Effects of Climate Change on the Carbon Sequestration Potential of Forest Vegetation in Yunnan Province, Southwest China

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Abstract: Ongoing climate changes reportedly affect the potential distribution and carbon sequestration potential (CSP) of forest vegetation. The combined effects of increasing temperature and decreasing precipitation on these features of forest vegetation are poorly understood. In this study, classification and regression tree (CART) models were used to predict the potential distribution and estimate the CSP of forest vegetation in Yunnan Province, Southwest China, under different simulation scenarios. The minimum temperature of the coldest month (TMW) was the main factor limiting the suitable habitat of all forest vegetation types except for warm–temperate coniferous (WTC) forests. When the temperature increased by 1 °C and the precipitation decreased by 20%, the potential distribution area of the 7 forest vegetation types decreased by 12.41% overall. The potential distribution of WTC forests was the least sensitive to temperature increases and precipitation decreases. The CSP of vegetation was higher (1187.69 TgC) under the constant temperature and 10% precipitation decrease scenario than the CSP of vegetation under the 2 °C temperature increase and constant precipitation scenario (647.24 TgC). Specifically, the highest CSP (1337.88 TgC) was observed under the 1 °C temperature increase and 10% precipitation decrease scenario, and the lowest (617.91 TgC) occurred under the constant temperature and 20% precipitation decrease scenario. In summary, the forest vegetation in Yunnan Province has a high CSP under climate change, and the combined effect of increased temperature and decreased precipitation can increase the CSP of forest vegetation in Yunnan Province. This finding is important for improving scientific decision making and policy planning.

Keywords: temperature increases; precipitation decreases; CART models; potential vegetation distribution; carbon sequestration potential

1. Introduction

Temperature increases and precipitation decreases significantly influence the structure, functions, dynamics, and distribution of forest vegetation, and these changes in turn influence the carbon sequestration potential (CSP) of forest vegetation [1–4]. Many studies have revealed that recent climate change has caused shifts in forest vegetation distributions [5–8], which lead to changes in CSP [9–11] and affects carbon cycling [12,13]. An understanding of the potential distribution of forest vegetation and an assessment of its CSP are needed to improve scientific decision making and policy planning.

The CSP of forest vegetation has been explored at multiple scales using different methods. Liu et al. (2014) [14] used forest resource inventory data to estimate the CSP of
mature forest vegetation in China, and other researchers utilized these data and logistic equations to estimate carbon storage at the species level and predict forest vegetation carbon storage with a stage-classified matrix model [15–17]. Peng et al. (2017) [18] quantified CSP using moderate-resolution imaging spectroradiometer (MODIS) data and analyzed its response to precipitation decreases. However, prediction results at the national scale may not be suitable for prediction at smaller scales because of differences in prediction accuracy. At the regional scale, Peng et al. (2009) [19] simulated the carbon dynamics of boreal and temperate forests in Northeast China using the TRIPLEX model, but this model is limited in its ability to model vegetation succession and future dynamics. Classification and regression tree (CART) models are a practical technology that can be used to explore the relationships between environmental variables and vegetation, and these relationships have been used to predict the distribution of plant habitats [20–23]. In a previous study, Peng et al. (2017) [18] found that the CART model is more accurate in explaining the relationships between climatic factors and forest vegetation distribution in Yunnan Province than the generalized linear model and generalized additive model [23]. In these studies, precipitation uncertainty and stand age can be ignored. Although some studies have explored the CSP in Yunnan Province [24–26], these studies assumed that all forests are mature and did not consider the succession and distribution changes in forest vegetation in the future. In addition, temperature and precipitation are the key factors that regulate the CSP of forest vegetation. In our previous study, the effects of temperature increase on the CSP of forest vegetation in Yunnan Province were explored [23], but we did not consider the combined effects of different factors (e.g., temperature and precipitation). Although precipitation has not changed considerably around the world, frequent and severe drought events are predicted to occur over a large area in Yunnan Province [27–29] and drought events occur frequently and forest vegetation facing the risks of precipitation decreases in Yunnan [13,30]. Forest vegetation presents physiological and structural responses to decreases in precipitation to prevent excessive water loss, which affects carbon uptake for photosynthesis and total ecosystem respiration emissions and limits the distribution area of certain forest vegetation types [31]. The combined effect of temperature increase and precipitation decrease is expected to severely impact the structure and function of forest ecosystems and to change the distribution area of forest vegetation worldwide [32,33]. Large-scale biogeographical shifts in vegetation are predicted to occur in response to altered precipitation and temperature regimes [34,35]. Additionally, the forest vegetation in Yunnan Province is predominantly part of mountain ecosystems, which are sensitive to climate change [4]. Therefore, the combined effect of temperature increases and precipitation decreases on the potential distribution and CSP of the main forest vegetation types in Yunnan Province need to be assessed. Although the factors influencing the CSP of forest vegetation are complex, such as stand age, carbon dioxide, and human activities, etc., all affect the CSP of forest vegetation, this study used a model to explore the change of CSP caused by the change of forest vegetation area, assuming that other factors do not change.

