# Modelling the Coupled Effects of Climate Change and Management Approaches in the Plantations of Southern China

**Xiaofan Wang, Erfu DAI, Zhuo WU and Xudong GUO, China**

**Key words**: Climate Change, Forest Management, Biomass, Timber Production, Southern China

## SUMMARY

Global climate change has caused real and also derived potential risks to forest ecosystems, especially affecting their composition, spatial distribution and ecological services. Learning how to adopt appropriate adapting and mitigating approaches on plantations is vital to sustainable forest management. This study aims at examining the coupled effects of climate change and management approaches in the plantations of Southern China, so as to propose sustainable forest management approaches that can fulfil the requirements of ecological service improvements and timber production of the plantations. Taihe County in Jiangxi Province, where plantations occupy more than half of the total forest area, was selected as the study area. The LANDIS-II (Landscape Disturbance and Succession) model was used to simulate the influences of climate change and forest management on biomass and timber production of plantations. Finally the trade-off between biomass and timber production was investigated based on a statistical approach of standard deviation. Results showed that biomass of plantations in the study region under RCP 4.5 will be greater than that of RCP 2.6 and 4.5 scenarios. Though increased temperatures over the next hundred years will increase the biomass of plantations, timber production capability will be greatly determined by harvesting techniques. In the Red Soil Hilly Regions (RSHR), as one of the most important plantation distribution areas in China, the most appropriate forest management approach appears to be middle harvest intensity under the RCP 4.5 scenario, which can fulfil the coupled requirements of ecological services and timber production on plantations.

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## 1. Introduction

Projected changes in global climate due to increasing greenhouse gas concentrations present potential risks to forests ecosystems and challenges for forest managers in the future (Bonan 2008, Keenan 2015). With so many uncertainties in climate change projections (IPCC 2013,Millar, et al. 2007) and the resultant impacts on forests (Xu, et al. 2009, Duveneck, et al. 2014), altering existing forest management practices for climate change can be considered a strategy to increase adaptive capacity (Dale, et al. 2001,Spies, et al. 2010).

There is a rapidly increasing worldwide interest in developing forest policy and management approaches to maintain carbon storage (Bonan 2008,Seidl, et al. 2007) and improve the capacity to adapt to climate change (Bright, et al. 2014). Managers are increasingly interested in the trade-offs between the ability of carbon sequestration (biomass accumulation) and forestry production, especially regarding timber production under climate change (Boisvenue and Running 2006). The effects of climate change on forest biomass accumulation and timber supply may vary, showing as either a positive or negative relationship through different management activities or under a temporal and spatial scale (Bonan 2008). Adaptive and sustainable forest management strategies are urgently needed in forest ecosystems, especially plantations, worldwide.

Because of the continuously increasing need for timber and forest ecological services such as carbon sequestration (biomass accumulation), forest management has developed into sustainable forest management with multiple goals (Seidl, et al. 2007,Vacik and Lexer 2014). An effective way to check which forest management alternative is suitable to both timber production and forest biomass accumulation is calculating the trade-offs between them (Bradford and D'Amato 2012,Lu, et al. 2014) Furthermore, the trade-offs reflect the adaptive capability of the forest management alternatives to climate change, and so examining these trade-offs became the objective of our study.

In this study, our objectives were to investigate the landscape scale effects of forest sustainable management alternatives and climate change on the plantations of Taihe County in Southern China. We also wanted to understand the trade-offs between forest aboveground biomass (AGB) and timber production, which can represent management adaptation to climate change. We used the LANDIS-II modelling framework to project and analyse the AGB and timber production changes over the next 100 years (2009-2109). We also made comparisons of simulations incorporating four climate scenarios (including current climate, RCP 2.6, RCP 4.5 and RCP 8.5) and four forest management alternatives (including no harvest, low harvest intensity, middle harvest intensity and high harvest intensity).

