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Impact of Management Measures on Multiple Ecosystem Function Trade-Offs and Their Dynamics in Subtropic *Pinus massoniana* Plantations

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Abstract: With the changing demands imposed on forests by human beings, optimizing forest management to fully utilize their multifunctionality has become a priority. Reasonable forest management measures can maintain stable forest ecosystems that fully coordinate the balance between ecological, societal, and economic aspects. As planted forests are the main application scenario of forest management worldwide, it is of great importance to understand the trade-offs between ecosystem functions and their dynamic changes in planted forests. This paper investigates the effects of different management measures on the ecosystem function of *Pinus massoniana* plantation forests in the subtropics. It examines four different management measures and explores how they impact multiple ecosystem function indexes and the trade-offs between ecosystem functions during forest restoration. The different management measures effectively promoted the studied ecosystem functions, with higher annual growth rates of the integrated functional indices for timber production, carbon sequestration, and biodiversity compared to the control. Over time, the ecosystem function interactions under the different management measures alternated between trade-offs and synergistic. Only the stand with a 65% harvesting intensity and replanting of various native broadleaf species was able to sustain the synergistic relationships among ecosystem functions, and the dominant function trended toward biodiversity. These observations of dynamic changes and interactions in ecosystem functions of *Pinus massoniana* plantation forests under various management measures will serve as a valuable reference for the sustainable management of these forests in subtropical regions.

Keywords: management measures; ecosystem function trade-offs; ecosystem management; *Pinus massoniana* plantation forests

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1. Introduction

Human demands on forests are no longer limited to a single service. Indeed, considering the multifunctionality of forests, sustainable development in forestry has become a hotly debated topic [1,2]. Forest ecosystems provide natural environmental conditions and utilities essential for human survival and contribute significantly to sustainable well-being [3]. Ecosystem functions vary in type, supply and demand, spatial distribution, and time scales. When people prioritize and utilize one particular ecosystem function, other ecosystem functions can be affected through complex networks of direct and indirect interactions. This can make it impossible to maximize the value of multiple ecosystem functions simultaneously. These complex interactions also make it challenging to determine the individual "relationships" among functions [4,5]. Currently, most scholars recognize three types of relationships among ecosystem functions, these are trade-off, synergistic, and neutral relationships, in which ecosystem functions exhibit negative, positive, or no correlations, respectively [6,7]. The trade-off relationship occurs when increases in one ecosystem function come at a cost to another ecosystem function [8]. The synergistic relationship, or "mutual gain" relationship, occurs when two or more ecosystem functions work together and increase their functional benefits simultaneously. Neutral relationships, on the other hand, are those in which different ecosystem functions do not interact or influence each other [9]. Among the many forest ecosystem function studies, the three most widely studied aspects are timber production, carbon storage, and biodiversity [10,11]. In Sweden, by observing major changes in forest structure due to the replacement of fossil fuels by wood burning, Pang et al. explored the trade-off and synergistic relationships among the above three ecosystem functions with the aim of understanding the multifunctionality of forest ecosystems and developed a corresponding forest management model [12]. Similarly, in a subtropical region, the optimal forest management model was matched to demand by studying the relationships between carbon sequestration, timber yield, and biodiversity in eucalyptus plantation forests under different management models [13]. Different forest management models directly affect forest structures, which in turn determine the dominant function of the forest ecosystem [14–16].

Forest management has made large advancements domestically, from the plantation management used by all logging operations in the past to the current near-naturalization and multifunctional forest management models characterized by selective logging. However, current ecosystem forest management models differ widely in their prioritization of ecosystem diversity, management concepts, and dominant functions [17,18]. Traditionally, to alleviate timber shortage problems, rotational logging has been widely used. Such rotational logging operations are short term, highly intensive, and easy to carry out, with timber production being prioritized as the dominant function [19]. As human demands on forests change, their dominant functions must shift to maintain the sustainable development of forests. Furthermore, forest management models must take into account multiple functions outside of timber production and maintain the stability of forest ecosystems, a topic that has been examined by many scholars. In the 19th century, German scholars started applying the "near-natural forestry" approach by creating mixed-aged forests with relatively stable stand structures. Near-natural management is a technical feature of selective felling of target trees, promoting natural regeneration and realizing mixed forests of different ages with multiple species and levels, which has the characteristics of improving the stand structure, promoting biodiversity and forest ecosystem stability, etc., and has obvious advantages in maintaining the land force and sustainably exerting the functions of forest production and ecological services, and is more in line with the current demand for the development of forestry that comprehensively exerts a wide range of functional benefits [20]. Subsequently, the United States, Japan, Australia, and many other countries have explored a variety of forest management models to balance ecological, societal, and economical demands while sustaining timber production and to promote the development of multifunctional forestry [21–23].

