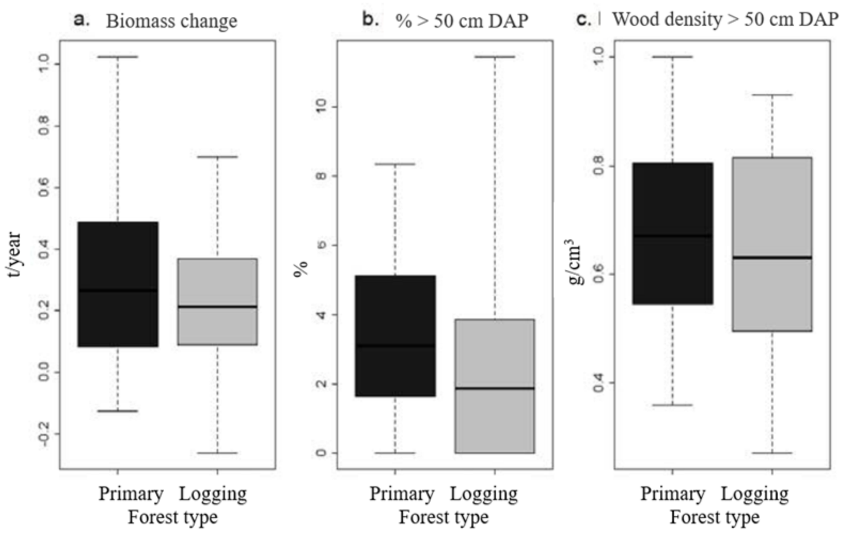

Figure 3. Comparison of structural aspects between 50 subplots of 20 × 20 m for primary forest and 50 subplots of 20 × 20 m for logged forest in the El Paujil reserve (Colombia). **(a)** Percentage of large trees (DAP > 50 cm), where the primary has a higher value *(t = 1.40, gl = 98, p = 0.04). **(b)** Wood density of large trees for primary and logged forest, where the primary has a higher value *(t = 2.17, gl = 107, p = 0.016).

3.3 Biomass change

The primary forest gained on average 4 Mg biomass ha^{-1} $year^{-1}$, going from having on average 459.5 Mg ha^{-1} in 2006 to having 487.6 Mg ha^{-1} in 2013, while the logged forest gained less biomass, with an average of 0.9 Mg ha^{-1} $year^{-1}$, going from having 440.6 Mg ha^{-1} in 2006 to having 447.1 Mg ha^{-1} in 2013. We found that there are fewer trees with a DAP greater than 50 cm in the logged forest (t = 1.40, gl = 98, p = 0.04; **Figure 3a**), and, that the wood density of these trees (<50 cm DAP) is lower than in the primary forest (t = 2.17, gl = 107, p = 0.016; **Figure 3b**).

4. Composition

The most important species in the primary forest plots differ from those in the logged forest, and they are mostly trees with good quality timber[24], the target of the reforesters (**Table 2**). The component that most influenced the determination of the importance index was the relative basal area (**Annex 2**). The conservation status of these species has mostly not been assessed, however Clathrotropis brunnea is known to be endangered, Hymenaea courbaril is of least concern and Grias haughtii is vulnerable (**Table 2**).

A high floristic affinity was found in the primary forest plots, while the logged forest is more heterogeneous, with one plot more similar to the primary forest group than that of the same forest type (**Figure 4**).

Table 2. Most important species for each one-hectare plot (two per forest type) established in the El Paujil reserve, with their importance index value, wood use, wood quality and conservation status in Colombia

Forest type	Plot	Species	Importance index	Use of wood	Wood quality	State of conservation
	P3	Eschweilera andina	11.87	x	good	NE
		Andira chigorodensis	7.62	x	very good	NE
		Garcinia madruno	7.11		bad	NE
Primary		Clathrotropis brunnea	6.21	x	bad	EP
	P4	Clathrotropis brunnea	14.66	x	bad	EP
		Pseudolmedia rigida	7.95	x	bad	NE
		Hymenaea courbaril	6.58	x	half	CA
		Eschweilera andina	6.2	x	good	NE
		Cavanillesia platanifolia	13.86		bad	NE
	P1	Simira rubescens	7.95	x	half	NE
		Grias haughtii	7.02	x	half	PM
Logging		Ephedranthus colombianus	6.79		bad	NE
		Pourouma melinonii	13.53		N/A	NE
	P5	Laetia procera	8.15	x	N/A	NE
		Chrysophyllum lucentifolium	7.63	x	good	NE
		Trichospermum galeottii	7.11		bad	NE

Conventions: NE = Not Evaluated, EP = Endangered, CA = Near Threatened, N/A = Information Not Found, PM = Least Concern.