## 2. Methods

### 2.1 Study area

We conducted the study over a 2667 km$^2$ study area (Figure 1) in central Jiangxi Province named Taihe County (26º27'-26º59'N, 114º18'-115º20'E). Taihe County is primarily a red soil hilly region ranging in elevation from 52m to 1176m. When determining the geomorphological type of Taihe County, five ecoregions with different natural conditions were identified: low hills, middle hills, high hills, mountains and inactive regions (including building land, farm land, economic forest, bamboo forest, etc.). The annual average temperature is 18.6°C, and the precipitation is 1378.5 mm annually, with approximately 60% of all rain falling between March and June. Forests of the region are dominated by man-made Chinese fir (*Cunninghamia lanceolata*), slash pine (*Pinus elliottii*), masson pine (*Pinus massoniana*), secondary soft-hardwood evergreen broad-leafed forests eyer ever-greenchinkapin (*Castanopsis eyrei*), farges ever-greenchinkapin (*Castanopsis fargesii*), faber oak (*Quercus fabri*), and camphor tree (*Cinnamomum camphora*). There are several deciduous tree species growing in the study area, such as beautiful sweetgum (*Liquidambar formosana*), Chinese sassafras (*Sassafras tsumu*), longpeduncled alder (*Alnus cremastogyne*), and so on. Considering the abundant diversity and dominant species in the study region, we chose 18 common and dominant species (Table S1) to represent the tree species of our study area in the LANDIS-II model.

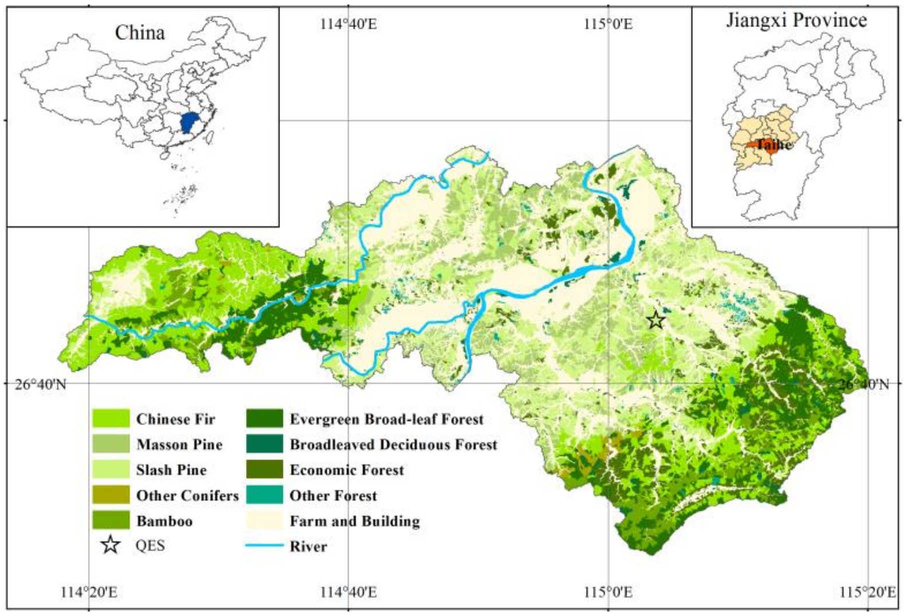

**Figure 1**Forest Distribution Map of the study area, Taihe County, China. It is divided into nine forest types in accordance with our study objectives. The Qianyanzhou Ecological Station (QES), a long-term observation station

of the Chinese Ecological Research Network (CERN), provided proper scientific research conditions and a solid research foundation in support our study.