Thus, the goals of this study were as follows: (1) determine the forest vegetation distribution changes under temperature increases and precipitation decreases in Yunnan Province; (2) evaluate the responses of the CSP of forest vegetation under different simulation scenarios of temperature increases and precipitation decreases in Yunnan Province.

2. Study Area

Yunnan Province is located in Southwest of China between 21°08′–29°15′ N and 97°31′39″–106°11′47″ E and situated at the meeting point of 3 geographic regions: the Eastern Asia monsoon region, the Tibetan Plateau region, and the tropical monsoon region of Southern Asia and Indochina. The total forest area in Yunnan Province is 1.89 × 10^7 ha, it is the second largest forest area in China, contributes a huge carbon sink, and is a hotspot for biodiversity [36,37]. Yunnan’s rich ecosystems comprise over 30 ecosystem types according to the Chinese classification, which span from the lower tropical valleys and basins in the southern part to the barren high peaks and deep valleys in the northwestern part [38]. The
climate is generally mild with a long growing period. There are cold winters at higher elevations in the northwestern mountain regions, moderate temperatures in the middle plateau region, and tropical, hot, and humid conditions at the lower elevations and valley bottoms in the southern region [39]. The ecosystems of Yunnan Province are sensitive to global climate change and are less stable than those in temperate zones [40].

3. Materials and Methods

Frequent and severe drought events are predicted to occur over a large area in Yunnan Province [27–29] and drought events occur frequently and forest vegetation facing the risks of precipitation decreases in Yunnan [13,30]. So, we choose the climate data included the annual mean temperature (TMA, °C), mean temperature of the warmest quarter (TMS, °C), minimum temperature of the coldest month (TMW, °C), annual precipitation (PRA, mm), precipitation of the warmest quarter (PRS, mm), and precipitation of the coldest quarter (PRW, mm) as predictor variables, which were obtained from WorldClim version 2.0 (https://www.worldclim.org/data/cmip6/cmip6_clim2.5m.html, accessed on 20 April 2020). TMS is a measure of the effective heat required for plant growth. TMW is a measure of extreme cold, which controls the altitudinal and northern range limits of evergreen broad-leaved forests. PRS and PRW are measures of water supply during the growing and winter seasons, respectively. Here, we focus on the effect of decreased precipitation and temperature increase on forest distribution. Seven forest vegetation types were selected as response variables based on advanced land observing satellite (ALOS) imagery from 2008 to 2011. These forest vegetation types included monsoon evergreen broad-leaved forests (MEB), semi-humid evergreen broad-leaved forests (SEB), mountainous humid evergreen broad-leaved forests (MHEB), warm–hot coniferous (WHC), warm–temperate coniferous (WTC), temperate–cool coniferous (TCC), and cold–temperate coniferous (CTC) forests. The CART models were built using climate data and forest vegetation distribution data to predict the potential distribution area of forest vegetation and estimate the CSP of forest vegetation under different simulation scenarios based on the raw six predictor variables climate data of Worldclim 2.0 (Table 1). In all of the simulation scenarios, the temperature increases (+), representative of TMA, TMW, and TMS, are increases, and the precipitation decreases (−) are means of PRA, PRS, and PRW decreases (Table 1).

