Climate Warming and Drought Intensification Aggravate Forest Pest and Disease Disasters in Jiangxi Province (Postprint)

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Abstract

Over the past 50 years, climate change has intensified, global warming has become evident, and land surfaces have trended toward aridification; meanwhile, losses from forest pest and disease disasters have continuously increased, with the two being closely related. Taking Jiangxi Province as the study area, data on climatic elements such as temperature, humidity, and sunshine from 1961-2010 and forest pest/disease disaster occurrence area and severity from 1992-2010 were collected. It was found that over the past 50 years, annual mean temperature and winter mean temperature in the study area have been increasing at rates of 0.16℃/10a and 0.27℃/10a, respectively, while annual mean relative humidity has been decreasing at a rate of -0.45%/10a, indicating a significant trend of climate warming and aridification. Simultaneously, forest pest/disease disaster area has been expanding at a rate of 58125hm2/10a. The study employed correlation analysis and principal component analysis to reduce dimensions and screen the selected 24 climatic elements, used stepwise regression to construct models, and utilized wavelet analysis to examine spatiotemporal variations within the study area to analyze the relationship between the two. 16 (related to disease occurrence) or 17 (related to pest-disease and pest occurrence) significantly correlated climatic elements were obtained. The maximum positive correlation element was summer mean temperature sliding mean, etc., while the maximum negative correlation element for all three was temperature-humidity coefficient sliding mean (温湿系数 = 年均相对湿度/年均温). Four or five principal components were obtained, with the principal component representing temperature or temperature-humidity combined variable characteristics having the highest contribution rate (pest-disease and pests: 41.43%, disease: 42%). Three optimal regression models with forest pest/disease disasters as the vertical axis and temperature-humidity coefficient sliding mean as the horizontal axis were established, possessing predictive capability (Y 病

虫害 =3.582×106-7.750×105 X, Y 虫害 =-6.375×105X+2.95×106, and Y 病害 =-1.375×105X+6.321×105), with linear fitting degrees of 77.9%, 79.1%, and 56.7%, respectively, and average prediction accuracies of 66.2%, 68.6%, and 47.9%, respectively. Meanwhile, the temperature-humidity coefficient sliding mean in the study area has significantly decreased over the past 50 years and shifted to negative anomalies after 1993. This indicates that climate warming and environmental aridification have a driving effect on the occurrence of forest pest/disease disasters in the region, promoting their intensification, particularly becoming more severe after entering the 1990s. It was found that the temperature-humidity coefficient sliding mean has a 29a periodic variation. If 1993 is taken as the starting point and non-climatic factors are not considered, the trend of intensifying pest/disease disasters will continue until 2022. Spatially, over the past 50 years, the temperature-humidity coefficient sliding mean was lowest in southern Jiangxi, predicting that forest pest/disease disasters will be more severe there compared to other regions, while the tendency rate of temperature-humidity coefficient sliding mean was highest in eastern and northern Jiangxi, predicting that the variability of forest pest/disease disaster occurrence may be greater there. The above results demonstrate that climate warming and environmental aridification have exacerbated forest pest/disease disasters in Jiangxi Province. Southern Jiangxi should be designated as a priority area for prevention and control efforts, while monitoring and early warning capabilities in eastern and northern Jiangxi should be enhanced.

Full Text

Global Warming and Droughts Aggravate Forest Damage Resulting from Pests and Diseases in Jiangxi Province