## 2.2 Model parameterization

We simulated forest landscape dynamics using a process-based, spatially dynamic model of forest succession and disturbance called LANDIS-II (Scheller, et al. 2007). LANDIS-II is designed for simulating forest dynamics including establishment, competition, growth, decomposition and biomass accumulation, while integrating multiple disturbances such as fire, wind, insects and harvest (Scheller, et al. 2007). LANDIS-II represents the landscape as a grid of interacting cells which utilizes species×age cohorts to describe the initial forest conditions. All cells can contain multiple species×age cohorts with associated age and AGB data. Cohort establishment following a reproduction event depends on light availability (Scheller and Mladenoff 2004) and species establishment probability (SEP). This is dependent upon soil and climate conditions (Scheller and Mladenoff 2005). Each SEP varies spatially because of differences in stand properties and temporally because of changing climate (Scheller and Mladenoff 2005). Tree species growth rates, represented by aboveground net primary productivity (ANPP), and SEP values were calculated using an ecosystem process model, PnET-II (Xu, et al. 2009,Aber, et al. 1995) for each tree species in each ecoregion. PnET-II has been coupled with LANDIS-II and calculates the LANDIS-II input ANPP and SEP under current climate conditions and climate change scenarios (Xu, et al. 2009).

The initial forest structure and composition for the study were derived from the FRI data which was investigated by staff of Forestry Bureau of Taihe County in 2009. The FRI data provided the forestry information of Taihe County, including the digitized forest types map and the attributes linking to the forest types. For our simulations, cell resolution was 100m×100m (1ha). All processes including succession and harvest disturbances were simulated at 10 years' time step.

We simulated the forest landscape under 4 climate scenarios using the PnET-II model. The no-changing scenario used the current climate conditions, an average of the 2001-2011 climate data derived from QES. The climate change inputs are obtained from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 5 (CMIP5) multi-model dataset which was provided by National Climate Center of China (http://www.climatechange-data.cn). Due to the data availability, we simulated three climate change scenarios including RCP2.6, RCP4.5, and RCP8.5.

We simulated forest dynamics in the study region based on four climate scenarios and four harvest scenarios. To estimate the relative influence of forest succession, climate change and timber harvest on AGB and timber production, we conducted a series of simulations in a full-factorial design which required a total of 16 different scenarios. Each scenario was run for 100 years, representing the period from 2009 to 2109. Harvest was parameterized using a sustainable forest management philosophy, achieved by using a classified forest management method conforming to the institution of China’s forestry administration. To study how forest management adapts to the impacts of climate change, we designed three harvest experiments with low, medium and high intensity (Table 1).

**Table 1** Details of the harvest experiments that were simulated using LANDIS-II.NH: no harvest; LH: low intensity of harvest; MH: medium intensity of harvest; HH: high intensity of harvest. The percentage data represents the harvest percentage of the management area in one harvest event.

| Harvest experiments | Short-rotation industrial plantation | Fast-growing and high-yielding timber plantation | General timber forest | Shelter forest | Forest for special purpose |
|---|---|---|---|---|---|
| NH | - | - | - | - | - |
| LH | 15% | 10% | 5% | 3% | 2% |
| MH | 25% | 20% | 15% | 5% | 2.5% |
| HH | 35% | 35% | 30% | 10% | 10% |

## 3. Results and discussion

### 3.1 The effects of forest management coupled with climate change

Our research objective was to understand the interactive effects of forest management and climate change on the plantations of Taihe County in Southern China with respect to AGB and timber production (Figure 2, 3). Our simulations showed that climate change might increase the AGB dependent upon the RCPs scenarios, while harvest treatment may significantly decrease the AGB to produce timber. The scenarios coupled climate change and harvesting, but ignored other disturbances (e.g. wind, fire, insect). The scenarios were used to explore the relationship between AGB and timber production. Climate change has a considerable effect on forest AGB both with and without harvest (Scheller and Mladenoff 2005,Steenberg, et al. 2013). However, there was also a possibility that climate did not have a significant effect on total biomass, likely because the positive effects of climate were negated by increased losses to fire (Gustafson, et al. 2010). Our results show that the AGB experienced a rapid increase and then decreased in the next century. This point has demonstrated that AGB will not keep increasing during forest succession (Scheller, et al. 2011,de Bruijn, et al. 2014), because the biomass would be reduced due to the age-related mortality that would begin at one half of a species’ lifespan (Scheller and Mladenoff 2004). The effects of climate change in the study area are positive in both the RCP 2.6 and RCP 4.5 scenarios, but more complicated in the RCP 8.5 scenario. The AGB in the RCP 8.5 scenario is higher than in the current climate before 2089, but decreases lead to less AGB by 2109. The acceptable reason may be that the temperature in RCP 8.5 scenario is beyond the suitable growth temperature of some tree species.