Table 1. Simulation scenarios that include changes in temperature and precipitation.

| Simulation Scenario | Temperature (°C) | Precipitation (%) |
|---------------------|-----------------|------------------|
| T00P00              | 00              | 00               |
| T01P00              | +1              | 00               |
| T01P10              | +1              | -10              |
| T01P20              | +1              | -20              |
| T01P30              | +1              | -30              |
| T02P00              | +2              | 00               |
| T02P10              | +2              | -10              |
| T02P20              | +2              | -20              |
| T02P30              | +2              | -30              |

+—three temperature variables increase; –—three precipitation variables decrease; 00—predictor variables no change.

The area under the curve (AUC) derived from receiver operating characteristic (ROC) analysis was calculated to validate the performance of the CART model. The AUC values were interpreted for model accuracy using the following standards: 0.90–1.00, excellent; 0.8–0.90, good; and 0.7–0.80, fair [41]. We divided the habitats into three categories—nonhabitats, marginal habitats, and suitable habitats—and the occurrence probability thresholds were obtained from the ROC analysis [42]. The areas where the predicted probability of occurrence was less than the low occurrence probability threshold (0.01) were defined as nonhabitats; the areas where the probability was equal to or greater than 0.01, but smaller than the optimal threshold, were defined as marginal habitats; and the
areas where the probability was greater than the optimal threshold were defined as suitable habitats. In this study, we selected suitable habitats as potential habitats. Climatic factors can be used to build CART models [20]. Deviance-weighted scores (DWSs) were applied to evaluate the contributions of each predictor variable to the model. Additional details on the climate data, forest vegetation interpretations, CSP calculations, and CART models are provided by Zhou et al. (2018) [23]. In this study, the present vegetation distribution was used as the observations data, and we assumed that the vegetation balanced with the climate, and, with the climate no longer changing, vegetation progressed to a climax over time.

4. Results

4.1. Prediction Accuracy and Contribution of Climate Variables

The AUC values were approximately 0.85 for all simulation scenarios. The TMW was an exceptionally strong explanatory variable among the 6 climate variables, and the DWS was approximately 50% in each simulation scenario, indicating that extremely cold temperatures within a year play a decisive role in the broad-scale distribution of forest vegetation in Yunnan Province. The TMS, PRS, and PRW also affected the distribution to some extent. The TMA and PRA did not affect the forest distribution under each simulation scenario and thus are not shown in Table 2.

| Simulation Scenario | TMW | TMS | PRS | PRW | AUC |
|---------------------|-----|-----|-----|-----|-----|
|                     | DWS | %   | DWS | %   | DWS | %   | DWS | %   |     |
| T00P00              | 13,439 | 46.21  | 2023 | 19.82  | 7443 | 23.19  | 1986 | 10.78  | 0.85  |
| T01P00              | 19,334 | 54.45  | 1553 | 12.97  | 5497 | 23.44  | 3151 | 9.14   | 0.85  |
| T01P10              | 18,757 | 47.39  | 2056 | 19.31  | 5586 | 24.39  | 3060 | 8.91   | 0.85  |
| T01P20              | 19,397 | 54.15  | 1704 | 14.10  | 5454 | 22.70  | 3192 | 9.05   | 0.86  |
| T01P30              | 19,443 | 56.85  | 1367 | 8.49   | 5626 | 24.11  | 3223 | 10.55  | 0.85  |
| T02P00              | 20,003 | 57.08  | 1399 | 12.30  | 5552 | 22.76  | 2914 | 7.86   | 0.86  |
| T02P10              | 18,963 | 51.09  | 2060 | 15.11  | 5502 | 23.38  | 3287 | 10.42  | 0.86  |
| T02P20              | 19,433 | 54.23  | 1688 | 13.86  | 5550 | 23.03  | 3107 | 8.88   | 0.85  |
| T02P30              | 18,642 | 48.25  | 2126 | 19.05  | 5545 | 23.68  | 3090 | 9.03   | 0.85  |

DWS—deviance-weighted score; AUC—area under the curve.