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Abstract: Over the past 50 years, climate has changed rapidly with global warming and land surface drying, which has been accompanied by increased forest loss and damage resulting from pests and diseases. Climate data (e.g., air temperature, relative humidity, and sunshine data) from 1961 to 2010 showed that the climate in Jiangxi Province was warming significantly, with the annual mean temperature increasing by 0.16°C per 10 years, and the winter mean temperature rising by 0.27°C per 10 years. The Jiangxi Province climate was also drying throughout this period (annual mean relative humidity decreased -0.45% per 10 years). In addition, forest pests and disease occurrence from 1992 to 2010 showed that in Jiangxi, the area affected by forest diseases and pests increased significantly, with 58,125 hm^2 per 10 years. Pearson correlation and principal component analyses showed that 16 (for forest diseases) or 17 (for forest pests) climate elements were significantly related to the forest loss. From these individual elements, the most positively correlated was a 9-year sliding average of summer mean temperature, and the most negatively correlated component was a 9-year sliding average of hydrothermal coefficient (annual mean temperature/annual mean relative humidity). Amongst the four or five principal components, the variables temperature and temperature-humidity contributed most to explaining forest area loss (41.43% and 42.0%, respectively). In stepwise regression analyses, three optimal regression models (Total: Y = 3.582 × 10 - 7.750 × 10^3, forest pest: Y = -6.375 × 10 + 2.95 × 10^3, forest diseases: Y = -1.375 × 10 + 6.321 × 10^3) were analyzed to describe the forest loss by the 9-year sliding average of temperature humidity coefficient. The three models showed a linear fit of 77.9%, 79.1%, and 56.7% and a prediction accuracy of 66.2%, 68.6%, and 47.9%, respectively. A declining trend in the sliding average of temperature humidity coefficient was observed over the past 50 years, for which the anomaly transferred from positive to negative in 1993. This indicates that climate warming and droughts could have aggravated the forest loss and damage over the past 50 years, especially after the 1990s. A wavelet analysis showed a 29-year periodicity in the temperature humidity coefficient. If this anomaly started in 1993, the forest loss trend could potentially be relieved by the end of 2022. In Jiangxi, the temperature humidity coefficient significantly increases from the south to the north, suggesting that forest diseases and pest disasters should be more extreme in Gan Nan than in other areas. In addition, since the change rate of climate warming or drought was higher in Gan Dong and Gan Bei, a high variability of forest diseases and pest disasters can be expected there in the future. Overall, our results suggest that climate warming and environmental drought aggravates forest diseases and pest disasters in Jiangxi. They furthermore emphasize that Gan Nan could be a key area in preventing and controlling the effects of forest diseases and pest disasters, whereas the monitoring efforts in Gan Dong and Gan Bei should be increased.

Key Words: long-time; global warming; droughts; forest loss generated by pests and diseases; driving effect; regionality

1. Introduction

Climate change has intensified over recent decades, with significant global warming and a trend toward land surface drying. Various disasters have occurred frequently, including forest disasters, with losses increasingly severe. Forest biological disasters are important factors that damage forest ecosystems. Under climate warming, the survival rate of organisms, especially overwintering survival rates, improves. According to van' t Hoff' s law, this increases the population base for the following year, enhancing their destructive capacity. Climate warming can accelerate biological development rates, extend the annual growing period, increase reproductive capacity, and increase the number of generations per year, leading to an increasing trend in losses. Warming can also expand the suitable habitat areas for pests and shorten outbreak cycles, with complex and variable damage patterns and earlier peak periods.

Research on the relationship between long-term climate change and biological disasters helps understand disaster occurrence patterns under climate change backgrounds, predict future disaster dynamics based on key factors, and provide important references for pest early warning and prevention. Forest geographical distribution and ecosystem services show zonal and regional characteristics. To obtain representative case studies on the impact of climate change on forest biological disasters, a specific region must be selected.

Jiangxi Province is located in a subtropical monsoon climate zone with well-developed forest ecosystems. The region experiences significant climate variation and frequent meteorological disasters, such as summer-autumn droughts and extreme low temperatures. The area affected by forest pest and disease disasters has been increasing in recent years at a rate of 5,812.5 hm^2 per year. Some studies suggest that the rise in annual mean temperature (0.16°C/10a) has aggravated forest pest disasters such as *Tomicus piniperda*. The warming rate has increased, especially warm winters. From 1958–2009, the annual mean temperature in the region increased at a rate of 0.16°C/10a.