The creation of mixed forests has been identified as an effective measure to improve the forest stand structural stability. China has a long history of exploring multifunctional forest management with scholars conducting systematic studies of near-natural management. They have revealed that, based on multi-level, multi-species forest stand structures, forests can naturally regulate nutrient cycling, as well as light, moisture, and temperature. This ensures more stable growth and development, cultivating high-quality timber and promoting increased biodiversity in the forest stand [24–26]. By making full use of the natural growth law of forest ecosystems, the forest management model based on natural regeneration succession has been unanimously recognized as the most stable in terms of maintaining the balance of ecology, economy, and society [27,28]. However, it is important to apply these concepts to plantation forests, which remain the main application scenario of forest management measures.

As other ecosystem functions are gradually being recognized, planted forests are no longer used exclusively for timber production. As the ecosystem functions of planted forests are becoming increasingly characterized, researchers have noted their importance in improving soil fertility, regulating and conserving water, and promoting biodiversity. In light of this realization, many studies have examined ecosystem functions of planted forests and the trade-off and synergistic relationships among them. Most pure forests planted under conventional rotation management are aimed at rapid timber production. However, rotational logging and continuous cropping measures lead to the excessive depletion of soil fertility, resulting in the decline of stand productivity and land degradation, as well as having many negative ecological and societal impacts [29,30]. Roopsind et al. [31] and Hoque et al. [32] found a trade-off relationship between carbon sequestration and timber production in forests, with logging intensity determining the strength of the trade-off relationship between the two. Furthermore, most previous studies have found that biodiversity and carbon sequestration exhibit synergistic relationships, but some studies have observed trade-off relationships between the two functions, likely due to differences in spatial scales [33,34]. In this way, the trade-off and synergistic relationships between ecological functions are not static, and may depend on different management measures, different forest ages, or other factors. This emphasizes the importance of selecting appropriate and reasonable management measures, which is a process that needs to be investigated further. Therefore, this study monitored four *Pinus massoniana* plantation forests with different management measures at the Experimental Forestry Center of Tropical Forestry in Pingxiang City, Guangxi Province, China. By examining the dynamic data of the forest stands over 10 years of post-operational restoration, this study (1) investigated the differences in ecosystem functions of *P. massoniana* plantation forests under different management measures, (2) quantified the relative benefits and comprehensive function indices of the ecosystem functions of *P. massoniana* plantations under different management measures, and (3) investigated the trade-offs among the ecosystem functions of *P. massoniana* plantations under different management measures and their dynamic changes over time.

2. Materials and Methods

2.1. Overview of the Study Area

The study area was the Fubo Experimental Forestry Field (22°03′ N, 106°51′ E), Thermal Forestry Center, Pingxiang City, Guangxi Province, at an altitude of 400–1500 m. It has a southern subtropical monsoon climate with abundant rainfall and distinct wet and dry seasons. The average annual temperature ranges from 20.5 to 21.7 °C, with the lowest temperate reaching −1.5 °C and the highest 40.3 °C. The mean annual precipitation ranges from 1200 to 1500 mm, the annual evaporation ranges from 1261 to 1388 mm, and the relative humidity ranges from 80% to 84%. The landforms mainly include hills, terraces, and low mountains. The soil has a brick red color that originates from mottled granite and it is a mountainous, subtropical, evergreen, broad-leaved forest zone. The artificially planted trees were dominated by the horsetail pine *Pinus massoniana* and the fir *Cunninghamia lanceolata*, followed by *Castanopsis hystrix*, *Erythrophleum fordii*, and *Castanopsis fissa*, among others. The shrubs and herbs were mainly *Rhus chinensis*, *Phyllanthus emblica*, *Narenga fallax*, and *Arundinella anomala*.

2.2. Sampling Design

The study area was a *P. massoniana* plantation forest being managed with four different strategies. The *P. massoniana* plantation forest was planted in 1993, and in 2007, stands with relatively uniform slope directions, slopes, soil fertilities, and forest phases were selected for restoration with different management measures based on the near-naturalized renovation principle. The different management measures mainly used different harvesting intensities and different replanting species, with the harvesting intensity mainly being the stand stocking intensity. The four stands were subjected to four harvesting intensities, 65%, 70%, 75%, and 80%, and were replanted with fast-growing broadleaf species, including *Castanopsis fissa*, *Manglietia glauca*, the precious broadleaf species *Castanopsis hystrix*, *Erythrophleum fordii*, etc. Four replicate plots were set up for each management measure and a control plot was established. Each plot was circular with an area of 400 m^2.

2.3. Data Survey

The first survey was conducted in 2008, with measurements taken for each individual tree. The measurements included the diameter at the breast height (DBH), tree height (H), and crown spread of all trees with DBH greater than 5 cm. The stand data are summarized in Table 1. The sample plot was re-surveyed every two years thereafter, and at the end of the survey in 2016, a total of five data points had been obtained.

Table 1. Information of stands with different management measures.