4.2. Potential Forest Vegetation Distribution under Different Simulation Scenarios

Under the T00P00 scenario, the entire forest area in Yunnan Province increased by 130.42% compared with the current forest vegetation distribution area [23]. Overall, when the temperature increased by 1 °C, the distribution area of the 7 forest vegetation types initially increased, and then decreased as the precipitation decreased; however, when the precipitation decreased by 30%, an increase in the distribution area of 4.62% was observed. When the temperature increased by 2 °C and precipitation decreased by 10, 20, and 30%, the distribution area of the 7 forest vegetation types decreased by approximately 10%. In response to an extreme environment where the temperature increases by 2 °C and precipitation decreases by 30%, the distribution area of the primary forest vegetation increased by 3.46% in Yunnan Province. For each forest vegetation type, as the temperature increased and the precipitation decreased, the distribution area of the seven forest vegetation types (except WTC) decreased to varying extents (Tables 3 and 4). However, the distribution area of the WTC type increased by approximately 30% in all of the simulation scenarios. In response to a temperature increase of 1 °C and a precipitation decrease of 20%, the distribution area of the WHC forest decreased significantly (59.76%); although, in the other precipitation decrease scenarios, the distribution area decreased by only approximately 4.50–6.50%. When the temperature increased by 2 °C, the distribution area of the WHC forests decreased greatly (Tables 3 and 4) under the different precipitation decrease
scenarios (except for the T02P30 scenario). Under the T02P30 scenario, the distribution area of the WHC decreased by 6.28%, which was smaller than the decreases observed under the other simulation scenarios, and the entire distribution area increased under this scenario (Figure 1).

Figure 1. Potential spatial distribution of the forest vegetation in Yunnan Province under different simulation scenarios.

4.3. CSP under Different Simulation Scenarios

Overall, the CSP patterns of the seven forest vegetation types in Yunnan Province did not show consistent trends in response to variations in the intensity of the temperature increase and precipitation decrease, and high values were observed under certain simulation scenarios. The greatest CSP (1337.88 TgC) was observed when the temperature increased by 1 °C, the precipitation decreased by 10%, and the lowest CSP (617.91 TgC) was observed when the temperature did not change, and the precipitation decreased by 20%. The different forest vegetation types in Yunnan Province showed varying rates of increase in CSP under increases in temperature and decreases in precipitation, except for the SEB, which exhibited a negative CSP value under each simulation scenario. Among all forest vegetation types, the WHC and WTC types exhibited the largest CSP values when the temperature increased and the precipitation decreased (Table 5). Compared with the CSP under the T00P00 simulation scenario, the CSP of each forest vegetation type was low in the other simulation scenarios. However, MHEB had a higher CSP under the T01P00 and
T02P10 scenarios than under the T00P00 simulation scenario, and the WTC had a higher CSP under all other simulation scenarios than under the T00P00 simulation scenario. The largest CSP was observed under the T01P30 and T02P30 simulation scenarios. In total, much of the observed decrease in CSP was due to the change in CSP in the WHC, which showed the highest CSP values under each simulation scenario.

Table 3. Rate of change in the forest distribution area under scenarios with a temperature increase of 1 °C and different decreases in precipitation. Units: Area, × 10^5 ha; Rate of change, %.

| Forest Vegetation | T01P00–T00P00 | T01P10–T00P00 | T01P20–T00P00 | T01P30–T00P00 |
|-------------------|---------------|---------------|---------------|---------------|
| MEB               | −6.22         | −14.24        | −8.23         | −18.80        |
| SEB               | −10.33        | −54.17        | −9.68         | −50.74        |
| MHEB              | −2.39         | −37.18        | 8.52          | 132.48        |
| WHC               | −6.37         | −4.89         | −6.37         | −4.89         |
| WTC               | 50.15         | 27.32         | 50.09         | 27.29         |
| TCC               | −6.22         | −18.13        | −6.55         | −29.66        |
| CTC               | −4.46         | −18.56        | −3.72         | −15.49        |
| Mean              | 14.15         | 3.30          | 24.06         | 5.60          |

Table 4. Rate of change in the forest distribution area under scenarios with a temperature increase of 2 °C and different decreases in precipitation. Units: Area, × 10^5 ha; Rate of change, %.