Some pest outbreaks may be triggered by certain climate elements. For example, under drought stress and hot-dry climate conditions, the spruce sawfly (*Cephalcia abietis*) in the Italian Alps is prone to outbreaks. The rust-colored shoulder longhorn beetle (*Apriona swainsoni*) may also outbreak in years with low precipitation and low hydrothermal coefficient. The occurrence of *Dendrolimus punctatus* is influenced by precipitation and maximum wind speed, with prediction models achieving high accuracy. Various pests and diseases respond differently to climate change, adding complexity to their relationships.

The main forest biological disasters in Jiangxi include *Bursaphelenchus xylophilus* (pine wood nematode), *Hylobitelus xiaoi*, *Dendrolimus punctatus*, *Dendrolimus kikuchii*, *Lecanosticta acicola* (brown spot needle blight), *Colletotrichum gloeosporioides* (camellia anthracnose), *Solidago canadensis* (Canada goldenrod), and *Batocera lineolata*. In recent years, some secondary pest species have frequently occurred and caused disasters in some areas. In 2010, forest biological disasters in the region affected 57,586 hm^2, with direct economic losses of 13,529,750,000 yuan. Understanding the changing patterns of forest pest and disease disasters under climate change will undoubtedly benefit scientific forest protection and ensure healthy forest ecosystem development.

Many studies have focused on the impact of single climate elements such as temperature and relative humidity on forest pest and disease disasters, while research on the long-term comprehensive effects of climate is limited. This paper collects long-term climate data and forest pest/disease occurrence data from Jiangxi Province to reveal the impact and induction patterns of the former on the latter, providing references for forest pest and disease prevention and control work in the region and surrounding provinces.

2. Study Area

Jiangxi Province (24°29 -30°04 N, 113°34 -118°28 E) was selected as the study area. Located in a typical subtropical monsoon climate zone, it is a key forestry region in southern China with frequent forest pest and disease disasters, many disaster types, and high frequency.

3. Data Collection

Daily meteorological data from 16 weather stations in the study area were collected for 1961–2010, including precipitation, sunshine duration, and other surface climate data (from the Meteorological Data Center, http://www.escience.gov.cn/metdata/page/index.html, November 2014). Forest pest and disease disaster occurrence area data for Jiangxi Province were collected from the Jiangxi Forestry Statistical Yearbook or related materials, including disease and pest data. For missing or precipitation values, the least squares method was used to check and interpolate missing values, and solid precipitation values were corrected. Before analysis, other data were also interpolated for missing values using the least squares method.

Selected meteorological indicators considered both uniform annual changes and short-term mutations. A sliding filter method was used for smoothing processing to ensure the indicators represented the multi-year climate state of the study area, allowing analysis of mean values and variability at multiple levels. To ensure the sliding mean could display trends in climate element means and variation coefficients, odd-numbered years were typically used for sliding means (9 years in this study), with the time series midpoint added to the time coordinate.

[Figure 1: see original paper] Weather data sampling sites of Jiangxi Province

4. Climate Element Determination and Screening

Climate change is a combination of changes in means or deviations of various climate elements. When the mean shifts left, it decreases; when it shifts right, it increases. The variation coefficient of a climate element indicates the magnitude of change, meaning the frequency of extreme climate events changes if the intensity changes. This study selected climate elements including annual mean temperature, annual mean relative humidity, and annual sunshine duration.

To avoid collinearity interference, all climate elements were first correlated with forest pest/disease occurrence area, then principal component analysis was performed. The variables with the highest loadings in each principal component were selected as independent variables, with forest pest/disease occurrence area as the dependent variable to build prediction models, ultimately obtaining important climate elements affecting forest pest/disease disasters.