Figure 4. Dendrogram comparing the floristic composition of 2 one-hectare plots established in primary forests (P3 and P4) and 2 one-hectare plots in logged forests (P1 and P5), in the Quinchas mountain range (Colombia).

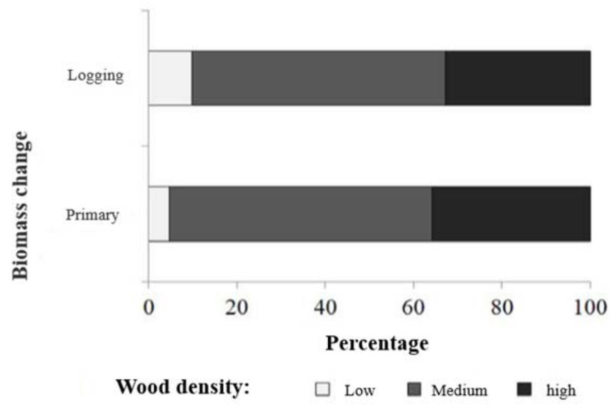

Figure 5. Proportion of individuals sampled in 2 plots of 1 ha for primary forest and 2 plots of 1 ha for logged forest in the El Paujil reserve (Colombia) grouped into three categories of wood density, corresponding to: low between 0.10 g/cm^3 and 0.39 g/cm^3, medium between 0.40 g/cm^3 and 0.69 g/cm^3 and high between 0.70 g/cm^3 and 0.90 g/cm^3.

As a result of the classification by wood density, it was found that the proportion of trees in each wood density category depended on forest type (g = 44.266, gl = 2, $p < 0.01$), finding a higher proportion of species with low wood density in logged forest (**Figure 5**).

5. Discussion

5.1 Demographics

The demographic components analyzed for the forests of the El Paujil reserve did not behave as expected. Mortality was the same for both forest types (**Table 1** and **Figure 1a**), although it was expected to be higher in the logged forest due to mechanical damage because of greater exposure to wind from trees adjacent to logged areas[4]. Recruitment, which was expected to be higher in logged forest due to the greater amount of light available as a consequence of logging, was higher in primary forest (**Table 1** and **Figure 1b**) and in fact there were no differences in the amount of light entering the understory in the two forest types (**Figure 2a**). The population of primary forest did not change, while that of logged forest decreased (**Table 1** and **Figure 1c**), showing significant differences between the two forest types.

As mentioned above, the forest sites sampled have a geographic altitude ranging from 194 m to 471 m, in areas with slopes up to 40°. It has been shown that soil slope is a primary ecological factor, which controls the mortality rate by tree fall and, therefore, induces a strong light gradient in the understory that favors the growth and recruitment of pioneer species[26]. In the forest of the El Paujil reserve, where high mortality is almost equal in areas with selective logging and primary forest, it can be said that the effect of slope on tree mortality can mask the effect of logging as suggested by Ferry[26].

On the other hand, a high abundance of lianas in the primary forest would contribute to the formation of clearings, since it negatively affects mature forest trees[7]. To evaluate this explanation, the relative abundance of lianas in both forest types was determined and compared, which corroborated the prediction, as it was higher in the primary forest (Welch's t = 2.09, gl = 85, p = 0.02). However, it could be seen that the percentage of lianas in the primary forest of the El Paujil reserve has a high value (2.98% on average) compared with other plots of the same extension established by researchers of the Laboratory of Ecology of Tropical Forests and Primatology (LEBTYP) in Colombia, but not significantly higher compared to the other plots of dry land (1.46% on average N = 20) (Welch's t = 2.92, gl = 2 p = 0.93). Therefore, there is still uncertainty about the effect of liana abundance on the dynamics of these forests.

5.2 Clearance analysis and regeneration

The magnitude of the clearings in the forests of the El Paujil reserve, is similar in both forest types (**Figure 3**) as well as the previous results. It leads us to think that the dynamics are mainly shaped by the effect of the slope of the terrain, causing a high mortality by falling trees similar to or greater in magnitude than that caused by the effect of disturbance (wind) after logging activities. Winds have been identified as a key factor in mortality and post-disturbance dynamics mainly in relatively flat areas, as for example in the Amazon, where the influence of wind can be greater[27,28].