| Forest Vegetation | T02P00–T00P00 | T02P10–T00P00 | T02P20–T00P00 | T02P30–T00P00 |
|-------------------|---------------|---------------|---------------|---------------|
| MEB               | −6.67         | −15.44        | −71.94        | −16.44        |
| SEB               | −10.35        | −54.28        | −81.77        | −42.88        |
| MHEB              | −1.28         | −28.33        | 10.08         | 156.78        |
| WHC               | −77.94        | −59.76        | −77.94        | −59.76        |
| WTC               | 57.92         | 31.56         | 55.87         | 30.45         |
| TCC               | −5.00         | −22.63        | −41.51        | −18.79        |
| CTC               | −3.72         | −15.49        | −34.49        | −14.36        |
| Mean              | −47.66        | −11.10        | −34.96        | −8.14         |

Table 5. CSP of forest vegetation in Yunnan Province under different simulation scenarios. Unit: TgC.

| Forest Vegetation | T00P00 | T01P00 | T01P10 | T01P20 | T01P30 | T02P00 | T02P10 | T02P20 | T02P30 |
|-------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| MEB               | 78.79  | 38.32  | 25.35  | 32.05  | 31.63  | 34.89  | 32.05  | 34.89  | 34.89  |
| SEB               | 29.69  | −40.51 | −30.09 | −49.23 | −27.43 | −40.66 | −25.87 | −46.09 | −47.91 |
| MHEB              | 52.89  | 5.00   | 223.56 | 40.05  | 28.08  | 16.40  | 254.87 | 40.05  | 5.00   |
| WHC               | 567.62 | 743.28 | 743.28 | 234.96 | 747.34 | 234.96 | 234.96 | 240.77 | 730.36 |
| WTC               | 156.78 | 193.30 | 246.83 | 251.39 | 246.94 | 260.36 | 257.22 | 264.21 | 253.54 |
| TCC               | 119.00 | 69.66  | 66.99  | 78.92  | 86.05  | 79.32  | 86.05  | 76.79  | 83.92  |
| CTC               | 95.84  | 55.24  | 61.96  | 64.41  | 64.16  | 61.96  | 64.41  | 57.98  | 42.92  |
| Sum               | 1100.61| 1064.29| 1337.88| 652.57 | 1176.76| 647.24 | 903.70 | 668.61 | 1102.72|

5. Discussion
5.1. Climatic Conditions of Suitable Forest Vegetation Habitats

Temperature and precipitation are the main factors that influence the distribution of suitable habitats for forest vegetation [2,43,44]. Temperature increases may have impacts on the species composition and community structure of forest vegetation [20]. The DWSs of climate variables (Table 2) revealed that the TMW was the main factor underlying the suitable habitat of forest vegetation, which is similar to the results of Beane and
Rentch (2015) [45], who used a maximum entropy model to predict the suitable habitat of red spruce (Picea rubens) forests. For the CTC forest, a TMW lower than $-3.75\, ^\circ\text{C}$ (Table 6) or even $-4.05\, ^\circ\text{C}$ is required [20]. For the WTC type, the main limiting factor was the TMS (Table 6), and for beech (Fagus)-dominated deciduous forests, the TMW was not the main factor limiting suitable habitat [46]. In tropical zones, precipitation is the main factor determining the suitable habitat area [47]. For the WTC, suitable habitat climatic conditions included a TMS between $14.25\, ^\circ\text{C}$ and $20.35\, ^\circ\text{C}$; however, precipitation and the TMW were not limiting factors. Therefore, the WTC forest type has a broad potential distribution area and high CSP under scenarios with different temperature decreases and precipitation decreases (Figure 1). The TCC and CTC types have small suitable habitat areas because they are limited by lower TMW values; therefore, the potential distribution area decreases as temperature increases [23]. Considering the TMW is important when determining the drivers of vegetation and ecosystem functioning [48]. Indeed, Federer et al. (1989) [49] investigated three regions in northeastern US and found that the determining factors were temperature in the latter part of the previous growing season and temperature in winter. Suitable habitat climatic conditions for the WHC type are a PRS > 646.5 mm, a PRW > 63.5 mm, and a TMW > $-1.85\, ^\circ\text{C}$ (Table 6), which are observed over a wide range in Yunnan Province; thus, this forest type has a large potential distribution area and CSP under each simulation scenario. Weiskittel et al. (2012) [50] found that suitable habitat for forest vegetation was sensitive to the maximum temperature in the warmest month and mean annual precipitation. Moreover, factors other than temperature and precipitation codetermine the suitability of forest vegetation habitats [51]. For example, elevation is an important factor that influences the suitability of coniferous forest vegetation habitats [45]. In addition to temperature, precipitation, and elevation, other factors—such as dispersal and colonization rates, geographic barriers, landscape fragmentation, and disturbance regimes—can control suitable habitat areas [52]. Therefore, the factors limiting habitat suitability vary among forest vegetation types. Future research must consider the comprehensive influences of these factors on the suitability of forest vegetation habitat.

