# RESEARCH ON THE DYNAMIC PROCESS OF *PINUS ELLIOTTII* PLANTATION BIOMASS AND VOLUME ON POYANG LAKE SANDY LAND, CHINA

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**Abstract.** The sandy land of Poyang Lake is a typical area of subtropical sandy land in southern China. Its ecological management and restoration are of great significance to the construction of regional ecological civilization. To clarify the dynamic process of aboveground biomass and volume of *Pinus elliottii* plantation in different desertification lands from 2009 to 2018, field investigation and model estimation were used. The results show the following: (1) The growth process of the aboveground biomass and volume of *P. elliottii* presented a trend from slow-to-fast, after nine years, the aboveground biomass in the light desertification area (72.3 $t{\cdot}hm^{-2}$) was higher than that in the moderate (18.21 $t{\cdot}hm^{-2}$) and the severe desertification area (11.67 $t{\cdot}hm^{-2}$). (2) The proportion of the total biomass of *P. elliottii* trunk biomass is increasing, the proportion of branches biomass is decreasing, and the proportion of leaves biomass is basically stable. (3) The diameter breast height, tree height, and biomass of each organ were significantly correlated with volume ($P<0.01$). After nine years, the volume of *P. elliottii* in the light desertification area (101.53 $m^3{\cdot}hm^{-2}$) was significantly higher than that in the moderate (21.37 $m^3{\cdot}hm^{-2}$) and the severe desertification area (14.84 $m^3{\cdot}hm^{-2}$). The lower the degree of desertification, the better the vegetation recovery was. Therefore, the ecological management of the desertification areas of Poyang Lake should be gradually promoted from light desertification area to severe desertification area.
**Keywords:** *above-ground biomass, growth model estimation, desertification area of Poyang Lake, P. elliottii forest, wood volume*

## Introduction

Poyang Lake is the largest freshwater lake in China, and the healthy development of its ecological environment could have great significance to Jiangxi Province and even the whole of China (Zhang, 1988; Wang, 2004). Due to the influence of various factors in recent years, such as sand mining activities, reclamation of the lake, and indiscriminate logging. The problems of land desertification in the Poyang Lake area need to be urgently addressed (Cao et al., 2017). Desertified land not only affects the lives and production of nearby residents but also causes serious damage to the ecosystem of the lake area. The destruction of the ecological environment will cause a series of natural disasters, threatening the safety of human life and property (Zhao et al.,


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2016). With the gradual increase in the area of desertified land of the lake, the difficulty of maintaining continues to increase, and it is urgent to control the sandy land.

Biomass is an important functional indicator of the productivity level of forest ecosystem biomes, and it is also a comprehensive reflection of the environmental quality of the ecosystem (Geng et al., 2018; Zaki et al., 2018). It's used to measure the stability and health of the forest ecosystem (Li et al., 2011). Research on forest biomass measurement in China began in the late 1970s. At first, small-scale biomass measurements such as sample plots were mainly carried out through actual measurement methods (Li et al., 1981; Feng et al., 1982). Since then, biomass research has developed rapidly, expanding from sample plots to regional and even global scales. Research methods are increasingly diverse (Xu et al., 2018). The volume of wood is the economic productivity of forests and the basic economic index of forest management and utilization. It is of great significance in assessing the biological productivity of the forests, the comprehensive benefits of forest ecosystems, and the potential of renewable resources (Levick et al., 2016).

*Pinus elliottii* is an evergreen coniferous tree belonging to the Pinaceae family. In general, its growth potential is usually superior to that of *P. massoniana* or *P. thunbergii* in the same area, and it is seldom harmed by pine caterpillars (Lin, 2002; Guo, 2021). *P. elliottii* can grow vigorously in arid and barren areas and can be used as a pioneer tree species for barren mountain greening or vegetation restoration (Ni et al., 2017). Many scholars in China and in other countries have proved that *P. elliottii* is a fast-growing, high-yield and high-quality conifer with the advantages of drought resistance, flood resistance, barren resistance and strong adaptability (Zhang and Li, 2011). 93.3 $hm^2$ of *P. elliottii* plantations were established in 2008-2010 in the sandy land of Duobao Township of Poyang Lake by introducing high-quality *P. elliottii* seedlings for planting (Cao et al., 2016). Taking Duobao Sandy Land of Poyang Lake as an example, the experimental study on the biomass and volume of *P. elliottii* was carried out by constructing the experimental area for desertification control and research, which provided the necessary theoretical basis for the sustainable development and utilization of sandy vegetation, as well as reference for the prevention and ecological restoration of desertified land.