Management Measures	Harvesting Intensity (%)	Stand Density (Trees/ha)	Average Diameter at Breast Height (cm) of Retained Tree	Average Height of Retained Tree (m)	Re-Planting Species
I	80%	1200	17.16 ± 2.80	13.21 ± 3.04	*Castanopsis hystrix*, *Michelia hedyosperma*
II	70%	1200	18.45 ± 1.78	15.04 ± 1.82	*Erythrophleum fordii*, *Castanopsis fissa*
III	75%	1200	18.72 ± 3.80	14.30 ± 3.95	*Mesua ferrea*, *Manglietia glauca*
IV	65%	1200	20.64 ± 1.07	17.09 ± 0.45	*Castanopsis hystrix*, *Erythrophleum fordii*, *Castanopsis fissa*, *Mesua ferrea*, *Michelia hedyosperma*
CK	0	1200	18.50 ± 1.25	15.92 ± 0.73	/

2.4. Quantification of Ecosystem Functions

2.4.1. Timber Production

Based on the DBH data and heights of individual trees in the fixed sample plots, the volume of individual trees was calculated based on the binary timber volume equation for forest trees provided by the Center for Thermal Forestry. The volumes of all of the individual trees in a sample plot were summed to obtain the volume of the sample plot level.

2.4.2. Carbon Sequestration

Carbon sequestration is vital for supporting the global carbon cycle and carbon balance. Therefore, this paper examined the aboveground (branches, leaves, and stems) and belowground (roots) carbon storage (CS) of trees. Based on the DBH data and heights of individual trees obtained from the survey, we calculated the carbon storage of individual trees using the derived biomass anisotropy equation and carbon content coefficients of different tree species [35]. The individual tree carbon storage values were then summed to obtain the total carbon storage at the plot level.

Expression for carbon stock in monocarbon:

$$CS = B_{above} \times P_{above} + B_{below} \times P_{below}$$

where CS is the carbon stock of a single tree; B_{above} and B_{below} are the aboveground biomass and belowground biomass of the tree, respectively; and P_{above} and P_{below} are the carbon content coefficients of aboveground and belowground parts of the tree, respectively.

2.4.3. Biodiversity

The four management measures in this study replanted different broadleaf species, so a reasonable stand structural diversity measure was selected. Stand structural diversity is an important component of biodiversity, and usually uses a combination of spatial distribution, species diversity, and tree size variation. The Shannon−Wiener index was used to estimate the stand structural diversity (size diversity) by dividing the forest trees according to DBH into two cm diameter classes. In this case, the larger the diversity value, the more evenly distributed the sample plot with the proportions of trees in different diameter classes tending to be equal. When the size diversity value was 0, the distribution of the sample site was not uniform and all the trees were in the same diameter class [36].

$$SD_n = -\sum_{j=1}^{d_c} \frac{n_j}{n} \ln\left(\frac{n_j}{n}\right)$$

where d_c is the value of the diameter steps in the sample plot and n_j is the value of plants in the jth diameter step in the sample plot.

2.5. Quantification of Integrated Functional Indices and Ecosystem Function Interactions

The trade-off and synergistic relationships among ecosystem functions were quantified using the Pearson's correlation coefficient and root mean square deviation ($RMSD$). Each ecosystem function was first standardized to eliminate unit differences between ecosystem functions. The standardization was conducted as follows:

$$ES_{std} = \frac{ES_{obs} - ES_{min}}{ES_{max} - ES_{min}}$$

where ES_{std} is the standardized value (between 0 and 1 closed intervals) of each ecosystem function; ES_{obs} is the observed value of an ecosystem function in the sample site; and ES_{max} and ES_{min} are the maximum and minimum observed values of an ecosystem function in the sample site, respectively.

The composite functional index mainly represents the average level of the different ecosystem functions measured, and is usually calculated using the mean value method with the following formula:

$$MF_{ave} = \frac{1}{F} \sum_{i=1}^{F} g(ES_{std})$$

where MF_{ave} is the composite functional index obtained based on the mean value method, F is the number of observations, and ES_{std} is the standardized value for each ecosystem function.

$RMSD$ is calculated according to following formula [37,38]:

$$RMSD = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n} (ES_i - ES\exp_i)^2}$$

where ES_i is the standardized value of the ith ecosystem function and $ES\exp_i$ is the average value after standardizing the value of the ith ecosystem function. In addition, the degree of benefit between two ecosystem functions can be determined using the diagonal graphical method (Figure 1), where $RMSD$ is expressed as the distance from the coordinates of the standardized values of a pair of ecosystem functions in dimensional space to the 1:1 line. In this method, when the angle with the vertical axis is greater than that with the horizontal axis, it indicates that the ecosystem function represented by the horizontal axis benefits more from the relationship, and vice versa. Furthermore, when the arrow lengths are the same, the angles between the arrow and the 1:1 line indicate which ecosystem function will be utilized (i.e., point A is more likely to utilize ES_1 and point B is more likely to utilize ES_2).