Although there is a similar proportion of clearings and quantity of seedlings and juveniles in the two forest types, the higher recruitment observed in the primary forest could be the result of the effect of mechanical damage caused to seedlings and juveniles in the logged forest by the constant movement of people (e.g. tourists and researchers). That is due to its easy access has a much higher influx than in the primary forest.

5.3 Biomass change

Estimates of biomass reserves per hectare for the two forest types are relatively high when compared to estimates made for these forests in Colombia[29], however, this is explained by the fact that in this study trees from 5 cm DAP were included. This is not a common practice in biomass estimation studies. However, it is important to include smaller individuals, given that it not only increases the estimates of biomass reserves per ha[14], due to the effect of the increase in the number of individuals counted, which can be almost double, but also the estimates of species diversity (**Annex 1**).

As expected, the primary forest had a higher net biomass gain per hectare than the logged forest. This is in agreement with what has been reported in studies of biomass dynamics in tropical primary forests, where annual increases in biomass per hectare have been reported in the order of 3 to 20 tons[30]. However, it is notable that the lower values, reported in the present study for logged forest, resemble values reported by other studies of biomass dynamics in fragmented forests[31]. Additionally, the greater number of large trees observed in the primary forest (**Figure 2b**), added to the fact that these have trees with higher density timber (**Figure 2c**), shows an effect of selective logging that cannot be easily compared with intrinsic factors of forest dynamics and that takes long periods of time to return to normal. The decline in the populations of certain tree species, which are subject to logging for the quality of their timber, is clear. It is important to highlight that, if fragmentation and selective logging continue in this region, the effects on carbon dynamics could be extremely negative to the point that these forests may cease to be carbon reservoirs and become sources of CO_2 emissions, as has been predicted for fragmented forests in the Amazon[32].

5.4 Composition

Assuming that the forests had a similar composition before logging, the differences in comparing composition and dominance between forest types (**Table 2** and **Figure 4**) can be related to this activity. For example, large tree species (larger basal area) and high wood density (considered an important quality factor) are less important in the logged forest (**Table 2**, **Figure 5**). Again, it is evident that the strongest effect of selective logging on the forest was to generate changes in species composition by decreasing the populations of timber tree species. This factor should be considered in timber industry management plans, as some of these species are in a state of vulnerability (**Table 2**) or their current conservation status is unknown[25]. Additionally, it may have implications in the trophic interactions of the ecosystem, where critically endangered and declining populations of critically important dispersers such as the spider monkey (Ateles hybridus hybridus) inhabit[11].

Other studies have reported changes in the species composition of forests in the region, as a response to changes in climate[33], which added to the effects of selective logging that we evidenced in this study, could cause strong declines in the populations of plant species in these forests.

6. Conclusions

The dynamics of the forest in El Paujil Reserve do not show great differentiation due to selective logging in the past. It is important to highlight the effect of topography on forest dynamics and studies on the effect of vines and human traffic are recommended. The structure of the forest changes and biomass reserves decrease due to selective logging, as there is a significant decrease in the populations of large trees of species with good quality wood in the logged forest, which can affect the trophic interactions of the forest and its capacity to be carbon sinks. This type of species must be managed to avoid irreversible declines in their populations.

Conflict of interest

The authors declare that they have no conflict of interest.

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Annexes

Annex 1. Number of individuals and species for each one hectare plot including trees over 5 cm DAP and over 10 cm DAP, taken from Aldana *et al*.[11]

Forest type	Plot	DAP >5 cm		DAP >10 cm	
		No. Species	No. Individuals	No. Species	No. Individuals
	P3	246	1,048		606
Primary	P4	226	924		446
	P1	234	1,070		721
Logging	P5	201	1,000		545

Annex 2. Most important species for each one hectare plot (two per forest type) established in the El Paujil reserve with values of density, frequency, relative basal area and importance index

Forest type	Plot	Species	Relative density	Relative basal area	Relative frequency	Importance index
Primary	P3	Eschweilera andina	2.19	9.57	0.11	11.87
		Andira chigorodensis	1.90	3.81	1.90	7.62
		Garcinia madruno	3.24	1.97	1.90	7.11
		Clathrotropis brunnea	1.81	3.17	1.23	6.21
	P4	Clathrotropis brunnea	3.87	8.06	2.73	14.66
		Pseudolmedia rigida	4.62	1.03	2.30	7.95
		Hymenaea courbaril	1.00	4.72	0.86	6.58

Annex 2. (Continued).