## Materials and methods

### *Study area*

The study area (*Figure 1.*) is located in the middle and lower reaches of the Yangtze River in China, in the sandy area of Duobao Township, Jiangxi Province, which is the main distribution area of the sandy land of Poyang Lake (29°21′22″-29°27′18″ N, 116°03′-116°07′42″ E), with an average annual temperature of 17.5 °C, an average surface temperature of 21.3 °C, annual precipitation of 1300 mm-1600 mm, annual evaporation of 1880 mm, and a maximum temperature of 42 °C. The surface temperature of the bare sandy land in summer is as high as 69.5 °C (Gong and Shen, 2001; Huang and Qian, 2007; Ding et al., 2010). The annual average wind speed is 2.9-3.8 $m \cdot s^{-1}$ (Ge et al., 2019), and the wind speed is larger from September to January of the following year, with the maximum wind speed reaching 23.3 $m \cdot s^{-1}$ (Wan et al., 2015). Duobao sandy land can be divided into three parts: (1) Severe desertification area, which is distributed in the lakeside sand zone and consists of mobile dunes and semi-mobile dunes, with sparse vegetation and a coverage rate of less than 5%. (2)


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Moderate desertification areas, mainly semi-fixed dunes, with a vegetation coverage rate of 20%-30%. (3) Light desertification areas, distributed in the inner sandy land, mainly fixed dunes, with vegetation coverage of 50%-60%. The dominant plants in the sandy land mainly include *Cynodon dactylon*, *Lespedeza Formosa*, *Vitex trifolia*, *Crataegus pinnatifida*, *Ligustrum quihoui*, and *Glochidion wilsonii*, etc., artificially planted *Vetiveria zizanioides*, *P.elliottii*, *Nerium* indicum Mill, etc. (Ding et al., 2010).

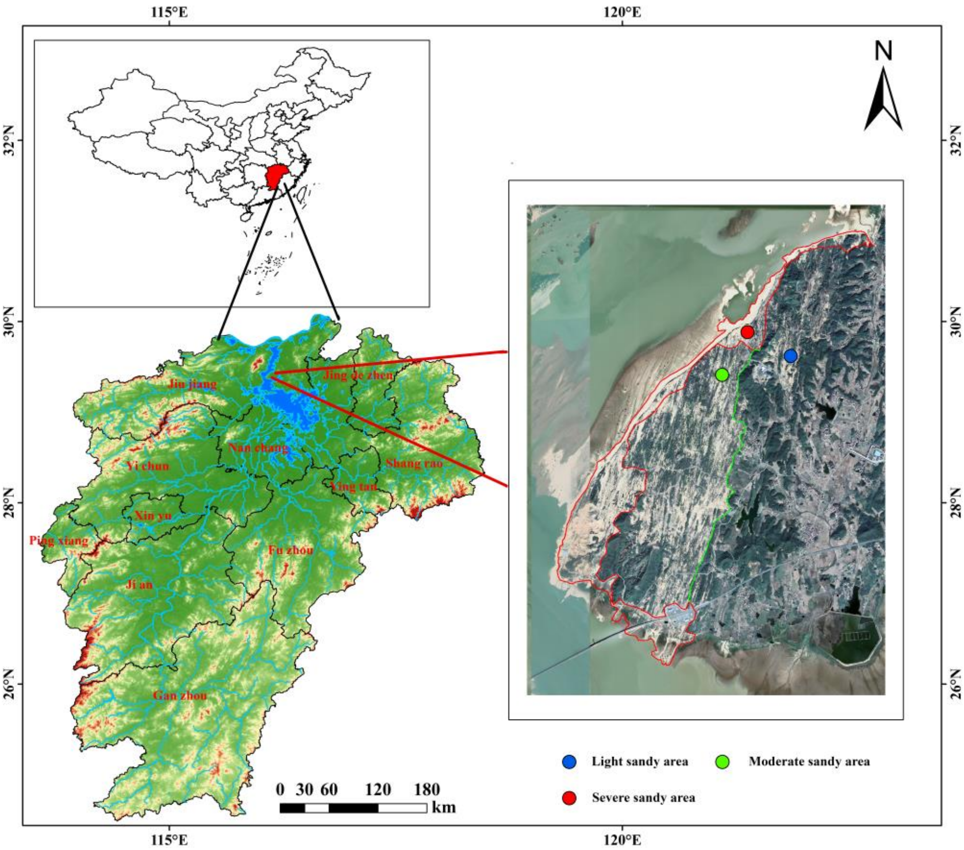


***Figure 1.*** *Study area*

## ***Data sources***

### *Field survey*

From March 2009 to April 2018, samples of *P. elliottii* were randomly set in three types of desertification areas of Poyang Lake every three to four months, and three replicates were set in each type of desertification area (*Figure **1.**2*). The size of the plot was 20 m×20 m. *P. elliottii* was inspected by a ruler for each wood, to monitor its growth indicators (tree height, DBH, etc.) and its biomass and volume was calculated based on the biomass model and volume of wood formula. The GPS coordinates of the sampling sites are as follows: Light sandy area (116°06'35" E, 29°25'18" N), Moderate sandy area (116°05'39" E, 29°25'05" N), Severe sandy area (116°05'57" E, 29°25'28" N).