| Forest Vegetation | Suitable Habitat Climatic Conditions |
|-------------------|--------------------------------------|
| MEB               | PRS > 638.5 mm and TMW > 3.45 $^\circ\text{C}$ and PRW > 63.5 mm |
| SEB               | TMW < 3.75 $^\circ\text{C}$ and PRW > 63.5 mm |
| MHEB              | TMW < 1.05 $^\circ\text{C}$ and PRS > 699.5 mm |
| WHC               | PRS > 646.5 mm and PRW > 63.5 mm and TMW > $-1.85\, ^\circ\text{C}$ |
| WTC               | $14.25\, ^\circ\text{C} < \text{TMS} < 20.35\, ^\circ\text{C}$ |
| TCC               | $-6.05\, ^\circ\text{C} < \text{TMW} < -1.15\, ^\circ\text{C}$ and PRW > 325.5 mm |
| CTC               | TMW < $-3.75\, ^\circ\text{C}$ and PRS < 537.5 mm |

5.2. Effects of Climate Change on the Potential Distribution of Forest Vegetation

The ongoing changes in climate reportedly affect the potential distribution of forest vegetation [43,53]. Temperature increases and precipitation decreases drive changes in species, such as rapid range shifts, community alterations, tree line migration, and mosaic structure alterations, which in turn lead to changes in the potential distribution area [54,55]. The potential distribution area of moist forest vegetation types may increase under wetter scenarios, whereas moderate precipitation decreases will increase the potential distribution area of MHEB forest [56]. The potential distribution area of MHEB forest increased by 132.48% and 156.78% under the T01P10 and T02P10 simulation scenarios, respectively (Tables 3 and 4), which can be explained by the more mountainous terrain in Yunnan Province because areas of higher elevation became more suitable for the MHEB type under temperature increases and precipitation decreases [57]. The potential distribution areas of CTC and TCC forests decreased under all scenarios with temperature increases and precipitation decreases, which was similar to the results of Soja et al. (2015) [44], who indicated that most of Russia would not be suitable for the distribution of CTC forests
under warmer and drier conditions. The Hengduan Mountains in Yunnan Province are highly sensitive to climate change, which also explains these results (Weng and Zhou, 2006). Under the T01P10 scenario, the potential distribution area of all forest vegetation in Yunnan Province increased by 5.60% as a result of the increased distribution area of MHEB forest. Thus, moderate temperature increases and precipitation decreases can increase potential distribution areas in Yunnan Province. However, the large number of future climate change scenarios suggests that there is considerable uncertainty about possible future ecological impacts [58,59], and certain scenarios may generate the opposite results. The entire potential distribution area showed the greatest decrease (−12.41%) under the T01P20 scenario because the potential distribution area of WHC forest decreased by 59.76% under this scenario. It indicates that the temperature increase and precipitation decrease combined affect the potential distribution area of forest vegetation. A number of the most important conifer forests in Britain are expected to lose a large portion of their suitable habitat under different climate change scenarios [60]. The potential distribution area of WTC forest increased by nearly 30% in each simulation scenario, which indicates that this forest type is the least sensitive to climate change. However, WTC forests have been strongly influenced by human activity [61]; therefore, the model simulations may be inaccurate.