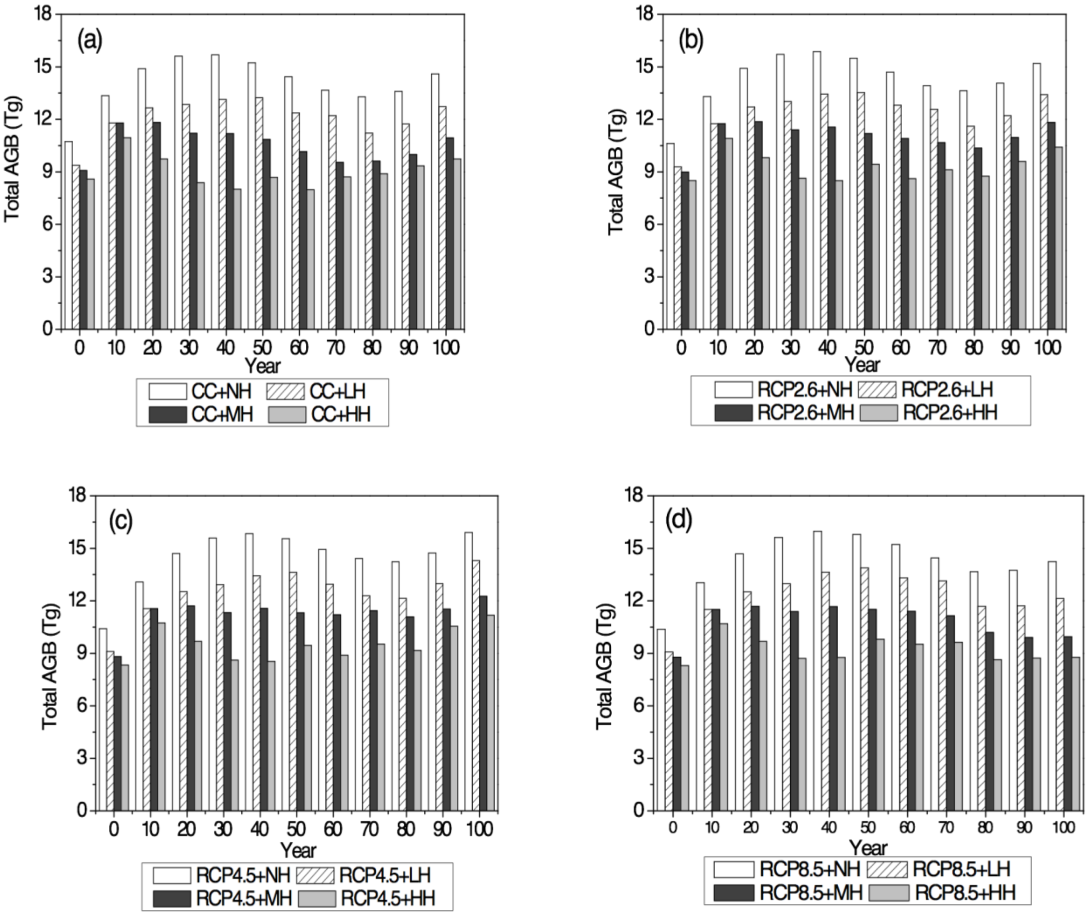

**Figure 2** The forest AGB of Taihe County under different forest management scenarios and climate scenarios. (a): current climate scenarios, (b): RCP2.6 scenarios, (c): RCP4.5 scenarios, (d): RCP8.5 scenarios.