The natural soils in the study area are mainly red loam and yellow-brown loam, which have been degraded to sandy soils under the action of wind, with a loose soil structure. The soil particle size composition is mainly medium sand and fine sand, with smaller fractions of pink sand and clay (Mo et al., 2016). There are differences in soil


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moisture content in different desertification areas. The average soil moisture content in severe, moderate, and light desertification area is 3.89%, 3.80%, and 4.98%. With the decrease of desertification degree, the content of soil organic matter gradually increased. The average content of soil organic matter in severe desertification area is (0.70%±0.56%), for moderate desertification area it is (0.87%±0.21%), and for light desertification area (1.31%±0.24%). The content of available nitrogen and phosphorus in the study area showed a low level due to the low vegetation coverage and soil texture.

***Figure 2.*** *Habitats of Pinus elliottii*

### *Calculation of the aboveground biomass of individual standing trees*

The main methods for estimating biomass are the traditional harvesting method, empirical formula method, model estimation method, and remote sensing inversion method (Wang et al., 2019). In this study, we estimated the aboveground biomass (dry weight) and its distribution of *P. elliottii* in the experimental area combining the actual test data of *P. elliottii* sample plots with the biomass model obtained by Ma Zeqing on *P. elliottii* plantation in Qian yan zhou, Jiangxi Province, China (Ma et al., 2007). The results are shown in *Table 1.*

***Table 1.*** *The model of aboveground biomass on different organs of P. elliottii*

| Biomass type | Biomass model W | Determine the coefficient $R^2$ | Correlation coefficient p | Number of samples n |
|---|---|---|---|---|
| Leaf biomass | $W=0.0120741D^{2.1515}$ | $R^2=0.72$ | $p<0.001$ | n=19 |
| Branch biomass | $W=0.0401892D^{2.0074}$ | $R^2=0.71$ | $p<0.001$ | n=19 |
| Trunk biomass | $W=0.02488D^{2.5459}$ | $R^2=0.99$ | $p<0.001$ | n=19 |

Note: W: Biomass kg; D: DBH cm

### *Calculation of standing timber volume per plant*

Ma et al. (2011) collated three wood volume equations for *P. elliottii* through field investigation of *P. elliottii* in Qian yan zhou, combined with the results of trunk analysis (*Table 2*). From the table, the equation $V=0.0000213D^{2.9870924}$ had the highest coefficient of determination $R^2=0.97$ and the best fitting effect. This equation was used for the calculation of wood volume in *P. elliottii* plantations in this paper.


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***Table 2.*** *The model of stem volume of P. elliottii*

| Stem volume model V | Determine the coefficient $R^2$ | Correlation coefficient p | Number of samples n |
|---|---|---|---|
| $V=0.015644-0.0056647D+0.00074757D^2$ | $R^2=0.95$ | p<0.001 | n=59 |
| $V=0.023776-0.0057348D+0.00058595D^2$ | $R^2=0.93$ | p<0.001 | n=59 |
| $V=0.0000213D^{2.9870924}$ | $R^2=0.97$ | p<0.001 | n=59 |

Note: V: Stem volume $m^3$; D: DBH cm

### *Data processing*

The data were processed using Excel 2010 and plotted using Origin 2018. Statistical analysis of data was performed using SPSS 20.0. One-way ANOVA was used to analyze the significance and correlation of each indicator. Multi-factor ANOVA was used to investigate the effects of DBH, tree height, and biomass of each organ of *P. elliottii* and the interaction effect of the three on the changes in above-ground biomass and wood volume.

## Results and analysis

### *Basic growth condition of P. elliottii plantation in Poyang Lake sandy land*

After nine years of planting, all indicators showed an increasing trend, with vegetation cover in the light sandy area reaching 85%-90%, greater than that in the severe and moderate sandy area (15%-20% and 45%-50%). The significance of tree height and DBH in different desertification degrees was analyzed by one-way ANOVA. There are significant differences in tree height and DBH between light desertification areas and other two types of desertification areas. The average DBH and average tree height of *P. elliottii* in the light sandy area were classified as 9.81±0.22 cm and 5.07±0.17 m, which were greater than those in the severe sandy area (8.42±0.25 cm and 3.46±0.13 m), and the moderate sandy area (7.44±0.25 cm and 3.71±0.11m). The density of *P. elliottii* in each type of sandy area was 5,200 trees·$hm^{-2}$ in the light sandy area, 1,200 trees·$hm^{-2}$ in the severe sandy area, and 2,500 trees·$hm^{-2}$ in the moderate sandy area respectively (*Table 3*).