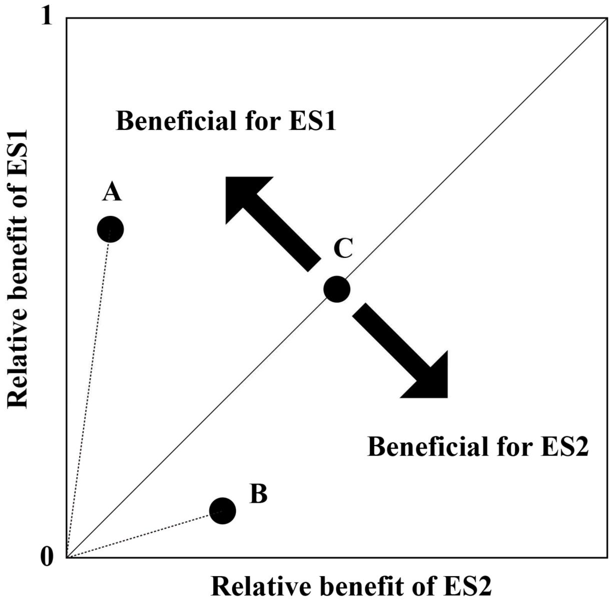

Figure 1. Map of ecosystem function trade-off benefits.

2.6. Data Analysis

Analysis of variance (ANOVA) was used to test for differences among timber production, carbon sequestration, and biodiversity across management measures; Pearson's correlation was used to quantify the trade-offs among ecosystem functions; and graphical representations of *RMSD* values were used to indicate the degrees of benefit between pairs of ecosystem functions. Statistical analyses, correlation analyses, and *RMSD* were conducted in *R.4.3.1*. Plots were constructed using *Origin2021*.

3. Results

3.1. Quantitative Analysis of Ecosystem Functions with Different Operational Measures

Carbon sequestration, timber production, and biodiversity increased with time in all four management measures (i.e., I–IV) and control stands. The differences in the mean values of carbon sequestration, wood function, and biodiversity function for different management measures are shown in Figure 2. During the nine-year restoration period, the annual growth rates in carbon sequestration and volume in Management Measure I stands (28.46% and 29.39%, respectively) were higher than those in the other plots. The annual growth rates of biodiversity in the Management Measure I–IV stands were 6.36%, 10.73%, 6.55%, and 8.95%, respectively, with the Management Measure II stand being the highest, followed by the Management Measure IV stand and then the Management Measure I and III stands, which were similar. The carbon sequestration, volume, and biodiversity of the control stand were significantly lower than those of the Management Measure I–IV stands.