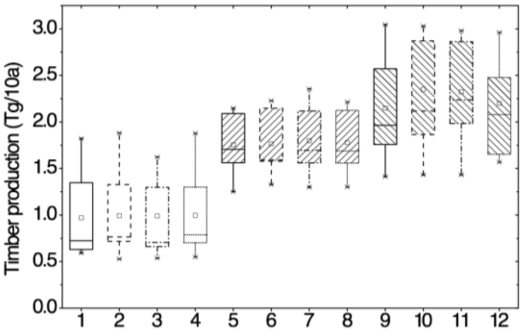

**Figure 3** Timber production every 10 years in 12 scenarios of harvest treatment. The numbers from 1 to 12 on the horizontal axis stand for the different scenarios. Specifically, 1: CC+LH; 2:RCP2.6+LH; 3:RCP4.5+LH; 4:RCP8.5+LH; 5:CC+MH; 6: RCP2.6+MH; 7: RCP4.5+MH; 8: RCP8.5+MH; 9: CC+HH; 10: RCP2.6+HH; 11: RCP4.5+HH; 12: RCP8.5+HH.

Our results suggest that the AGB will be far more affected by forest management strategies than by climate change over next century. Gustafson et al. (Gustafson, et al. 2010) found that most response variables were more strongly influenced by timber harvest and insect outbreaks than by the direct effects of climate change. Direct climate effects on forest biomass and composition have a lag time, but harvest activity produces a sudden and significant change (Gustafson, et al. 2010). Harvest treatments reduced the AGB greatly as expected (Steenberg, et al. 2013). When the harvest intensity increased, the losses of AGB increased (Figure 4). The harvest activity and its intensity altered the trends of forest biomass succession compared with the situation without harvest, especially when the harvest intensity is at a high level (Figure 3). In high harvest intensity scenarios, there was no biomass increase under the current and PRC 2.6 and PRC 8.5 climates. Human activities can change the forest ecosystem drastically with their dynamic processes (Bu, et al. 2008,He, et al. 2011). It is important to make a suitable forest management strategy to protect and improve forest ecosystem services (Limaei, et al. 2014). Moreover, the work is more urgent and meaningful in plantations such as our study area. Timber production is the most important production function of plantations. Our study results show that harvest intensity had significant effects on the quantity of timber production. On the other hand, climate change didn’t affect the quantity of timber production directly.

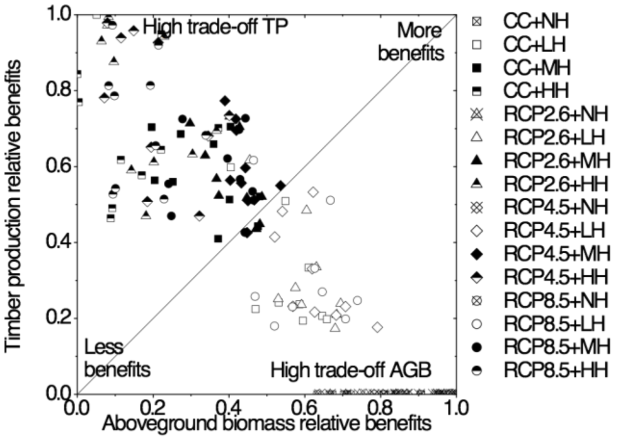

**Figure 4** The overall benefits and trade-offs under multi-objective forest management and climate change scenarios. The scatter plot depicts the relationship between timber production and AGB for a long-term forest management and climate experiment. Relative benefit for AGB (x axis) is plotted against relative benefit of timber production (y axis), and spot shapes relate to specific scenarios. Overall benefit increases from low benefit in the lower left to greater benefit in the upper right. Trade-off increases with distance from the diagonal of x=y, where benefit in AGB equals benefit in timber production.