***Table 3.*** *The growth situation of the P.elliottii artificial forest on sandy land of Poyang Lake*

| Degree of desertification | Vegetation coverage | Sample number | Mean DBH (cm) | Average tree height (m) | Density (Plants·$hm^{-2}$) |
|---|---|---|---|---|---|
| Severe sandy area | 15%-20% | 49 | $8.42±0.25^a$ | $3.46±0.13^a$ | 1200 |
| Moderate sandy area | 45%-50% | 52 | $7.44±0.25^a$ | $3.71±0.11^a$ | 2500 |
| Light sandy area | 85%-90% | 24 | $9.81±0.22^b$ | $5.07±0.17^b$ | 5200 |

Note: The data in the table is derived from field measurements in April 2018. The size of the quadrat is 20 m×20 m

### *Above-ground biomass of individual plants and its distribution*

Biomass, plays a very important role not only in the formation of ecosystem structure and function, but also in a functional indicator of the ecosystem and a concentrated expression of its ability to capture energy (Levick et al., 2016; Rodriguez-Veiga et al.,


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2017; Singh et al., 2017). From *Figure 3* at the initial stage of transplanting, the aboveground biomass of individual *P. elliottii* had no obvious change. There is a significant difference between the aboveground biomass of the light desertification area and that of the other two types of desertification areas. There is no significant difference in the aboveground biomass between moderate desertification area and severe desertification area.

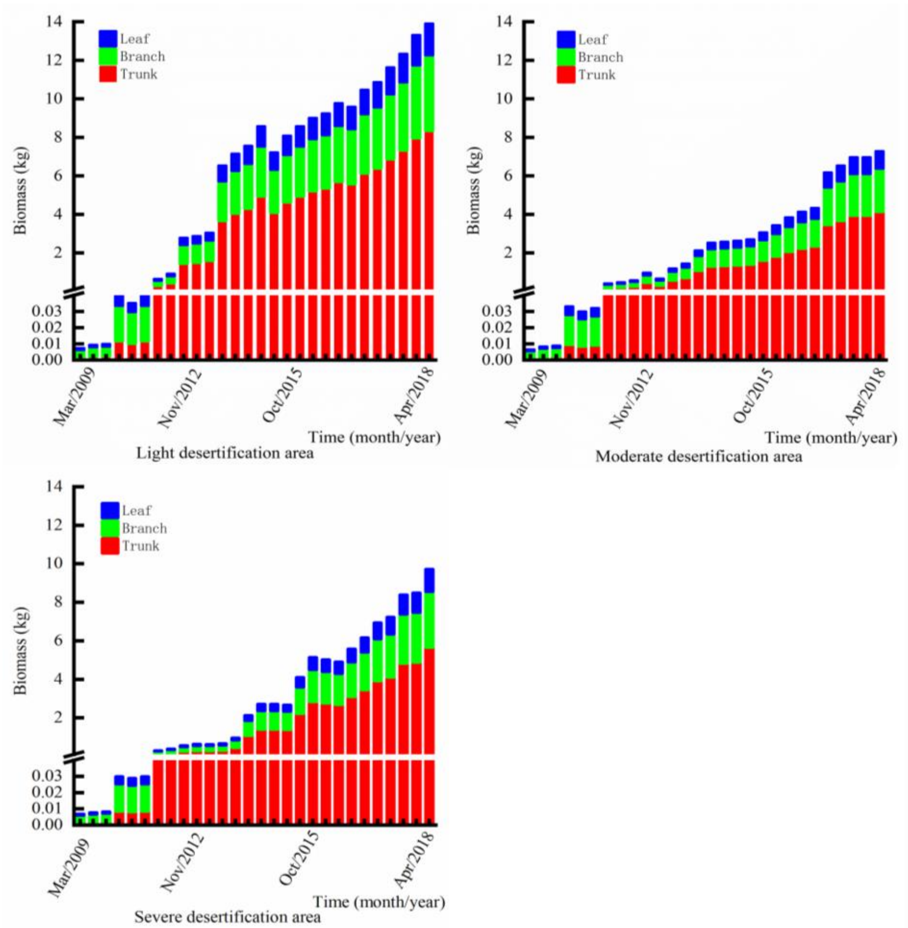


***Figure 3.*** *The variation and distribution of individual aboveground biomass of P.elliottii*

After two years of transplanting, the aboveground biomass accumulation rate of individual *P. elliottii* showed a rapid fluctuation and upward trend. After nine years of transplanting, the biomass changes of *P. elliottii* in different desertification areas are different. In the severe sandy area, the above-ground biomass of a single plant increased from 6.73 g·plant$^{-1}$ at the beginning of transplanting to 9720 g·plant$^{-1}$; in the moderate sandy area, the above-ground biomass of a single *P. elliottii* plant increased from 6.63 g·plant$^{-1}$ at the beginning of transplanting to 7280 g·plant$^{-1}$; The fastest increase was the light sandy area which increased from 7.56 g·plant$^{-1}$ at the beginning to 13900 g·plant$^{-1}$ (*Figure 3.*).