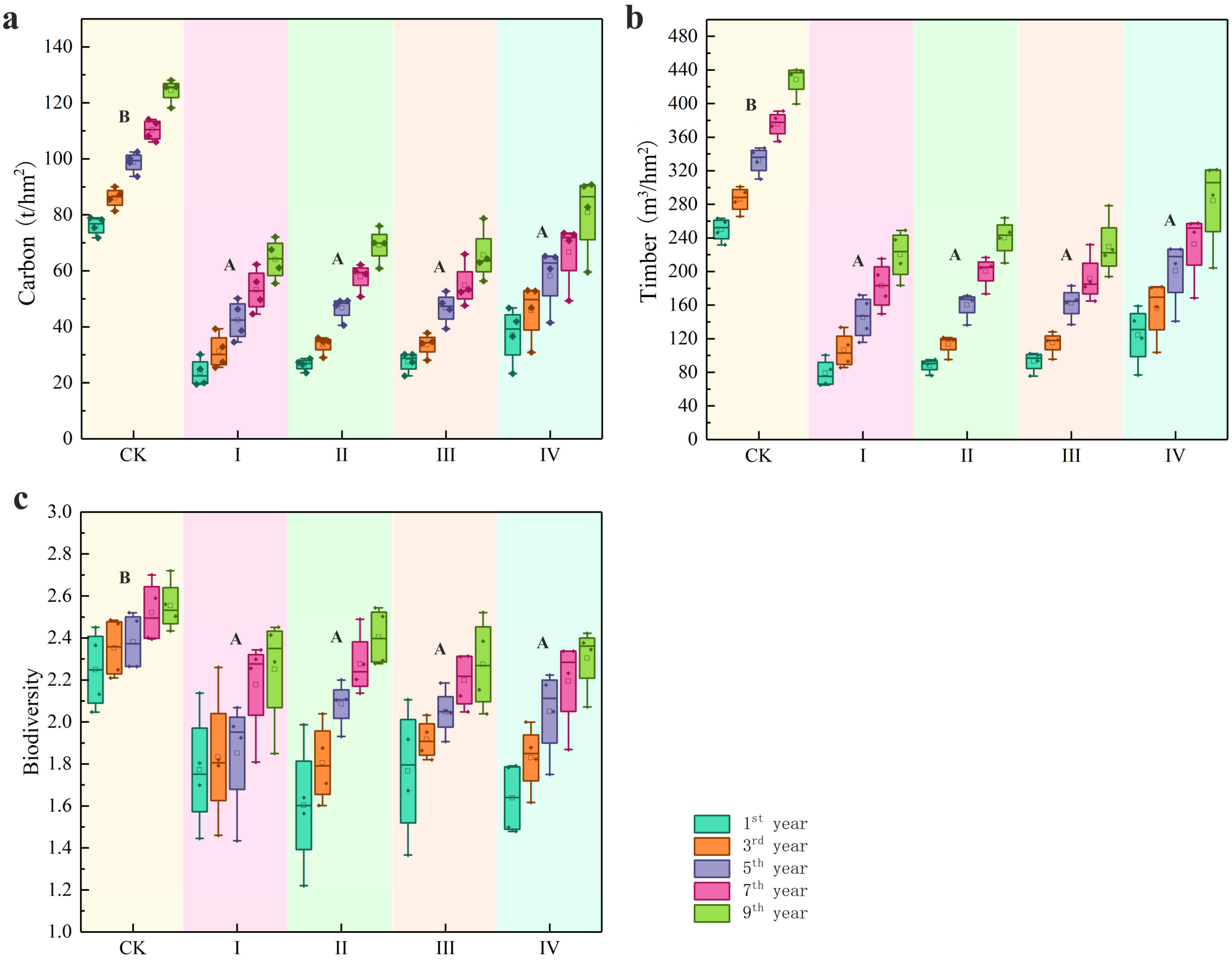

Figure 2. Carbon sequestration, timber production, and biodiversity in stands with different management measures. (**a**) Carbon sequestration in stands with different management measures. (**b**) Timber production in stands with different management measures. (**c**) Biodiversity in stands with different management measures. Note: Different letters (A and B) indicate significance of differences between different management measures ($p < 0.05$).

3.2. Relative Benefits of Ecosystem Functions

As shown in Figure 3, the relative benefits of the three ecosystem function indicators in the forest stand under Management Measures I–IV ranged from 0.04 to 0.97, so we defined values >0.51 as having "high benefit", values between 0.26 and 0.51 as having "medium benefit", and values <0.26 as having "low benefit". In the first year of restoration, the relative benefits of the three ecosystem function indicators in the Management Measure I–IV stands were low and medium, while the relative benefits of the three ecosystem function indicators in the control stand were medium and high.

From the first to the ninth year of restoration, the relative benefits of timber production in the Management Measure I–IV stands all changed significantly and, with the exception of the Management Measure I stands, all of the management measure stands reached a high efficiency, while there was no change in the relative benefit of timber production in the control stand. Timber production in the Management Measure I–III stands increased from low benefit to medium benefit and high benefit, while in forest stands under Management Measure IV, the benefit increased from medium to high.

The relative benefits in carbon sequestration and timber production in forest stands with Management Measures I–IV exhibited similar trends. The highest relative benefit for carbon sequestration occurred in the forest stands under Management Measure I, but it was still medium benefit. Out of the other three management measure and control stands, the next highest change in relative benefit in carbon sequestration occurred in the Management Measure IV stands. The relative benefits in biodiversity in the forest stands of Management Measures I–IV were sustained at moderate or above. The relative benefits of biodiversity in the Management Measure IV and control forest stands remained stable at high benefits, while the relative benefits of biodiversity in the forest stands fluctuated under Management Measure II and Management Measure III.