In linear trend analysis, y represents a climate element with sample size n, t represents the year corresponding to y , a is the regression coefficient, and b is the regression constant, estimated using the least squares method. The linear regression equation y = a + bx is established, where a represents the climate tendency rate, used to quantitatively describe climate trends. A positive a indicates an upward trend, while a negative a indicates a downward trend. Climate anomaly indices were used to evaluate whether climate elements exceeded normal ranges, with annual anomalies greater or less than one standard deviation indicating abnormally high or low values.

To understand spatiotemporal climate change characteristics in the study area and predict forest pest/disease disaster trends, wavelet analysis was used to analyze periodicity and spatial variation dynamics of relevant climate elements. Statistical analysis was performed using Matlab, ArcGIS, and SPSS 17.0.

5. Results

5.1 Forest Pest and Disease Disaster Trends

Forest pest and disease disasters in the study area showed a clear upward trend over the past years, with disease and pest areas expanding continuously and significant linear trends. Most newly affected areas were mild or moderate disaster zones, while the growth trend in severely affected areas was not obvious. The forest pest/disease area increased at an average rate of 58,125 hm^2 per 10 years (1992–2010).

Linear equation and trend of forest diseases and pest of Jiangxi Province during 1992/1998 to 2010

5.2 Impact of Climate Element Changes on Forest Pest and Disease Disasters

The study area showed clear warming and drying trends. Annual mean temperature and winter mean temperature increased at rates of 0.16°C/10a and 0.27°C/10a respectively (1961–2010), while annual mean relative humidity decreased at a rate of -0.45%/10a. Annual mean temperature sliding mean, summer mean temperature sliding mean, and summer mean temperature mean increased significantly, while annual precipitation sliding mean, relative humidity sliding mean, and relative humidity mean decreased significantly. Other climate elements such as sunshine duration sliding mean, relative humidity variability, and hydrothermal coefficient variability also increased significantly, while hydrothermal coefficient mean and annual precipitation variability decreased significantly.

Trends of climate elements and Pearson correlation between them and forest diseases and pest

Different climate elements had varying impacts on forest pest/disease disasters. Among the 16 climate elements significantly correlated with pest/disease occurrence, positively correlated elements included summer mean temperature sliding mean, sunshine duration sliding mean, precipitation variability, winter mean temperature variability, annual mean temperature sliding mean, relative humidity variability, summer mean temperature mean, hydrothermal coefficient variability, and annual mean temperature mean. Negatively correlated elements included hydrothermal coefficient sliding mean, annual mean temperature variability, and relative humidity mean.

The maximum positive correlation elements for disease, pest, and combined pest/disease occurrence were summer mean temperature sliding mean (r = 0.838, 0.839, 0.647 respectively), while the maximum negative correlation element for all three was hydrothermal coefficient sliding mean (r = -0.883, -0.890, -0.753 respectively). This suggests hydrothermal coefficient sliding mean may play a more critical role in negatively affecting forest pest/disease occurrence and trends in the study area.

5.3 Key Climate Elements Affecting Forest Pest and Disease Disasters and Their Impact Trends

To further consolidate the significant elements, principal component analysis was performed on those significantly correlated with pest/disease and disease occurrence. For pest/disease, four principal components were obtained with characteristic root contributions of 41.43%, 13.9%, 13.66%, and 7.85%, with a cumulative contribution rate of 76.84% (KMO = 0.647, ^{2} = 16359.97, df = 136, $p < 0.001$). The first principal component mainly reflected temperature or temperature-humidity joint variable characteristics, including hydrothermal coefficient sliding mean, annual mean temperature sliding mean, annual mean temperature mean, hydrothermal coefficient mean, summer mean temperature sliding mean, and summer mean temperature mean.

For disease occurrence, five principal components were obtained with characteristic root contributions of 42.00%, 20.81%, 8.04%, 6.91%, and 6.37%, with a cumulative contribution rate of 84.13% (KMO = 0.660, ^{2} = 16286.514, df = 120, $p < 0.001$). Similarly, the first principal component mainly reflected temperature or temperature-humidity joint variable characteristics.