Logging	P1	Eschweilera andina	1.87	4.33	0.04	6.24
		Cavanillesia sp01	0.26	13.25	0.35	13.86
		Simira rubescens	3.55	2.88	1.52	7.95
		Grias haughtii	3.29	1.73	1.99	7.02
		Ephedranthus colombianus	1.90	3.37	1.52	6.79
	P5	Pourouma melinonii	4.62	5.91	3.00	13.53
		Laetia procera	2.49	3.80	1.86	8.15
		Chrysophyllum lucentifolium	2.72	2.91	2.00	7.63
		Trichospermum galeottii	2.72	2.81	1.57	7.11

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Review Article

Economic analysis of forestland use rights transfer and forestland welfare change

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ABSTRACT

This paper qualitatively analyzes the connotation of woodland welfare and the changes of woodland welfare that may be caused by the transfer of the right to use, and interprets the welfare improvement caused by the transfer of the right to use of woodland in the ideal state by using the relevant theories and models of microeconomics. Based on the prospect theory and psychological account theory of behavioral economics, this paper analyzes the reasons why the transfer of forestland use right has not been carried out on a large scale in China.

Keywords: Woodland Use Right; Circulation; Woodland Welfare; Behavioral Economics

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1. Introduction

Forest land is an important part of forest resources and land resources. The right to use forest land is a property right separated from forest land ownership, including the right to occupy, use, benefit and dispose of the forest land under certain conditions[1]. In the 1990s, some provinces (autonomous regions and municipalities directly under the Central Government) of our country made a beneficial attempt to the circulation of forestland use right and achieved some results[2]. With the deepening of the reform of collective forest tenure system, it has become an inevitable choice to promote and regulate the circulation of forest land use right[3]. Previous studies on this aspect mainly focus on the following two points: first, the transfer mechanism of forestland use right, and macro-qualitative research on existing problems and countermeasures[4-6]. The second is the field investigation and research on the circulation of forestland use right[2,7,8]. However, there is a lack of economic research based on the micro perspective of farmers. But in terms of land transfer welfare, Yuan *et al.*[9], Liu *et al.*[10], Gao *et al.*[11], Xiong *et al.*[12], Fan[13] carried out some pioneering studies, which provided important references for the study of forest welfare. Based on the basic theories and methods of welfare economics, microeconomics and behavioral economics, this paper analyzes the benefits of forestland transfer from the perspective of farmers. It also explains the difference between the ideal welfare improvement and the actual transfer situation, and promotes the normalization, marketization, rationalization and efficiency of the use of forestland use rights transfer in our country.

2. Forestland use right circulation and forestland welfare

2.1 Connotation of woodland welfare

In microeconomic theory, welfare is considered to be a reflection of individual or collective preferences or level of satisfaction. Economics generally assumes that agents are rational and its goal is to maximize welfare. Forest land is a rare and precious resource. The multifaceted use of forest land brings a wide range of benefits to people. The main aspects are as follows: (1) economic welfare: farming forest land can obtain forest land economic production, provide farmers with tradable forest economic products, thus generating economic benefits; (2) ecological welfare: forestland can provide water conservation, wind prevention and sand fixation, environment purification, carbon sequestration, climate regulation, wildlife habitat and biodiversity protection and other multi-ecological services; (3) social welfare: for farmers, forest land not only has productive function, but also has non-productive function. Forestland can provide farmers with a series of social welfare, such as production and living guarantee, employment opportunity, social status, psychological comfort, labor preference, inheritance rights for future generation, future development and compensation mechanism guarantee.

2.2 Forest land welfare ment brought by transfer of forest land use right under ideal state

Under the ideal condition of assuming that the circulation of forest land use rights is smooth and effective, the circulation of forest land use rights can give full play to the allocation function of the market and make full use of idle forest land resources which is an effective measure to deepen the reform of forestry management mechanism and an effective mean to improve forestry productivity. It is conducive to promoting the scale, intensification and efficiency of forestry management, and promoting the realization of the goal of sustainable forest management[5,14,15]. Generally speaking, the circulation of forestland use right can bring the following benefits: (1) promoting large-scale management of forest land, revitalize forests with science and technology, and improve the economic welfare of forest land. Household management of forest resources usually results in fragmentation of forest resources and ecosystem. And due to limited human resources and technology, household management is often in a low-level operation. Forestland can make forestland transfer to the main body that has the ability to engage in large-scale intensive management, so as to help realize the centralized production of forestland, unify the operation and form a standardized economy. After acquiring the right to use forestland in the form of paid transfer, the operators pay more and more attention on improving economic benefits by relying on science and technology. They actively hire forestry technical personnel to give guidance, take initiative to understand forestry related laws and regulations, and learn new forestry technologies and achievements actively, so as to promote the application of science and technology in forest management and effectively improve the economic welfare of forest land.