The distribution of the aboveground biomass in *P. elliottii* varies significantly among the organs. At the early stage of transplanting, branch biomass accounted for about 60% of the total aboveground biomass, which was the largest proportion of all *P. elliottii* organs. The above-ground biomass of *P. elliottii* plantations increased with the growth

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of DBH and tree height, and the proportion of trunk biomass was increasing rapidly, while the overall proportion of branch biomass decreased significantly. After two years of transplantation, *P. elliottii* in light sandy area grew faster, and the proportion of trunk biomass in total aboveground biomass (43%) exceeded that of branch biomass (42%) for the first time, while the proportion of trunk biomass in moderate and severe sandy areas exceeded that of branch biomass three years after planting. The average proportions were 58%, 30%, and 12%, respectively (*Figure 4.*).

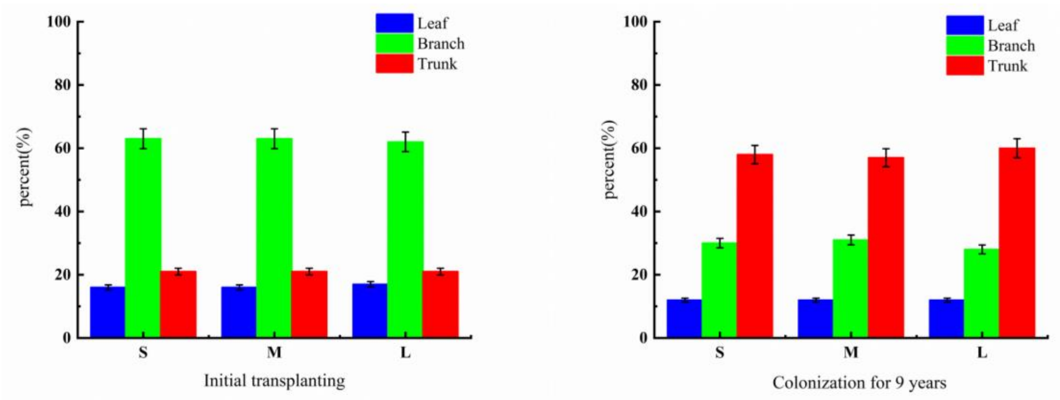


***Figure 4.*** *Organ biomass allocation proportion changes of P.elliottii during different periods. Note: S represents severe desertification area; M represents moderate desertification area; L represents light desertification area. Error bars represent standard errors*

### *Variation in the volume of wood and DBH per plant*

According to the trend of changes in the volume of *P. elliottii* timber in the experimental area, the trees can be roughly divided into two stages according to their growth rate. Early stationary stage (2009-2013): the seedlings were just transplanted from the nursery to the sandy area in the early stage of transplanting, and they were in the stage of adaptation to the environment of the sandy area. The trees grew more slowly. Rapid growth stage (2013-2018): the trees at this stage have adapted to the local ecological environment, and *P. elliottii* grows rapidly at this time. After planting for nine years, the individual volume of *P. elliottii* in severe and moderate sandy areas was 12,370 $cm^3 \cdot plant^{-1}$ and 8,548 $cm^3 \cdot plant^{-1}$, respectively. *P. elliottii* grows rapidly in light sandy areas, and its volume reached 19,525 $cm^3 \cdot plant^{-1}$ (*Figure 5.*).

The DBH of *P. elliottii* plantations in different afforestation years in southern Fujian affected the volume, and the DBH of Pinus elliottii was in a rapid growth period 22 years ago (Wei et al., 2016). The *P. elliottii* planted in the sandy area of Poyang Lake for nine years is also in the rapid growth period. The overall trend of DBH increased with the age of the trees, and the change of DBH was not obvious in the first planting stable stage. The survival rate of moderate desertification area is higher than that of severe desertification area, so the density of *P. elliottii* is relatively high. It may be that the average DBH of *P. elliottii* is smaller than that of severe desertification after 4 years because of the competition among individuals (Cao et al., 2017). After planting for nine years, the average DBH of *P. elliottii* in the light sanded area was 9.81 cm, which was greater than that of 8.42 cm and 7.44 cm in the severe and moderate sandy areas (*Figure 5.*).