5.3. Combined Effects of Temperature and Precipitation on CSP

Although temperature increases and precipitation decreases have been shown to be the major drivers of decreases in CSP [23,62], Dai et al. (2015) [63] indicated that the CSP of forest vegetation was more sensitive to temperature increases and showed only slight decreases with a corresponding decrease in precipitation. Moreover, temperature has been reported to be the main factor driving the CSP of forest vegetation in the United States, Russia, and Canada [64–66]. However, the effects of temperature increase on CSP differ among ecoregions and forest vegetation types, with increased forest vegetation carbon observed in colder and wetter ecoregions and the opposite result observed in warmer and wetter ecoregions [10,67]. Forest vegetation responds positively to rising temperatures, temperature determines the CSP of tropical forest vegetation, and precipitation determines the CSP of savanna forest vegetation [13,68,69]. Under scenarios with a temperature increase and precipitation decrease, Fei et al. (2018) [13] found that the CSP of MHEB and CTC forests might increase; however, this finding is inconsistent with the results of our research (Table 5), possibly because we did not consider changes in the potential distribution area under climate change and focused only on changes at the site–point scale. The spatial variation in terrestrial ecosystem carbon exchange in the Asian region is controlled by temperature and precipitation [70]. The different forest vegetation types in Yunnan Province showed varying rates of increase in CSP under increases in temperature and decreases in precipitation, except for the SEB, which exhibited a negative CSP value under each simulation scenario, it means that the CSP of SEB forests is most sensitive to temperature increases and precipitation decreases. The combined and interacting effects of the two factors will increase the CSP of forest vegetation. Under the T01P10 simulation scenario, the CSP of forest vegetation in Yunnan Province was 1337.88 TgC, which was higher than the values observed under T01P00 (1064.29 TgC) and T00P20 (617.91 TgC) scenarios (Tables 5 and 7). Therefore, an interaction between a moderate temperature increase and precipitation decrease increases the CSP of forest vegetation in Yunnan Province. However, the combined and interacting effects are uncertain; for example, under the T00P10 scenario, the CSP is 1187.69 TgC, which is the largest value among all simulation scenarios and is associated with the CSP of the WHC forest type (Table 7). WHC forests can occupy a variety of habitats and show rapid growth and strong natural regeneration abilities [38,71]. The response of the CSP of forest vegetation to temperature and precipitation changes is influenced by the terrain associated with the forest vegetation as well as other factors, such as CO₂ fertilization effects, nitrogen limitation and land cover change, which can be used to predict the CSP of forest vegetation [72–75]. The factors that affect the carbon sequestration of forest vegetation are complex and include, forest age, carbon dioxide, precipitation.
This study assumes that forest vegetation is balanced with environment variables, predicts the distribution area of succession to the climax under different situations, and uses area change to explore the carbon sequestration of forest vegetation. In the future, the combined effects of these factors should be studied to produce more accurate results.

Table 7. CSP of forest vegetation in Yunnan Province under different precipitation decrease scenarios. Unit: TgC.

| Forest Vegetation | T00P00 | T00P10 | T00P20 | T00P30 |
|-------------------|--------|--------|--------|--------|
| MEB               | 78.79  | 25.36  | 31.63  | 31.63  |
| SEB               | 29.69  | −25.52 | −47.59 | −45.34 |
| MHEB              | 52.89  | 54.80  | 16.20  | 20.08  |
| WHC               | 567.62 | 743.28 | 236.60 | 234.96 |
| WTC               | 156.78 | 255.62 | 257.19 | 245.26 |
| TCC               | 119.00 | 78.92  | 74.43  | 79.32  |
| CTC               | 95.84  | 55.24  | 49.47  | 64.41  |
| Sum               | 1100.64| 1187.69| 617.91 | 638.33 |

6. Conclusions

CART models are capable of modeling suitable habitats and the CSP of forest vegetation under changing climatic conditions. The TMW was the main factor limiting the suitable habitat area of all forest vegetation types except for WHC forests in Yunnan Province. The CSP of forest vegetation in Yunnan Province does not decrease as temperature increases and precipitation decreases. Temperature increases and precipitation decreases jointly affect the CSP of forest vegetation. The entire potential distribution area showed the most significant decrease (−12.41%) under the T01P20 scenario. When the temperature increased by 1 °C and precipitation decreased by 10%, the forest vegetation in Yunnan Province had the largest CSP (1337.88 TgC). The CSP of SEB forests is most sensitive to temperature increases and precipitation decreases, and the lowest CSP (617.91 TgC) was observed under the simulation scenario with a constant temperature and 20% precipitation decrease. Under the T01P10 simulation scenario, the CSP of forest vegetation in Yunnan Province was 1337.88 TgC, higher than the values observed under T01P00 (1064.29 TgC) and T00P20 (617.91 TgC) scenarios. Overall, the forest vegetation in Yunnan Province has a high CSP under climate change.

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