Four/five principal components and matrix of climate elements

From the above principal components, the variables with the highest loadings (hydrothermal coefficient sliding mean, relative humidity sliding mean, sunshine duration variability, precipitation variability, and temperature difference mean) were selected as independent variables, with forest pest/disease occurrence area as the dependent variable for stepwise regression analysis. Three optimal regression equations were obtained:

$Y \quad / \qquad = 3.582 \times 10 \; - 7.750 \times 10^3$
$Y \quad = -6.375 \times 10 \; + 2.95 \times 10^3$
$Y \qquad = -1.375 \times 10 \; + 6.321 \times 10^3$

All three equations were based on hydrothermal coefficient sliding mean. The linear fit of the three models was 77.9%, 79.1%, and 56.7% respectively, with prediction accuracies of 66.2%, 68.6%, and 47.9% respectively. When hydrothermal coefficient sliding mean was substituted back, the average prediction accuracy was 77.9%, 79.1%, and 56.7%. Compared with other climate elements, hydrothermal coefficient sliding mean showed a significant negative relationship with forest pest/disease occurrence area in the study area, with the former decreasing significantly over the past decades while the latter increased significantly, suggesting hydrothermal coefficient sliding mean may be the most critical factor affecting forest pest/disease occurrence and trends.

[Figure 3: see original paper] Model fitting and trend of hydrothermal coefficient sliding average, forest diseases and pest of Jiangxi during 1992 to 2010

6. Spatiotemporal Characteristics of Hydrothermal Coefficient in Jiangxi Province

6.1 Hydrothermal Coefficient Change Trend Rate and Periodicity

The hydrothermal coefficient sliding mean from 1961–2010 showed an overall significant decreasing trend with a linear tendency rate of -0.075 ($p < 0.001$). The negative anomaly turning point occurred in 1993. Wavelet analysis revealed a 29-year periodicity in hydrothermal coefficient changes, with the most significant periodic oscillation at this timescale.

[Figure 4: see original paper] Variation, tendency and periodicity of hydrothermal coefficient sliding means during 1961 to 2010 in Jiangxi Province

6.2 Spatial Distribution Characteristics of Hydrothermal Coefficient Change Trend Rate

Hydrothermal coefficient values varied significantly across Jiangxi' s counties, with notable regional characteristics. The hydrothermal coefficient sliding mean generally increased from western and southern Jiangxi to eastern and northern regions. The linear change tendency rate or change degree was lowest in the Jitai Basin, with a significant low-value area appearing in Ganzhou. Southern Jiangxi experienced more severe high temperatures or drought, while northern Jiangxi showed greater variability.

[Figure 5: see original paper] Spatial variation of hydrothermal coefficient sliding average and change trend rate in Jiangxi counties during 1961–2010

7. Discussion and Conclusion

Climate change has intensified, with global warming and land surface drying. Forest biological disasters have shown an increasing trend in China in recent decades, with increasing losses. In the study area of Jiangxi Province, annual mean temperature increased at rates of 0.16°C/10a and 0.27°C/10a (1961–2010), while annual mean relative humidity decreased at -0.45%/10a. Summer mean temperature sliding mean and other temperature indicators increased significantly, while annual precipitation sliding mean, relative humidity mean, and relative humidity sliding mean decreased significantly. These clearly demonstrate significant climate warming and drying in the study area.

Meanwhile, forest pest/disease disasters in the region have also increased, with expanding disaster areas. Climate warming drives accelerated biological development rates, enhanced reproductive capacity, improved survival rates (especially overwintering survival), earlier peak periods, extended annual growing periods, and increased generations per year. Warming also expands suitable habitats for pests, providing opportunities for secondary or occasional pest outbreaks. This study supports the view that climate change aggravates forest pest/disease disasters.