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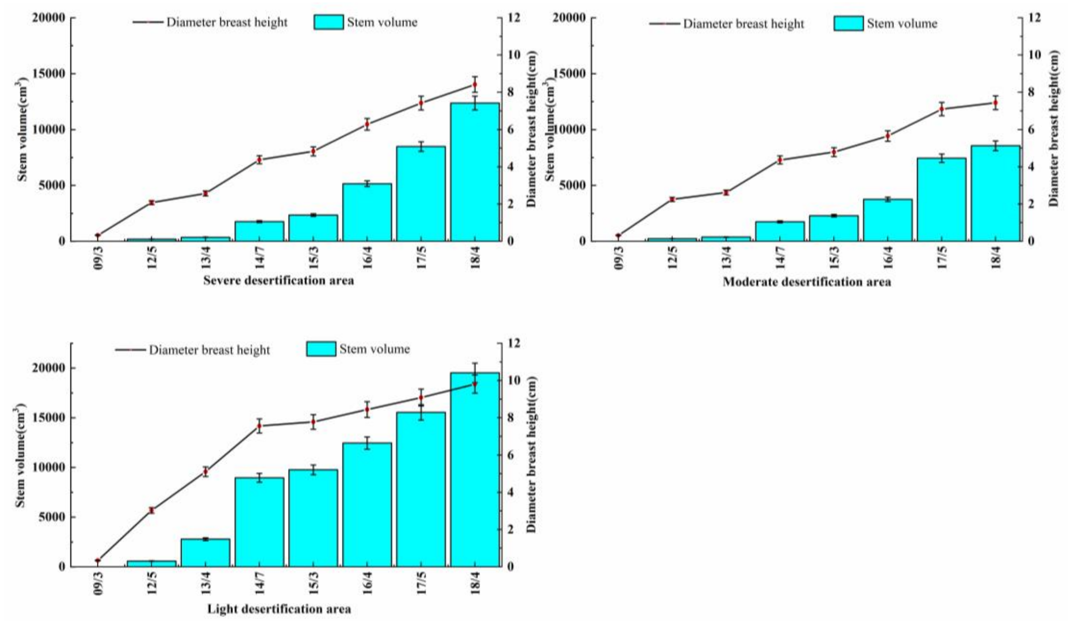


***Figure 5.*** *The stem volume and diameter breast height changes of P.elliottii plantation forest on sandy land of Poyang Lake. Note: Error bars represent standard errors*

## *Above-ground biomass and wood volume*

The growth of biomass and wood volume of *P. elliottii* was suppressed to different degrees with the increase of sanding. After nine years of planting, the aboveground biomass and volume per unit area of Poyang Lake sandy land have been increasing, and there are significant differences in different desertification types. The biomass and wood volume of *P. elliottii* in the light sandy area grew faster, reaching 72.3 t·hm$^{-2}$ and 101.53 m$^{3}$·hm$^{-2}$ respectively, which were higher than those in the other two sandy areas. The biomass and wood volume in the moderate sandy area reached 18.21 t·hm$^{-2}$ and 21.37 m$^{3}$·hm$^{-2}$ respectively, while those in the severe sandy area were only 11.67 t·hm$^{-2}$ and 14.84 m$^{3}$·hm$^{-2}$ (*Figure 6***.**).

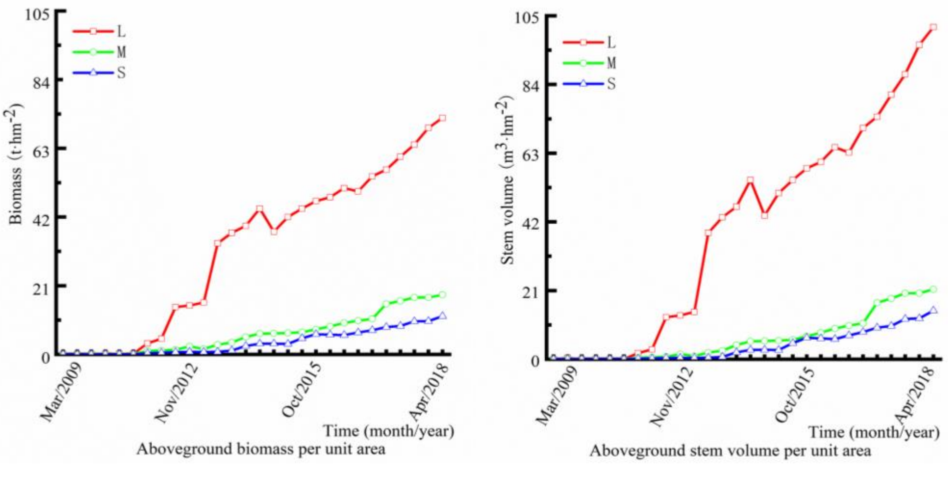


***Figure 6.*** *Above-ground biomass and stem volume per unit area changes of P. elliottii artificial forest on sandy land of Poyang Lake. Note: S represents a severe desertification area; M represents a moderate desertification area; L represents a light desertification area*