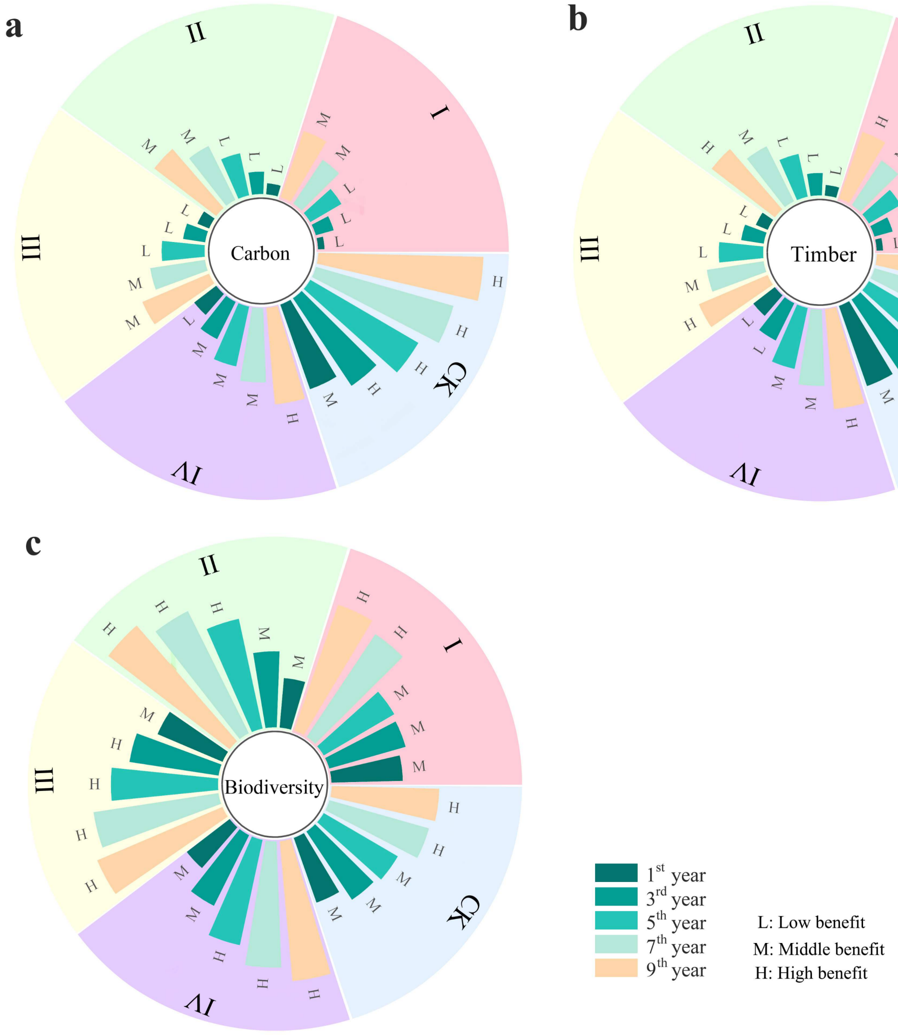

Figure 3. Relative benefits of three ecosystem functions. (**a**) Carbon sequestration ecosystem function. (**b**) Timber production ecosystem function. (**c**) Biodiversity ecosystem function.

3.3. Differences in Composite Functional Indices of Different Operational Measures

With increasing time, the composite function index of all management measures (i.e., I–IV) and control stands increased (Table 2). In the first nine years of restoration, there was a significant difference in the composite function indices of the Management Measure I–IV and control stands, with the control stand having the highest composite index. As shown in Table 2, there was a significant difference in the average annual growth rate of the integrated function index of the Management Measure I–IV and control stands. The average annual growth rates in the integrated function index of the Management Measure I–IV stands were significantly higher than that of the control stand, with the highest average annual growth rate being 33.21%.

Table 2. Composite functional indices for different management measures.

Year	I	II	III	IV	CK
1st year	0.17 ± 0.09 a	0.18 ± 0.08 a	0.19 ± 0.10 a	0.21 ± 0.10 a	0.47 ± 0.06 b
3rd year	0.23 ± 0.12 a	0.23 ± 0.05 a	0.26 ± 0.04 a	0.36 ± 0.08 a	0.56 ± 0.05 b
5th year	0.30 ± 0.10 a	0.39 ± 0.03 a	0.38 ± 0.06 a	0.45 ± 0.10 a	0.65 ± 0.05 b
7th year	0.45 ± 0.09 a	0.46 ± 0.06 a	0.47 ± 0.04 a	0.59 ± 0.09 a	0.76 ± 0.06 b
9th year	0.53 ± 0.09 a	0.54 ± 0.05 a	0.55 ± 0.06 a	0.66 ± 0.10 a	0.86 ± 0.08 b [1]

[1] Different letters (a and b) indicate significance of differences between different operational measures ($p < 0.05$).

3.4. Trade-Offs between Ecosystem Functions

During the first nine years of restoration, the relationships between the carbon sequestration–timber production functional pairs in the Management Measure I–IV and control stands remained synergistic. Similarly, the relationships between the carbon sequestration–biodiversity functional pairs and timber production–biodiversity functional pairs exhibited sustained synergistic relationships in the Management Measure I, Management Measure IV, and control stands, but in the Management Measure II stands they alternated between synergistic and trade-off relationships and in the Management Measure III stands the relationship shifted from synergistic to trade-off five years after restoration was initiated (Figure 4). In the first five years of restoration, the Management Measure I–III stands and the control stands performed carbon sequestration and timber production functions to varying degrees. In the seventh to ninth years of restoration, the biodiversity function gradually took over as the dominant function; in the Management Measure IV stands, the biodiversity function was dominant throughout the restoration period (Figure 5).