Among 16 climate elements significantly correlated with forest pest/disease occurrence, summer mean temperature sliding mean showed the strongest positive correlation, while hydrothermal coefficient sliding mean showed the strongest negative correlation. This indicates that high temperatures (especially summer heat) or environmental drought have driven the aggravation of forest pest/disease disasters over recent decades, consistent with some studies emphasizing the important driving role of annual mean temperature increase. Some studies emphasize the important role of warm winters in driving pests like *Hylobitelus xiaoi* and *Tomicus piniperda*, while others highlight summer high temperature as a key driver, such as for *Dendroctonus frontalis* outbreaks in Honduras. This study supports that forest pest/disease disasters are more likely driven by summer high temperatures.

The dual or combined effects of climate warming and environmental drought may be stronger than single-factor effects. In analyzing climate element impacts, all elements were first correlated with forest pest/disease occurrence area, then principal component analysis was performed to reduce dimensionality and collinearity. The first principal component representing temperature or temperature-humidity joint variables contributed most (41.43% for pest/disease, 42% for disease), supporting the important role of temperature while highlighting the significant role of temperature-humidity combined effects.

Climate change impacts on pest/disease disasters are complex because changes in single climate elements often cause corresponding changes in others. For example, the suitable temperature range may shift due to humidity changes, so different temperature-humidity combinations may produce similar biological effects. The occurrence of *Pristiphora erichsonii* is simultaneously affected by temperature, humidity, and precipitation, while *Dendrolimus punctatus* occurrence is not controlled by single climate factors because temperature, humidity, and precipitation in mountainous areas all affect its occurrence. Previous studies and this research support that environmental temperature change is a major factor affecting forest pest/disease disasters, but environmental humidity changes may also participate or exert joint effects. Environmental drought directly contributes to some pest outbreaks, such as *Sparganothis pilleriana* in the Xiaolongshan forest area, which is closely related to warm-dry climate conditions. The spruce sawfly in the Italian Alps is prone to outbreaks under drought stress or hot-dry conditions, and *Apriona swainsoni* often outbreaks in years with low precipitation.

In model construction, the comprehensive element of hydrothermal coefficient sliding mean performed best. After principal component analysis, stepwise regression models based on hydrothermal coefficient sliding mean achieved the highest fit (77.9%, 79.1%, 56.7%) and prediction accuracies (66.2%, 68.6%, 47.9%). As the ratio of annual mean relative humidity to annual mean temperature, the hydrothermal coefficient reflects the combined relationship between temperature and humidity. When annual mean relative humidity decreases or annual mean temperature increases, or both occur simultaneously, the hydrothermal coefficient decreases. In Jiangxi, the annual mean temperature sliding mean increased significantly over the years, while relative humidity mean and sliding mean decreased significantly, causing the hydrothermal coefficient to show a significant decreasing trend, creating favorable conditions for some forest pest/disease disasters.

The study area' s hydrothermal coefficient sliding mean has a large cycle characteristic of about 29 years, turning to negative anomaly after 1993. With global warming entering the warmest period in a century during the 1990s, the hydrothermal coefficient decline was most obvious, driving the deepening aggravation of forest pest/disease disasters. The hydrothermal coefficient sliding mean shows regional distribution characteristics, forming a low-value area in Ganzhou City and its surroundings. If the 29-year cycle is considered starting from 1993, the aggravation trend of forest pest/disease disasters could continue until 2022.

The linear change tendency rate of hydrothermal coefficient sliding mean increases from western-southern to eastern-northern Jiangxi, suggesting that with climate warming or drought, the damage progress in northeastern Jiangxi forests from pest/disease disasters will be faster than in other regions. Gan Nan, Jitai Basin, and other areas are heavy disaster zones for forest pests and diseases in Jiangxi. Although the future variability of pest/disease disasters in light disaster areas may be greater than in heavy disaster areas, monitoring and early warning efforts should be strengthened in northeastern Jiangxi.

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Note: Figure translations are in progress. See original paper for figures.