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A regression model between biomass and timber volume was fitted, as shown in the table below (*Table 4.*). The coefficient of determination $R^2$=0.99 for the linear type and polynomial type is greater than that for the logarithmic type and multiplicative power type and exponential type ($R^2$=0.53, $R^2$=0.94, $R^2$=0.61). The larger the coefficient of determination $R^2$, the stronger the correlation between the two variables was, the better the model fit, and the higher the reference value were.

***Table 4.*** *The regression models between biomass and volume of P. elliottii on sandy land of Poyang Lake*

| Model type | Regression model | $R^2$ decisive factor |
|---|---|---|
| Linear type | V=0.0013W - 0.0006 | 0.99 |
| Logarithmic type | V=0.0015ln(W) + 0.0045 | 0.53 |
| Polynomial type | $V=4E-05W^2+0.0009W-0.0001$ | 0.99 |
| Power type | $V=0.0007W^{1.1982}$ | 0.94 |
| Index type | $V=7E-0.5e^{0.6041W}$ | 0.61 |

Note: W: biomass $t\cdot hm^{-2}$; V: stem volume $m^3\cdot hm^{-2}$

## *Correlation analysis*

During the growth of *P. elliottii*, the growth indicators were closely related and influenced each other, with the same trend and significant correlation among them (*Table 5*). The correlation coefficients between tree height and wood volume and between tree height and trunk biomass ranged from 0.87 to 0.90. The remaining growth indicators all had correlation coefficients $R^2$>0.9 and were all highly significant at the $p<0.01$ level. Tree height, DBH, and organ biomass were all important factors influencing changes in above-ground biomass and lumber volume, with branch biomass and trunk biomass having the greatest effect on aboveground biomass and DBH having a slightly greater effect on lumber volume than height.

***Table 5.*** *The correlation between different indicators of P. elliottii on sandy land of Poyang Lake*

| Item | Above-ground biomass | Stem Volume | DBH | Tree height | Leaf biomass | Branch biomass | Trunk biomass |
|---|---|---|---|---|---|---|---|
| Above-ground biomass | 1 | | | | | | |
| Volume | 0.9959** | 1 | | | | | |
| DBH | 0.9339** | 0.9000** | 1 | | | | |
| Tree height | 0.9096** | 0.8714** | 0.9979** | 1 | | | |
| Leaf biomass | 0.9994** | 0.9922** | 0.9447** | 0.9221** | 1 | | |
| Branch biomass | 0.9978** | 0.9878** | 0.9542** | 0.9333** | 0.9995** | 1 | |
| Dry biomass | 0.9991** | 0.9988** | 0.9190** | 0.8926** | 0.9971** | 0.9943** | 1 |

Note: **. representative significant correlation at P < 0.01 level


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## Discussion

### *Changes in above-ground biomass of single pine plants in the sandy areas of Poyang Lake and their distribution*

The growth of plants is influenced and conditioned by multiple external environmental factors, such as climate change, lack of water, or other resources. However, plants stressed by external factors usually respond differently according to their characteristics and stress degree, which will have an impact on plant physiology and morphology (Kawano et al., 2009; Gaur and Sharma, 2014). With the growth of the tree, the above-ground biomass of Poyang Lake *P. elliottii* grows from slow-to-fast. The biomass distribution of each organ is from the largest to the smallest: trunk > branches > leaves. The results of studies have shown that with the increase of planting time, the most accumulated biomass of *P. elliottii* is the trunk, which increases continuously in the proportion of total biomass, the accumulation of branches and leaves is less, and the pattern of the biomass of each organ of *P. elliottii* follows trunk > branch > leaf > root > bark (Zhu et al., 2018), the growth of *P. elliottii* in Poyang Lake area conforms to the above rules.

The order of biomass distribution among the organs of *P. elliottii* in the Qian yan zhou area was: trunk > total roots > bark > leaves > branches. In terms of the proportion of each organ biomass, trunk biomass accounted for the largest proportion, with a mean of 51.9%, and had a direct influence on the above-ground biomass of the stand, followed by the root system with 16.4%, leaf biomass with 9.4% and branch biomass with 9.1% (Luo, 2016). The main reason for the slight difference between the above results and the results of this study is that the *P. elliottii* species in the Qian yan zhou area have been planted for more than 20 years and have a strong adaptation to the soil and climate. However, with the shorter transplanting time and shorter height of the saplings in this experimental area. In addition, in the case of high temperature and little rain, and strong evaporation, the growth of the *P. elliottii* lacked sufficient water and nutrients. After planting for nine years, the proportion of total biomass of *P. elliottii* trunk biomass in each desertification area increased continuously and tended to be about 58%, while the proportion of total biomass of branch biomass decreased.