(2) Promoting the protection and sustainable management of forest resources and enhance the ecological welfare of forest land. The paid circulation of forestland use right makes forestland users pay the cost for using forestland. Therefore, it is the most effective way to motivate farmers' forest land economic activity through interest drive. Driven by the interest mechanism, protecting forest land is to protect a part of their own property rights and interests. They take forest as their own assets and have a stronger initiative to protect forest land, which makes it better protected. In addition, in order to realize the forestland pre-harvest benefits, farmers value the forestland management rights, actively increase the pace of afforestation and greening, strengthen forest tending management, take measures such as watering, fertilizer, disease and insect pest prevention and treatment to improve the level of forest operation and management, promote the sustainability of forest resources, so as to enhance the ecological welfare of forest land.

(3) Widening the forest industry investment channels, promoting labor force shift, improving the social welfare of forest land. The circulation of for-

estland use right revitalizes forestland resources, turning forestland resources into forestland assets, which in turn become forestland capital under the support of financial instruments. Farmers can obtain profits through the circulation of forest land, carry out forest land capital operation through forest tenure mortgage, further expanding the channels of forestry investment. After the circulation of forestland use rights, a good situation has gradually formed in which the whole society runs forestry, and the state, collective and individual investors actively participate in forestry construction. In addition, with the rapid development of non-agricultural and non-forestry industries in rural areas, the opportunity cost of farmers to operate forestry has increased, and the transfer of forestry labor is also very obvious due to the temptation of comparative interests. Through the transfer of forestland use right, more rural surplus labor force can be released from forestland, promoting the non-forestland industry, social transformation and economic development of rural villages, and improving the social welfare of forestland.

Ideally, the transfer of forestland use rights can not only promote the improvement of individual welfare, such as the individuals' economic benefits and social welfare from forest land transfer, but also can promote the overall level of social welfare. Forestland circulation can improve the scale benefit of forestland, promote the transfer of labor force, promote the transformation of ecological conditions and environmental benefits. Certainly, the increase of the overall welfare of the society is not the same as the increase of the individual welfare of farmers. Farmers usually consider the change of their own welfare level when rationally choosing the behavior of forestland transfer.

3. Microeconomic analysis on welfare improvement of forestland use right transfer

From the point of view of economics, farmers are usually assumed to be economic people. The circulation of forestland use right is a rational choice. In the followings, microeconomic theories are used to explain the main welfare improvement brought by the transfer of land-use rights, that is, it can promote the transfer of rural labor force and employment opportunities, and optimize the allocation and scale management of forest resources.

2.2 A shift in employment opportunities

The essence of forestland use right transfer is the transaction process of forestland use right and management right, and also the transfer cess between forestry employment opportunities and non-forestry employment opportunities for both parties involved in the transferring process. The non-forest employment income level of the transferring households is the opportunity benefit of transferring out the forest land use rights. Whether there are sufficient non-forest employment opportunities and a high level of non-forest income will greatly affect the willingness and actual behavior of transferring households.

Pareto optimality in microeconomic theory refers to a state of resource allocation. Without making any human situation worse, it's impossible to make somebody's situation better. In the optimal allocation of two given amounts of resources between two consumers, if the satisfaction of each utility (or interest) is maximized, then the state of Pareto optimal of the exchange of resources is reached[16]. Forestland use rights transfer is a mutual transfer between preference of forestland management behavior and preference of non-forestland management behavior without considering the forestland and non-forestland employment benefits expectations. Through the transfer of forestland use right, the demands of forestland management and non-forestland management of transfer-out party and transfer-in party have been satisfied. Their welfare level has been further optimized. This can be illustrated by the further use of the Edgeworth box diagram (see **Figure 1**).