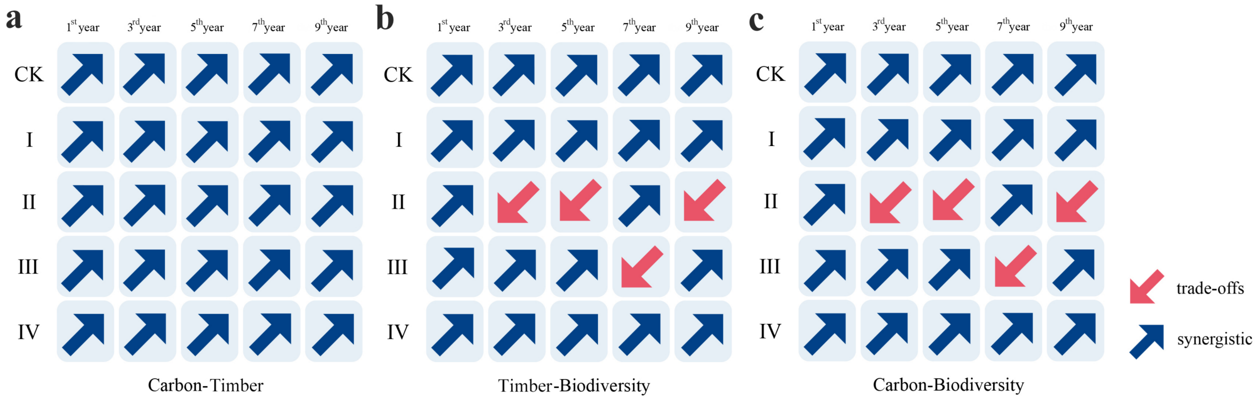

Figure 4. Trade-off and synergistic relationships between ecosystem function pairs. (**a**) Carbon sequestration–timber production. (**b**) Timber production–biodiversity. (**c**) Carbon sequestration–biodiversity.

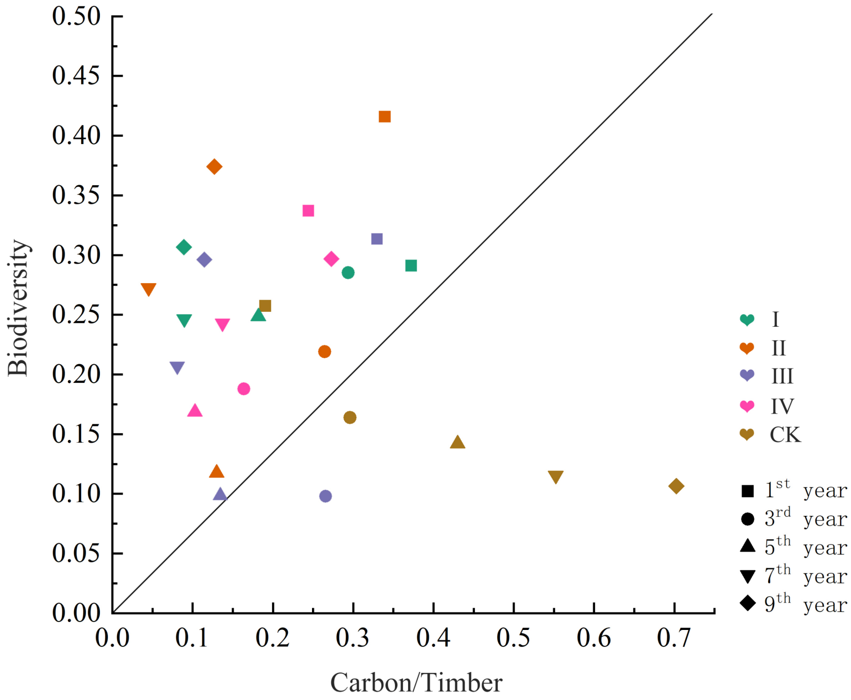

Figure 5. Ecosystem function trade-off benefits graph.

4. Discussion

4.1. Impacts of Different Management Measures on Ecosystem Functions

This study showed that different stand management measures had varied effects on the forest ecosystem. The management measure that had a harvesting intensity of 65% and replanted a variety of native broadleaf species had particularly significant effects. During years one to nine of restoration, the volume and carbon sequestration of the stands under the four management measures were significantly lower than those of the control stands. This may have been because the harvesting intensities in the managed stands in this study were all greater than 65%, qualifying as high-intensity harvesting. The densities of the retained wood in the stands were lower than that of the control stand, while the growth of the replanted native broadleaf species was also predominantly characterized by the presence of fast-growing broadleaf species and slow-growing broadleaf species. There was a large difference between the growth rates of the two categories of species, which resulted in the short-term timber production and carbon sequestration performances being relatively poor and also clearly indicated that the high-intensity harvesting measures disturbed the forest stands. Harvesting trees creates relatively large disturbances in forest stands, but suitable anthropogenic actions (e.g., replanting and nurturing) can facilitate the recovery of the forest stand to reestablish a stable high-level community and achieve ecosystem equilibrium in the shortest time possible [26,39]. The control group in this paper had the highest carbon, timber, and biodiversity values over the 10-year period, which may be due to the fact that the study diversity metrics were selected primarily for size diversity, which was influenced by stand growth, and that there were differences in the response of replanted fast-growing and slow-growing broadleaf species to varying harvesting intensities and in the competitive relationships among individual single-timber trees.

4.2. Impacts of Different Management Measures on Relative Ecosystem Benefits and Integrated Functions

In years one to nine of restoration, we found that the relative benefits to timber production, carbon sequestration, and biodiversity in stands with harvesting intensities of 70%, 75%, and 80% were generally evenly distributed between low and medium benefits, while those in stands with harvesting intensities of 65% were all evenly distributed between medium and high benefits. The most significant changes in the relative benefits of the three ecosystem functions occurred in the period after the 5th year of restoration, when native fast-growing broadleaf species such as *Castanopsis fissa* and *Manglietia glauca* gradually grew out to the upper layer. At this point, a mixed forest stand was initially formed, which meant the pressure of individual single-tree competition within the forest was weakened and the relatively slow-growing valuable broadleaf species could grow in a better radial direction, laying the foundation for greater biodiversity in the stand [40–42]. In our study, the stand size diversity calculated based on the radial order distribution was used to represent the complexity of the tree size within the stand, but there was no significant difference in the biodiversity of stands with and without management measures. Management measures can enhance the stand structural complexity and the species richness can be enhanced by replanting with native tree species to maintain relatively stable stand structures in cases of reduced plant density [43]. Under conditions with abundant light resources, this can enhance the forest's ability to utilize the resources and take full advantage of the complementary interactions within the ecosystem [44–46]. Most of the relative benefits to timber production, carbon sequestration, and biodiversity in the control stand were characterized as high efficiency, so its comprehensive function index was slightly higher than those in stands with management measures, but the annual average growth rate of its comprehensive function index was at least 17.13% lower than the stands with management measures. This indicated that reasonable management measures can enhance ecosystem stability and resilience [47,48]. Both appropriate harvesting and artificial replanting can effectively regulate the density of forest stands and ensure that single trees of different species can be planted to meet the demand for growing space [49,50]. Moreover, when the composition of tree species and the relationship between the upper and lower layers of the forest are well balanced and maintained, the quality of the forest stand will naturally improve; high quality forest stands can enhance the performance of timber production, carbon sequestration, biodiversity, and other functions, thus taking full advantage of the multifunctional potential of the forest [51,52].

4.3. Ecosystem Trade-Offs under Different Management Measures and Their Dynamics

Several studies have found that trade-off and synergistic relationships among ecosystem functions change over time, and that the interactions between ecosystem functions are stronger in the later stages of restoration compared with the pre- and mid-stages of restoration; however, those studies did not examine the specific dynamics of the trade-off relationships over time [42,53]. In addition to verifying this result, this study explored the differences in the trade-off relationships among timber production, carbon sequestration, and biodiversity functions among stands with different management measures during years 1–9 of restoration and explored the dynamic changes in those relationships over time. This study showed that synergistic relationships among the three ecological functions persisted throughout the study period in the 65% and 80% harvest intensity stands, while the trade-off relationships among the three ecological functions in the 70% and 75% harvest intensity stands changed in an alternating manner. It has long been recognized that interactions between pairs of ecosystem functions can differ among different regions and times. This is because timber production, carbon sequestration, and biodiversity all depend on ecosystem processes that change with scale and time. Furthermore, timber production and carbon sequestration are often considered to be synergistic, but trade-offs between them can gradually be observed as the stands reach a density threshold [7,54,55]. In the subtropics, biodiversity is a key research hotspot when examining ecosystem functions, and both trade-off and synergistic relationships between biodiversity and carbon sequestration have been found, demonstrating the importance of accurately judging relationships according to the scales of studies [56]. This also supports our own findings where the trade-off and synergistic relationships among ecosystem functions changed over time. Therefore, as multiple ecosystem functions cannot always be maximized at the same time, it is important to understand the dynamic changes in ecosystem function interactions under different management measures to determine the most rational forest management strategy and achieve sustainable forest development.

4.4. Limitations of This Study and Directions for Further Development

There were a number of limitations to our study exploring the interactions between ecosystem functions under different management measures. The first limitation was that, among the many management measures, only harvesting intensities ranging between 65%–80% were included. Many management measures worldwide utilize harvesting intensities below 65% to achieve roughly the same main objective, which is to realize the multifunctional potential of forests [57]. The second limitation was that, due to limited survey conditions, we only obtained observational data for the four different management measures over a 10-year restoration period, and the 10-year growing period was not sufficient for replanting slow-growing broadleaf trees to maximize the potential of ecological functions, which requires observational data over a much longer period of time to account for. This paper only reveals the dynamics between the three ecological functions, but the soil carbon and nitrogen storage function and the water conservation function are also important and need to be further studied. Although these ecosystem functions usually change relatively slowly [58], revealing the interactions among more ecosystem functions and their dynamic changes over time would better reveal the respective advantages of different management measures. With the assessment methods reported to date being limited to three or more ecosystem functions [37,38,59], more effective methods need to be developed to provide a more comprehensive basis for forest management decisions.

5. Conclusions

In summary, the average annual growth rates in the composite function indices of the four different management measures were significantly higher than those of the control. In the first nine years of restoration, the management measure with a 65% harvesting intensity and replanting of various native broadleaf species was the most effective. This management measure produced relative benefits to timber production, carbon sequestration, and biodiversity at or above the medium level of effectiveness. Furthermore, its dominant ecosystem function tended toward biodiversity over time. This management measure sustained synergistic relationships between pairs of ecosystem functions over time, while both trade-off and synergistic relationships were observed between pairs of ecosystem functions in the other three management measure stands.

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