### *Variation of the above-ground wood volume of single pine plants in the sandy areas of Poyang Lake*

Wood volume is one of the important indicators of plantation growth and management (Gonzalez-Benecke et al., 2014), the growth of *P. elliottii* plantation trees in the experimental area increased from slow-to-fast, and the change of wood volume was highly significantly correlated with tree height, and DBH, and above-ground biomass, etc. The influence of trunk biomass on wood volume was the greatest, with the correlation coefficient $R^2$=0.99. The *P. elliottii* in the sandy area of Poyang Lake was in the stage of rapid growth, and the growth conditions in the lightly sandy area were better. After nine years of planting, the volume of a single plant is 0.019 $m^3$, which has great growth potential and high development and utilization potential. In Nanping, Fujian Province, the volume of *P. elliottii* in 7 years is 0.018 $m^3$. (Lin, 2002). The growth volume of *P. elliottii* in this area is larger than that in the study area, because the soil nutrient conditions in this area are better, which is more conducive to the growth of *P. elliottii*. However, the soil in the study area is poor, and the growth of *P. elliottii* is mainly limited by N and P (Hu et al., 2014).


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### *Comparison of above-ground biomass and wood volume per unit area in different sandy types*

Above-ground biomass, as a fundamental attribution in forest ecosystems reflects the forest management and production in a region, it also indicates the health status of the ecosystem, and it is an important indicator of the energy acquisition capacity and ecosystem function of the forest ecosystem (Hu et al., 2005). There are differences in the aboveground biomass and volume of *P. elliottii* in different desertification areas, among which the biomass and volume of light desertification area increase significantly, and the advantages are greater than those of other desertification areas. Nine years after planting, the above-ground biomass and wood volume was 72.3 $t·hm^{-2}$ and 101.53 $m^3·hm^{-2}$ respectively, which were greater than those in the moderate (18.21 $t·hm^{-2}$ and 21.37 $m^3·hm^{-2}$) and severe sandy area (11.67 $t·hm^{-2}$ and 14.84 $m^3·hm^{-2}$). The main reason for the difference is that the light desertification area is relatively far away from Poyang Lake, less affected by wind and sand erosion, and its habitat is relatively superior. The growth of trees in this area is better than in the other two desertification areas. As the planting time increases, the biomass and volume increase rapidly, which means that planting *P. elliottii* has high survival rate and rapid growth in the early stage, which not only brings direct economic benefits but also plays an important role in improving the ecosystem. Previous scholars' research on carbon content and carbon storage of *P. elliottii* plantations in different sandy areas in Duobao Township sandy land ecological restoration demonstration area (Cao et al., 2016) showed that compared with severe sandy areas, in light sandy areas it is easier to restore vegetation and improve carbon sequestration to the benefits of ecosystems. Therefore, the ecological management of sandy areas should be promoted from light to severe, and herbaceous and broad-leaved plants should be introduced at the right time to increase the carbon stock of plantation forests on sandy land.

The research results of this paper provide a strong basis for clarifying the dynamic change process of biomass and volume of *P. elliottii* plantations in three types of sandy land. However, the reasons for the differences of biomass and volume in different desertification areas need to be further studied. In the future, it is necessary to carry out a long-term study on the differences and internal laws of the volume and biomass accumulation of *P. elliottii* in different cultivation environments and different ages, to understand the growth law of the aboveground biomass of *P. elliottii* more deeply.

## Conclusion

The aboveground biomass and volume of *P. elliottii* on sandy land increased from slow-to-fast. After planting for nine years, the aboveground biomass (72.3 $t·hm^{-2}$) in the light desertification area was higher than that in the moderate desertification area (18.21 $t·hm^{-2}$) and severe desertification area (11.67 $t·hm^{-2}$).

The proportion of total biomass of *P. elliottii* trunk biomass on the occupied land is increasing, the proportion of branch biomass is decreasing, and the proportion of leaf biomass is basically stable. The average ratio of trunk, branch and leaf to the whole plant is changed from 21%, 63%, and 16% at initial planting to 58%, 30%, and 12%, respectively.

DBH, tree height, and the biomass of each organ are significantly related to the volume $P<0.01$). After nine years of planting, the volume of light, moderate and severe


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desertification areas is 101.53 $m^3 \cdot hm^{-2}$, 21.37 $m^3 \cdot hm^{-2}$, and 14.84 $m^3 \cdot hm^{-2}$, respectively. The lower the degree of desertification, the better the vegetation restoration is.

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