In **Figure 1**, transfer-out household A and transfer-in household B are the two main bodies of the transformation. Their operating resources are limited. There are two alternative strategies for business behavior, that is, after dividing forest to households, choose forest land management or transfer out forest land to engage in non-forest

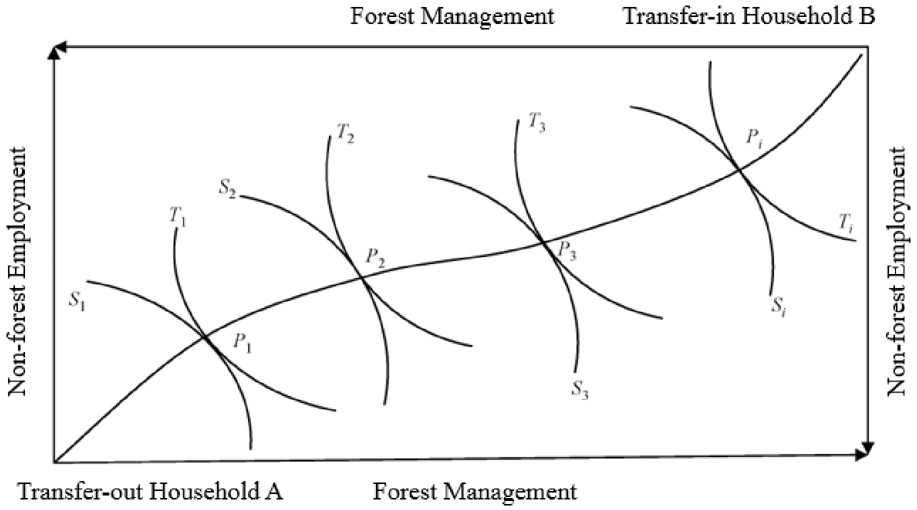

Figure 1. Edgeworth box diagram of conversion between forest management and non-forest employment of transfer-out household A and transfer-in household B.

management behavior. The indifference curve of transfer-out household A is $T = \{T_1, T_2, T_3, \ldots, T_i\}$, and the indifference curve of transfer-in household B is $S = \{S_1, S_2, S_3, \ldots, S_i\}$. Where, i represents the number of exchanges. The tangent point P_i of the indifference curves of transfer-out household A and transfer-in household B is the Pareto optimal point for resource allocation and exchange, while the curve $P = \{P_1, P_2, P_3 \ldots P_i\}$ constructed by all the tangent point P_i is the contract curve of resource exchange, representing the set of all optimal allocation (Pareto optimality) of two resources between the transfer-out and transfer-in households[16]. It can be seen from this those points outside the contract curve, the marginal substitution rates of the indifference curves of the transfer-in and transfer-out households are not equal. Both parties to the transaction did not reach Pareto optimal state. In this case, continuing the transaction can improve the situation of both parties and increase the welfare of both parties. Until the marginal substitution rates of the indifference curves of both sides to the transaction are equal on the contract curve, the two-way satisfaction is maximized, and the transaction reaches Pareto optimal state[16]. For transfer-out households, if there are not enough non-forest employment opportunities to guarantee the income level of farmers, their actual and expected income will decrease, the opportunity cost of circulation transactions will increase, and the willingness of circulation will decrease; for the transfer-in households, if there is no higher expected profit of forestland operation after the transfer, the willingness of farmers to transfer forestland will be significantly weakened. Therefore, only when the respective forest-land revenue and non-forest employment revenue of both sides after the circulation are optimized, that is, when each point on the optimal transaction contract curve P is reached, can the circulation transaction reach Pareto optimality.

3.2 Optimizing allocation and scale management of forest land resources

The transfer of forestland use right can effectively solve the fragmentation of rural forestland. The improvement of forest management model will help to realize the scale economy. Mass production can improve the application of production technology, change the input combination of production factors through production technology so as to lower costs and raise the productivity. This paper analyzes the short and long-term production equilibrium curves. As shown in **Figure 2**[13], short-term marginal cost curve SMC_{ab} and short-term average production cost curve SAC_{ab} represent the production scale of household A and household B under the short-term production equilibrium situation. Due to the small production scale of farmers A and B, it is difficult to rationalize the production cost ratio under the given production scale and production technology, and production costs are also relatively high, so households A and B's optimal point in the short-run production equilibrium is at point a. The production of its counterpart is Q_1. Under the condition that the existing resources are fully utilized in the long-term and the existing production factors are reasonably allocated, the farmers can produce at most at the lowest point *b* of the short-term average production cost curve SAC_{ab}, and the output is Q_2. If the forestland use rights circulation is implemented, making woodland A and B managed by one household, set as household C, then the short-term marginal cost SMC_C and short-term average production cost SAC_C represent the production scale of farmer C. In the long run, because of production factors such as labor input, production technology and production resources have changed and existing of scale economy, household C can produce at the long-term production equilibrium point *c*, which is tangent point between the long-term cost curve LAC and the long-term marginal cost curve LMC, and its yield is Q_3. Obviously $Q_3 > Q_2 > Q_1$, so the production goes up. Point *c* is lower than point *a*, indicating that the cost of centralized production of household A and household B is lower than that of individual production, thus, the optimal allocation of forest resources and scale economy are realized.

To sum up, under the ideal state, the transfer of forestland use rights promote the conversion of labor force and employment opportunities in rural areas, and the realization of scale economy of forestland, thus realizing the improvement of individual welfare and overall social welfare.

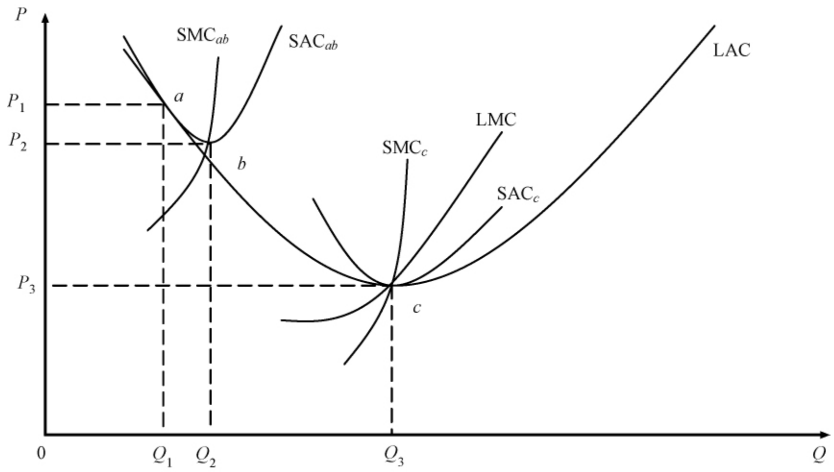

Figure 2. Utility of forest scale management.

4. Behavioral economics analysis of current situation of forestland use right transfer

Currently, the macro social and economic environment in our country has greatly changed, property rights further clarified, market economy system has improved a lot, social economy develops relatively fast, and non-agricultural income of farmers increased constantly. However, in practice, the large-scale transfer of existing forest land does not occur as expected as the ideal state analyzed above. From September to November 2007, the Economic Development Research Center of the State Forestry Administration conducted a survey of circulation of forest land use rights in 9 counties of four representative provinces of the national collective forest rights system reform (city): Jiangxi, Fujian, Liaoning and Yunnan, 18 townships (towns), 32 administrative villages, 305 rural households, 292 valid questions were obtained. The results showed that the occurrence rate of farmers' forest land transfer was still low, but significantly increased after the forest reform compared to the pre-forest reform. Farmers' forest land transfer has not reached a certain standard scale, and there is still a long way to go before the real forestry scale operation[17]. The reasons behind are worth investigating

In September 2009, the author organized a research team to conduct a questionnaire survey to the 180 typical sample farmers in Tonggu county and Jing'an County of Yichun City, Jiangxi Province. In December 2010, a total of 212 typical sample peasant households were investigated in Shaowu (county-level city) and Youxi County of Sanming in

Nanping, Fujian province. A total of 366 valid investigation papers were obtained, with an effective rate of 93.4 %. The investigation indicated that the farmers who were willing to transfer out accounting for 26 %, farmers who were not willing to transfer out accounting for 74%. This shows that under the current policy environment and income conditions, the majority of farmers choose to manage their own forest land, and there is a certain but not extensive mass base for forest right transfer[18]. 60 households of the investigated households once transferred in forest rights, accounting for 16%; 30 households once transferred out forest rights, accounting for 8%; 14 households once transferred in and transferred out forest rights, accounting for 4%; 262 households, accounting for 72%, did not transferred forest rights. The results also indicate that forest rights transfer has not been widely carried out in the sample areas.

The following uses the theory of behavior economics to analyze the behavior of farmers' forestland transfer, and the deeper and more realistic reasons why forestland transfer did not happen on a large scale. From a behavioral economics perspective, the main reason why farmers do not want to transfer out forestland use rights on a large scale is that their economic behavior is largely influenced by survival ethics, endowment effect, expectation effect and mental accounting, etc.[11].

4.1 "Safety first" and "risk avoidance" survival ethics

According to the prospect theory of behavioral economics, the decision-making process is mainly determined by the value function and the decision weight function, while the value function depends on the change of wealth and is expressed by the gain or loss relative to a reference point. People tend to be risk-averse when facing the prospect of profit[19]. For a long time, Farmers in China have been at the bottom of the society, forming the survival concept of "safety first" and "risk avoidance", and the purpose of farmers' economic behavior is not to pursue "efficiency" but for life. Farmers do not pursue the maximization of interests in economic rationality, but take survival protection as the starting point and prefer to reduce the probability of loss. In the farmers' consciousness, land is the guarantee for their survival due to the uncertainty of their future life and living period, and being separated from the soil means the risk of survival. The behavior decision of farmers for land must be based on survival and security. Therefore, under the survival principle of "safety first" and "risk avoidance" of farmers, although the living environment of farmers is still improving and forestland transfer has more economic benefit of scale, forestland transfer may not get the positive response from farmers[12].

4.2 Endowment effect and expectation effect

The endowment effect, which Thaler discovered in 1980, suggests that people value what they own so much that it takes a lot for them to give it up[19]. After the implementation of the land household contract responsibility system in China, farmers and people enjoy the contracted management rights and use rights of forest land, and can lease the forest land at a lower price or without compensation. In a sense, it can be considered that forest land has become a source of resources for farmers and family wealth. For farmers, the transfer of forestland use rights means that their original family resource endowment and means of production have changed, and the contracted forestland has changed from existence to non-existence, and farmers have lost the opportunity to obtain sustainable forestry benefits. In particular, with the advancement of property rights reform, the introduction of various preferential policies, and the decreasing cost of occupying and managing forestland, the endowment is even more obvious. In addition, with the improvement of forestry production level, people's environmental awareness and demand for environmental products and services is increasing day by day, and the potential value of forest land is also rising. Today, though, non-forest income of farmers in many areas is sufficient to sustain their livelihoods., the scale transferring of forest land is not occurring as expected. The important reason is that: farmers believe that the current transfer price of forestland use right is low and forestland value will continue to rise in the future. In addition, the uncertain expectation of future life makes them more inclined to retain forestland. On the one hand, they seek safety protection, and on the other hand, they expect to transfer forestland at a higher price in the future. Therefore, because of the endowment effect and the expectation effect, farmers are not willing to transfer out the forest land.

4.3 The influence of mental accounting

The mental accounting was developed by behavioral science professor Richard Thaler of University of Chicago. Whether it is an individual, a group or a company, there exists one or more explicit or potential account systems. These account systems tend to follow some underlying psychological operation rules that are contrary to the rules of economic operation and influence individual economic decisions[19]. In rural areas, farmers generally regard the right to contract forestland they enjoy and the forestland they contract as part of their assets, regardless of the form in which the forestland is retained, they are used to regard it as their own assets and form their own "mental accounting"[12]. Considering the uncertainty of future ic benefits, farmers will have a stronger sense of psychological panic after the loss of forest land use right. Farmers are more willing to entrust their idle forestland to members of the village group or relatives and friends for management without an agreed term, because there is no psychological impact on the final possession of the forestland contracted by the farmers, so they can take it back when necessary, and not lose the forestland psychologically. Therefore, the private management of off-site forest land between village members or friends is the main way of forest land transfer in practice.

5. Enlightenment

Farmers are directly involved in the transfer of forestland and their behavior decisions directly affect the smooth transfer of forestland. Therefore, the government should consider the gap between theory and practice in the process of formulating forest land policy and promoting forest land circulation. Farmers are limited rational subjects in the practice of forestland use right transfer. It is necessary to take a behavioral economic perspective, pay attention to farmers' "economic rationality" and "non-economic rationality" double conduct research. Focusing on households behavioral decision habit, understanding their real willingness to transfer, adding the related policy to transferring, stabilizing forest land management system, establishing and improving social society system, eliminating farmers' psychological worries, appropriately guiding households' economic behavior, so as to promote the formation of stable psychological expectation and mental accounting. Only in this way can we effectively promote the transfer of forest land use rights, and finally promote the effective improvement of forest land economy, ecological condition and social welfare.

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Conflict of interest

The authors declare that they have no conflict of interest.

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