## 3.2 Forest management as an adaptive strategy to climate change

Past research has demonstrated that the implications of climate change have led to a shift in forest management strategy in order to adapt (Bright, et al. 2014,Pyorala, et al. 2014). Management goals influence the choice of tree species and harvest of biomass, which in turn alters the risks related to climate change (Jonsson, et al. 2015). Adaptation to climate change involves monitoring and anticipating change, undertaking actions to avoid negative consequences and taking advantage of the potential benefits of those changes (Keenan 2015). Our results showed that climate change could have positive effects, meaning that making adaptations in the plantations of Southern China would allow them to take advantage of these benefits. This model study indicated that different forest management strategies result in variable overall benefits to the forest ecosystem services under climate change scenarios through a statistics based trade-off method (Bradford and D'Amato 2012). In the RCP 4.5 scenario, the accumulation of biomass was more than that under other climate scenarios. The overall benefits of biomass and timber production would be higher in the RCP 4.5 scenario if the same management strategy was used. If the future climate is more likely to resemble the RCP 8.5 scenario, there will be more risks because some species would not adapt well to it. In the RCP 8.5 scenario, the overall benefits of low harvest intensity are higher than high harvest intensity in both the RCP 4.5 and RCP 2.6 scenarios. When forest tree species growth faces increasing risks due to climate change, harvest strategy shouldn’t be done with high intensity. Effective adaption actions in the face of climate change should focus on optimizing regeneration conditions (e.g. increasing species diversity and selecting higher temperature and drought tolerant species) (Kolstrom, et al. 2011) and modifying frequency or intensity of tending and thinning activities (Bodin and Wiman 2007). For the RCP 4.5 scenario, forest management should take some adaptation measures due to increased productivity, for example increasing the cutting ratio of harvest and reducing the rotation lengths (Kolstrom, et al. 2011).

### 3.3 Uncertainty and model limitations

Our simulations should be interpreted as the trends of forest succession rather than predictions. Spatially dynamic landscape models can simulate spatial interactions among species (Scheller, et al. 2007,Dai, et al. 2015), but the results are limited by inherent uncertainties in what the response might be to climate change (Xu, et al. 2009). A series of tree species life history parameters and stand condition parameters determine succession behaviour. There is also uncertainty in many of the LANDIS-II parameter estimates. Our simulation results are simplifications of reality based on the best available data in our research area. Our simulations did not consider disturbances like wind (Scheller, et al. 2011), fire (Lucash, et al. 2014,Yang, et al. 2015), insects (Sturtevant, et al. 2012) etc., as forest fires and plagues of insects are strictly controlled in forests in China and wind throw rarely occurs in the study region. We also did not include species migrating from outside the landscape, CO2 fertilization (Reich and Hobbie 2013) or ozone pollution (Ainsworth, et al. 2012), which may interact significantly with other global change effects. The harvest parameters were set as experimental treatments. We recognize that a large amount of uncertainty exists in how policy makers and foresters will shift in terms of management (Duveneck, et al. 2014). Our alternative management strategies were based on the classified forest management, and future management will depend on dynamic management priorities, market fluctuations, and policy restrictions. However, our results do provide some insight into the potential effects of management strategies in the face of global change.

## 4. CONCLUSION

The study provided insights into the interrelations of climate change and forest management activity, and their effect on forest AGB and timber production in the next century. Climate change significantly increased the forest biomass but had little effect on timber production, which was controlled by forest management strategy. The RCP 4.5 scenario is the most suitable scenario for forests to accumulate biomass in Taihe County compared with the current climate, RCP 2.6 and RCP 8.5 scenarios used in our simulations. Forest ecosystems allow timber production through forest management, and harvest treatments sharply decreased the forest biomass. The forest biomass will be far more affected by forest management strategies than by climate change over next century. In order to achieve an ideal result, we analysed the trade-offs and overall benefits of forest biomass and timber production. The forest management style using medium harvest intensity under the RCP 4.5 scenario is the best choice of all of the scenarios we simulated for the forests of Taihe County. Taking advantage of the potential benefits of climate change is an important adaptation, and we are looking forward to finding more effective methods of sustainable forest management through modifying the frequency or intensity of harvest activities or selecting plant species which have a strong adaptability to climate change in future research.

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## CONTACTS

Dr. Xiaofan WANG
Key Laboratory of Land Use, Ministry of Land and Resources, China Land Surveying and Planning Institute
37, Guanyingyuanxiqu, Xicheng District
Beijing
CHINA
Tel. +86010 6656 2076
Fax + 86010 6656 2922
Email: 61146961@qq.com
Web site: