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Bamboo for climate-smart landscapes in Chishui, Guizhou province

Assessment of the Vulnerability of
Bamboo Forest Ecosystems to Climate Change

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International Network for Bamboo and Rattan

INBAR, the International Network for Bamboo and Rattan, is an intergovernmental organization bringing together some 41 countries for the promotion of the ecosystem benefits and values of bamboo and rattan.

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Keywords: bamboo, climate change, vulnerability, Chishui, China

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The **International Network for Bamboo and Rattan (INBAR)** is the multilateral development organisation of 41 Member States for the promotion of bamboo and rattan. INBAR supports its members to include bamboo and rattan in their sustainable development action plans and green economy strategies. It promotes innovative ways of using bamboo and rattan to improve rural livelihoods, protect the environment, address climate change and issues of international bamboo and rattan trade and standards. INBAR connects a global network of partners from government, private and NGO sectors to promote a global agenda for sustainable development using bamboo and rattan.



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Executive Summary

This report presents the first study into the vulnerability and resilience of bamboo forest ecosystems to climate change in China. The project team hope this pioneering research can serve as a starting point and reference for further related work. Due to the limitation of time, long-term data monitoring, lack of previous researches and the complexity of the issues, there are inevitably some inadequacies existed. We encourage more and more research to study the subject in greater depth.

According to the 4th IPCC Assessment Report (AR4), China has experienced warming temperatures, including higher extremes in winter since 1979. That lead an increase river runoff in Southern and decrease in Northern. A recent WWF report indicates the whole Yangtze basin will become warmer and dryer in the future, however, precipitation shows no obvious change, but there is notable spatial heterogeneity (Xu Ming etc, 2009). The upper reaches of the Yangtze River is not only an area which is the focus of the national poverty alleviation programme but, due to its ecological importance and high-vulnerability, it is also a key conservatory area for the China -- Yangtze River Shelter Forest, which is one of the ecological protection demonstration project areas in China.

Climate change is causing significant changes to eco-systems, socio economics and human health. Chishui, one of the famous hometowns of bamboo in China, is located in a transition area between the Yungui Plateau and the Sichuan Basin in the upper reaches of the Yangtze basin. Research has shown that Chishui's ecosystems are particularly vulnerable to environmental changes that are likely to be amplified by the effects of climate change. How to adapt to the climate change, especially warming trends? Does the system have enough resilience?

Commonly referred to as "poor man's gold", bamboo is a multi-purpose woody resource that is widely used in construction, pulping, plywood, handicrafts, and a diverse range of subsistence applications, generating job opportunities and cash income. According to INBAR's research report (INBAR, 2009), bamboo can absorb carbon as quickly into its biomass as other fast-growing sub-tropical tree species, such as Chinese Fir, and this offers huge potential to mitigate climate change for those in remote mountainous areas. Moreover, bamboos vast root and rhizome system holds soil and water, serves to protect the land and prevent soil erosion, thus helping communities adapt to future climate change risks.

As part of the first batch of demonstration sites of the National Sloping Land Conversion Programme, Chishui has used bamboo as the main species to return unproductive agricultural land back into forests since 2001. Some significant progress has already been made: the forest coverage has increased from 64% to 80%, and the total bamboo forest area of Chishui has reached 1.3 million mu (86,667 ha), accounting for 60% of total forestland.

Although the bamboo forest area has expanded greatly serious gaps still exist, which hinders generation of the full benefits of the bamboo industry: the low yields of bamboo forest (bamboo culms and edible bamboo shoots) due to lack of good management practices, the bamboo forest structure and species composition still need further improvement. Monoculture plantations are more vulnerable to damage caused by extreme climate events, such as extremes in temperatures (INBAR, 2014) which, due to climate change, are likely to increase in frequency and intensity.

The project "Bamboo for climate-smart landscapes in Chishui municipality, Guizhou province", kicked-off at Eco-Forum Global in Guiyang in June 2015, with funding from the Swiss Embassy in China, and is implemented by INBAR and Chishui forestry bureau. It aims to increase bamboo forest productivity and resilience for local communities to adapt to climate change through the introduction and demonstration of practical climate-smart landscape management techniques in Chishui municipality, Guizhou province.

As one part of the project, experts were invited to conduct an assessment of the vulnerability of bamboo forest ecosystems to climate change, to identify the vulnerability and risks faced by the Chishui communities in the context of climate change, and to find possible solutions to address these issues, which will enhance the resilience of local communities to adapt to climate change with bamboo.

Following a literature review, field research in Chishui was conducted by the investigation team in mid-October 2015. The investigators examined the distribution and growth status of several main bamboo forests at different altitudes. Together with climate data and data on Chishui's bamboo forest resource over the past 20 years, the group condensed the information into the present report. The following recommendations are made:

- Expand the area of *P. edulis* and *D. farinosus* at lower altitudes, and the area of *B. rigida* and *N. affinis* at higher altitudes.
- Reduce the area of *B. pervariabilis* × *D. daii*, gradually replacing it with *P. edulis* and *D. farinosus* to optimize the landscape structure.
- Maintain optimal numbers, ages, sizes and density of bamboo culms to enhance productivity of the forests.

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Key findings

A study was made of the vulnerability of Chishui's bamboo to the effects of climate change as predicted by evaluation of meteorological data and the bamboo forests, followed by recommendations for future bamboo forest management. The results showed:

- (1) In Chishui the average temperature showed an increasing trend, and precipitation showed a decreasing trend. The mean temperature in the 21st century was 0.4°C higher than in the 1990s. There were increasing amounts of rainfall in January-March, and October-December of the year, and a drop in April-September, the growth periods of the year.
- (2) Vulnerability assessment index of the major bamboo species in Chishui are all below 40, meaning that bamboo forests in Chishui have low vulnerability, are stable and have capacity to adapt to climate change. Due to the differing temperature and humidity found at different altitudes in Chishui, bamboo forests have high capacity to adapt to climate changes. In general, the overall climatic change in Chishui is expected to be rather slight in future, and it is not thought that there will be obviously changes of the vulnerability of the bamboo forest ecosystem.
- (3) Different bamboo species have different capacities to adapt to environmental changes and warming trends. The DBH, density and biomass of *P. edulis* and *D. farinosus* increased with the increase of temperature, the vulnerability of the bamboo forests decreased and stability increased. The warming trend has a positive effect on *P. edulis* and *D. farinosus*. However, the DBH, density and biomass of *B. rigida*, *B. pervariabilis* × *D. daii* and *D. affinis* decreased with the increase of temperature, indicating higher vulnerability and lower stability, but still within "slight" or "lower" levels of vulnerability.
- (4) It is proposed to expand the proportion of *P. edulis* and *D. farinosus* at lower altitudes and increase the proportion of *B. rigida* and *N. affinis* at higher altitudes. Strengthening bamboo forest structure management will help increase adaptability to climate change.
- (5) As the vulnerability of *B. pervariabilis* × *D. daii* and *D. affinis* increased with increasing temperature, indicating higher vulnerability and lower stability, it is suggested to decrease the planting area of *B. pervariabilis* × *D. daii* to optimize the landscape of bamboo forests in Chishui.

Background

Although there are still many uncertainties about prediction of climate change, the existence of the greenhouse effect and the possibility and tendency of global warming is widely accepted and validated by the IPCC. Research shows that the average temperature of China will increase by 2 or 3 °C in the next 50-80 years. Climate warming may decrease runoff in rivers in the north, and increase that in the south. It will increase average annual basin evaporation, intensify the contradiction between supply and demand of water resources and increase their instability, increase droughts, storms, low temperatures, rain, snow, freezing and other extreme weather events (Zheng, 2008).

Forests are an important part of the earth's biosphere. They can help adjust the environment to a certain extent, an increase the absorption of CO₂ and other greenhouse gases and thereby mitigate climate change directly. The distribution of forest types, system structures and composition, forest productivity, forest disasters and other factors may undergo important changes, as will the distribution of forest types (Wang, 2012). Predicting the structure and function of terrestrial ecosystems is one of the core objectives of global change research. Due to the uncertainty of climate change, the complexity of the ecosystems and limitations of human cognition, many problems are still not clear. There is an urgent need to explore the relationship between climate change and ecosystems, and the response of ecosystems to climate change, in order to better cope with the adverse effects of climate change and mitigate the harm it causes. Research that evaluates the vulnerability of ecosystems to climate change is one of the most important fields of study.

Ecological vulnerability is a concept of describing system state, which is based on the specific time section and specific space region to research, and used the natural ecological system, social economic system and man-land coupling system as research object. Based on the study of the time scale and spatial scale, by analyzing the characteristics of the system's exposure, sensitivity and adaptability, using the corresponding research model for the study of ecological vulnerability (Li *et al*, 2008). Vulnerability assessment is to discuss one natural and humanistic system's structure and function, and it can predict and evaluate the influence of external stress (natural and artificial) on the system, and evaluate the system's resistance to external stress and the ability to recover from adverse effects. Its purpose is to maintain the sustainable development of the system, reduce the adverse effects of external stress on the system and provide the decision-making basis for the comprehensive improvement of the system (Qiao *et al*, 2008).

Chishui in Guizhou province is the famous hometown of bamboo in China, bamboo forest area is 1.3 million mu (86.7 thousand hectares), the per capita area of bamboo is 4.3 mu (0.29 hectares). The per capita share and the total area of bamboo rank and the highest and second highest of all county administrative regions in China. After more than a decade of development, the bamboo industry has become the leading local industry, and Chishui's bamboo industry accounted for about 50% of GDP, with finance and farmers' income more than 50% are from the bamboo industry now. The climate conditions in Chishui are complex, the prevailing climate distribution characteristic being "different weather in different places" that varies with altitude, and has sensitivity to climate change. Therefore, research on the ecological vulnerability of bamboo forests to climate change in Chishui can be regarded as indicative for many other areas and has great significance as such.

Introduction to Chishui and methodology



1.1 Chishui

Chishui is located between 105° 36' - 106° 15' E and 28° 16' - 28° 46' N in the northwest of Guizhou province in southwest China. The middle and lower reaches of the Chishui river, a tributary of the Yangtse river, flow through the municipality. Chishui stretches 61.85 km from east to west, and 55.35 km from north to south. Bordered by the southern part of Sichuan, it is an important gateway from northern Guizhou province to Sichuan and Chongqing. Chishui municipality has a subtropical humid monsoon climate with a relatively mild winter followed by an early spring, a hot and dry summer, and rainy seasons in early summer and late autumn, with significant variations by location.

The mean annual temperature is 18.1°C. The mean in July is 28°C, and in January 7.9°C, and the mean annual temperature variation is 20.1 to 20.5°C. The extreme minimum temperature is minus 0.7°C, and the extreme maximum was 43.2°C. The average annual rainfall is 1292.3 mm, mainly concentrated from April to October, accounting for about 80% of the annual total. There are 1297.7 hours of sunshine per year, and the average annual relative humidity is 82%. The frost free period at the lowest altitude lasts for 340 to 350 days and decreases with altitude, with regions up to about 800 meters seeing about 300 frost free days, and regions above 800 meters with between 210 ~ 300 frost-free days. The wind is generally northerly, but southeasterly in summer and northerly in winter. The extreme maximum wind speed is 27 m/s; force 10. The average wind speed is 1.6 m/s, and winds of force 8 or over often occur from March to September, and most frequently in July and August. The terrain is mainly highland and dissected plateaus with mountainous deep valleys in southeast, undulating hills in the northwest and open and flat river valley.

The terrain is high in the southeast and low in northwest. The altitude descends from southeast to northwest, from 1730 meters to 221 meters above sea level – a difference of over 1500 meters. Chishui has 2.17 million mu (146,000 ha) of forest area, of which the bamboo forest area covers 1.30 million mu (86,700 ha). The major bamboo is *P. edulis* with 0.51 million mu (34,000 ha), and all the other bamboo species together cover 0.79 million mu (52,667 ha). There are over 300 species of bamboo in Chishui, of which 36 are endemic. Annual output is 40,000 cubic meters of bamboo wood, 5 million culms of *P. edulis*, 450,000 tons of other bamboos miscellaneous bamboo, and over 40,000 tons of bamboo shoots.



1.2 Collection of data

The data were collected from the National Forest Resource Inventories, historical studies, field sampling and modeling analysis. Plant biomass (table 1) was estimated according to existing models and project investigation models. Stand biomass was calculated using plant biomass and stand density:

$$W_{\text{stand}} = W_{\text{plant}} \times D$$

where W_{stand} is stand biomass, W_{plant} is biomass per plant, and D is density of bamboo forest.

Table1 The biomass regression model for bamboos

Bamboo species	Regression model	Cited Data
<i>Phyllostachys edulis</i>	$W=6.471D^{42.359}$	Project survey
<i>Dendrocalamus farinosus</i>	$W=0.2305D^{1.909}$	Project survey
<i>Bambusa rigida</i>	$W=0.2548D^{1.9927}$	Project survey
<i>Bambusa pervariabilis</i> × <i>Dendrocalamopsis daii</i>	$W=0.0649D^3-1.0285D^2+5.9098D^{8.7257}$	Liu Guanglu, etc, 2012
<i>Neosinocalamus affinis</i>	$W=0.216D^{1.743}$	Project survey

Note: *P. edulis*, *D. farinosus*, *B. rigida*, *N. affinis* biomass data is mainly from the survey data of the " Research and demonstration of the technology of high efficiency cultivation of bamboo and rattan resources" (2012BAD23B04) project, in accordance with the 12th Five Year Plan for science and technology.

1.3 Methods of vulnerability assessment

1.3.1 Scenario analysis method

Scenario analysis, also known as the prospect description, is a way to interpret the future in the uncertain environment, and helps us understand the future development of complex dynamic systems (Zhao, 2007). By analyzing the average diameter at breast height (DBH), bamboo stand density and biomass of several major types of bamboo forests at different time gradients, this study reflects the evolutionary trend of several main types of bamboo forests with temperature increases.

1.3.2 Comprehensive index method

This method is used to establish the evaluation index system from the aspects of vulnerability performance and other mathematical methods. It is a common method for evaluating the vulnerability at present (Li *et al*, 2008). In this report, the ecological vulnerability of bamboo forest in Chishui city was evaluated by using the analytic hierarchy process (Zhang *et al*, 2011).

1.4 Data processing

Excel 2010 software was used to collate data and for mapping, and SPSS13.0 software was used for analysis of variance, principal component analysis and other analyses.

Results and analysis



2.1 Changes of major climatic factors in Chishui during the last 20 years

2.1.1 Rainfall changes in Chishui in the last 20 years

Although annual rainfall between 1995 and 2014 varied highly year on year, there was an overall gradual decline (Figure 1). The highest annual rainfall of 1525mm occurred in 2000, and the lowest, 880mm, occurred in 2011. There were an obviously decline of average annual rainfall among four year periods: 1995-1999 (1263.68 mm), 2000-2004 (1202.22 mm), 2005-2009 (1203.94 mm), and 2010-2014 (1130.36 mm).

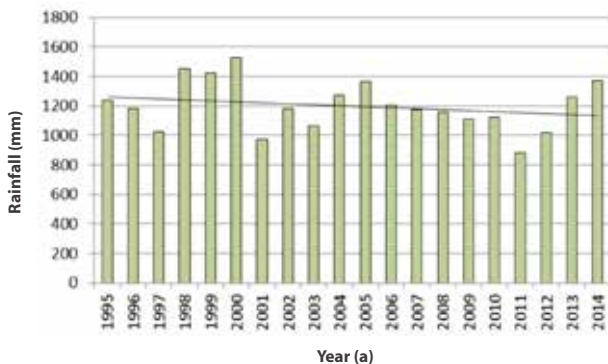


Figure1 The rainfall in Chishui from 1995 to 2014

The data also indicates a different distribution of rainfall by season. Increasing trends both for the period of January to March and the period of October to December were found among the four five-year periods 1995-1999 (7.82%, 12.99%), 2000-2004 (9.61%, 14.78%), 2005-2009 (11.19%, 17.23%), and 2010-2014 (10.41%, 18.45%). A declining trend was found for April to September, with the percentage of seasonal rainfall at 1995-1999 (79.20%), 2000-2004 (75.62%), 2005-2009 (71.58%) and 2010-2014 (71.14%).

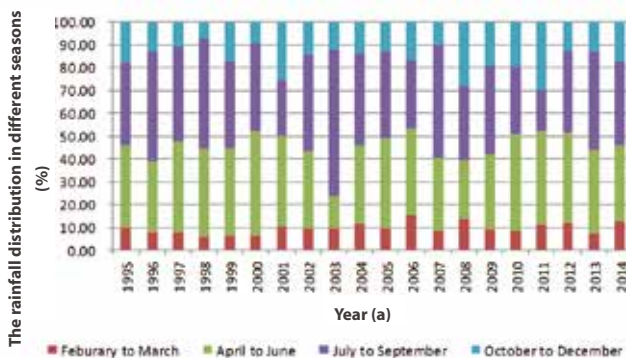


Figure2 The rainfall distribution in different seasons in Chishui from 1995 to 2014

2.1.2 Temperature changes in Chishui during the last 20 years

The average temperature in Chishui from 1995 to 2014 has increased slightly (Figure 3). The weighted average temperatures in the four five-year periods were 17.82°C(1995-1999), 18.16°C(2000-2004), 18.30°C(2005-2009) and 18.20°C(2010-2014). The average temperature in the 21st century is 0.4°C higher than in the late 1990s.

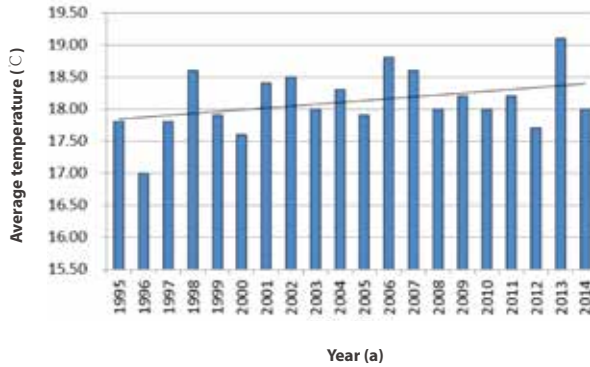


Figure3 Average temperature in Chishui from 1995 to 2014

The lowest temperature in Chishui from 1995 to 2014 fell significantly (Figure 4). The mean lowest temperatures in the four five-year periods were 1.90°C, 1.62°C, 0.90°C and 0.88°C. The average lowest temperature in 2010-2014 was 1.02°C lower than in 1995-1999.

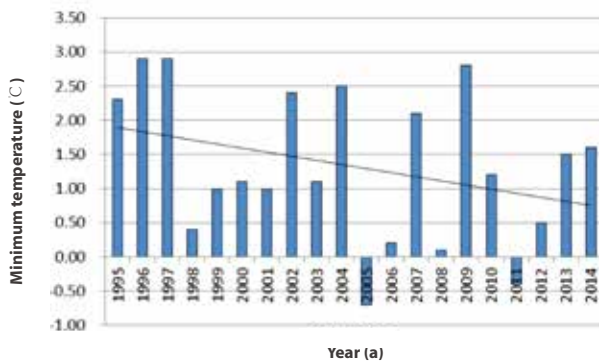


Figure4 Minimum temperature in Chishui from 1995 to 2014

The highest mean temperature in Chishui rose significantly (Figure 5) from 38.68°C in 1995-1999, through 39.02°C, and 39.82°C, to 41.08°C in 2010 - 2014. The highest mean temperature in 2010-2014 has increased by 2.40°C compared to 1995-1999.

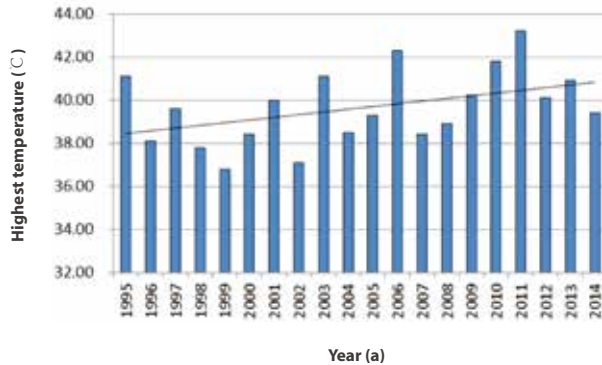


Figure5 Highest temperature in Chishui from 1995 to 2014

The effective accumulated temperature in Chishui from 1995 to 2004 showed no significant change (Figure 6). The effective accumulated temperature in 2005-2009 and 2010-2014 were 6239.12°C and 6170.64°C, a fall of 1.1%.

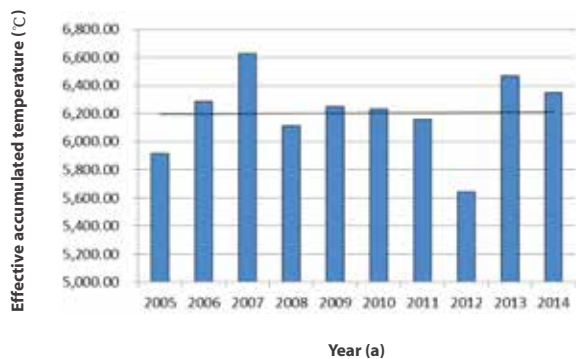


Figure6 Effective accumulated temperatures in Chishui from 1995 to 2014

2.1.3 Correlation analysis of precipitation and temperature

Correlation analysis between rainfall and minimum, mean and maximum temperatures found that rainfall was significantly correlated to maximum temperature and rainfall. The higher the maximum temperature, the lower the rainfall. If this trend continues in the long term, it may affect the growth of plants.

Table 2 Correlation analysis between rainfall and temperature

Item	Minimum temperature	Highest temperature	Average temperature
Rainfall	-0.047	-0.5650**	-0.014

2.1.4 Correlation analysis of altitude, precipitation and temperature

There is a significant negative correlation between altitude and temperature ($P < 0.01$), and a significant positive correlation between altitude and precipitation ($P < 0.05$). (Table 2).

Table 3 Correlation analysis of altitude, rainfall, and temperature

Item	Rainfall	Temperature
Altitude	0.68*	-0.97**

2.2 Variations of the main bamboo species resources in Chishui

2.2.1 Situations of main bamboo species resources in Chishui

The bamboo forest area of Chishui is 1.3 million mu (86,667 ha), which mainly consists of *Phyllostachys edulis*, *Dendrocalamus farinosus*, *Bambusa rigida*, *B. pervariabilis* × *D. daii*, *Neosinocalamus affinis*, *D. latiflorus*, *Gelidocalamus aunulatus* and other bamboo species (Figure 7). The areas of *P. edulis*, *D. farinosus*, *B. rigida*, *B. pervariabilis* × *D. daii*, and *N. affinis* are over 100,000 mu (6,667 ha) each.

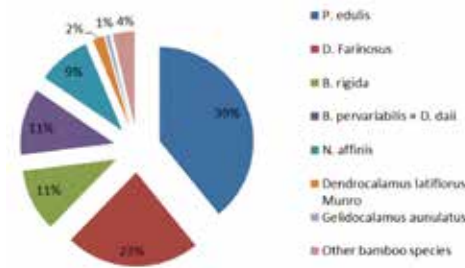


Figure7 Bamboo forest area distribution in Chishui

2.2.2 Variations of main bamboo species' area in Chishui

Since 2009, the total bamboo forests in Chishui has increased by 10%, (118,054 mu (7870.26 ha)), mostly the areas of *D. farinosus*, *B. rigida*, *D. latiflorus* and other bamboos (predominantly *Chimonobambusa quadrangularis*) which each increased by 16%. The area of *P. edulis* increased by 6%. The area of *B. rigida*, *B. pervariabilis* × *D. daii* and *Gelidocalamus aunulatus* did not change.

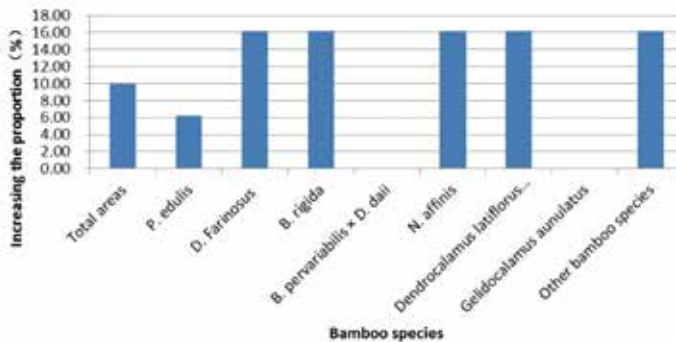


Figure8 Change of bamboo areas in Chishui from 2009 to 2014

2.2.3 Analysis of the distribution range of the main bamboo by altitude

Bamboo species are different, and suitable for different altitudes. In Chishui, *C. quadrangularis* is found at the highest altitudes, then *P. edulis* > *D. farinosus* > *N. affinis* > *B. rigida* = *B. pervariabilis* × *D. daii*. *N. affinis* is found at the lowest altitudes, and is followed by *D. farinosus* < *P. edulis* = *N. affinis* < *B. rigida* = *B. pervariabilis* × *D. daii* < *C. quadrangularis*. In general, grove-forming bamboos (e.g. *C. quadrangularis*, *P. edulis*) are found at higher altitudes, with *C. quadrangularis* naturally found in other areas between 1000-2100m. Clump forming bamboos (*D. farinosus*, *D. affinis*, *B. rigida* and *B. pervariabilis* × *D. daii*) are found at lower altitudes, but *D. farinosus* and *D. affinis* can be found above 1500m altitude. Both grove-forming and clump forming bamboos are found between 500-800m.

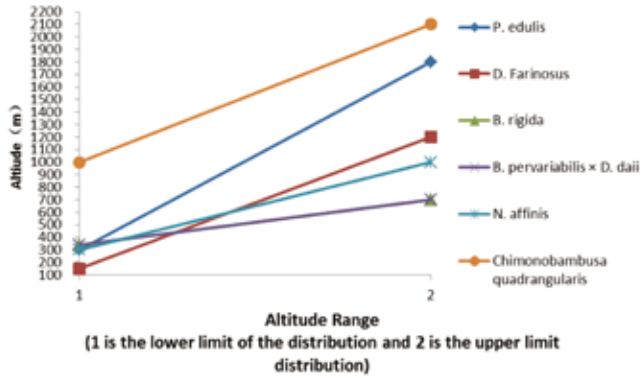


Figure9 Altitudinal range of main bamboo species (Deng, 2006; Zhang, 1979)

2.2.4 Distribution of main bamboo species in different altitudes of Chishui

(1) Distribution of total area of bamboo forests with altitude

Bamboo forests in Chishui are mostly found between 300-1300m, with 21% of the total area between 400-500m, and 71% between 400-900m. Grove forming bamboos predominate at higher altitudes, and clump forming bamboos at lower altitudes. Many different bamboos grow mixed in areas between 500m-800m.

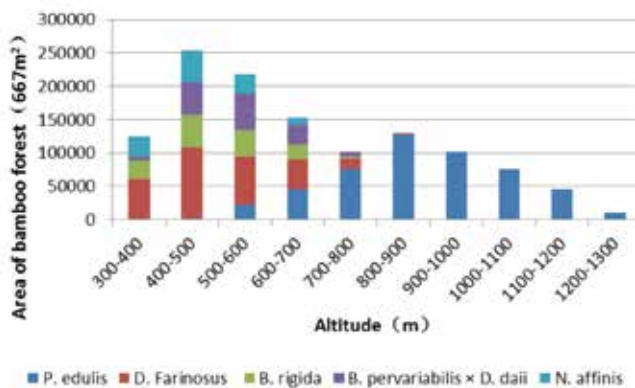


Figure10 Main bamboo species distribution with altitude gradient

(2) Distribution of *P. edulis* with altitude

P. edulis is mainly distributed in area with higher altitude between 700-1100m. 75% of *P. edulis* is found between 700-1100m, with 25% between 800-900m.

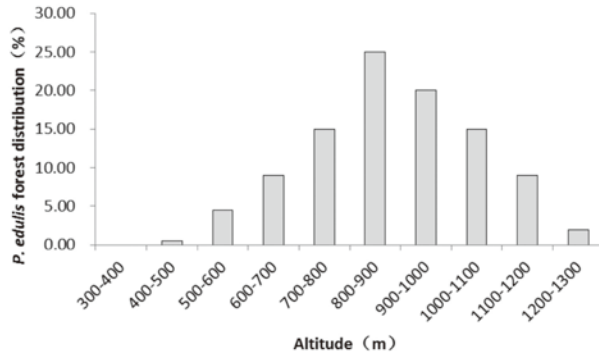


Figure 11 Distribution of *P. edulis* forest with altitude

(3) Distribution of *D. farinosus* with altitude

D. farinosus in Chishui is mainly distributed between 300-700m. 35% of it is found between 400-500m, and 79% between 300-600m. The upper limit is 800-900m.

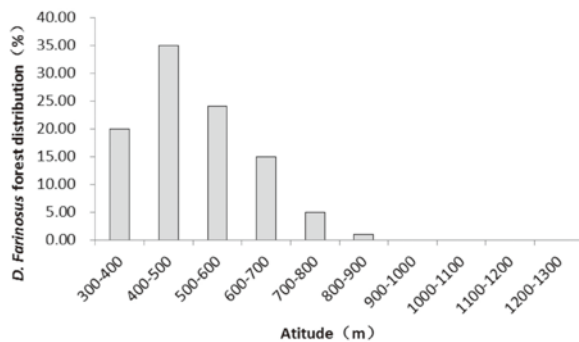


Figure 12 *D. farinosus* forest distribution with altitude gradient

(4) Distribution of *B. rigida* with altitude

B. rigida is found between 300-700m, overlapping with *D. farinosus*, but is distributed more narrowly than *D. farinosus*, with a highest altitude range of 700-800m. 35% of *B. rigida* grows between 400-500m, with 79% of the total between 300-600m.

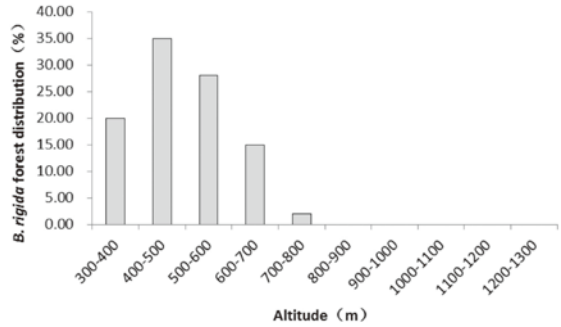


Figure13 *B. rigida* forest distributions with altitude gradient

(5) Distribution of *B. pervariabilis* × *D. daii* with altitude

The distribution of *B. pervariabilis* × *D. daii* overlaps with that of *B. rigida*. 37% of the resource is found between 500-600m, and 70% between 400-600m, and its distribution is more concentrated than *B. rigida*.

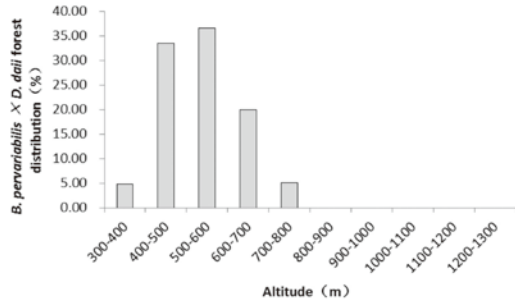


Figure14 Distribution of *B. pervariabilis* × *D. daii* forest with altitude

(6) Distribution of *N. affinis* with altitude

N. affinis is mainly found between 300-700m, and is mainly found at low altitudes. 90% of *N. affinis* is found between 300-600m, with 40% concentrated between 400-500m.

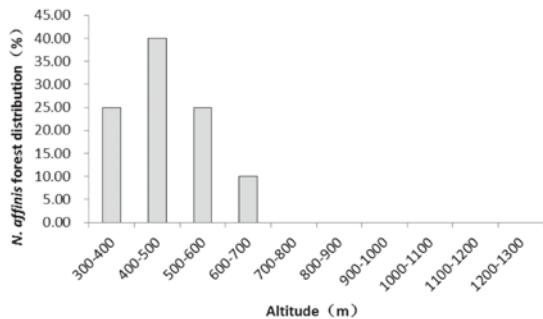


Figure15 Distribution of *D. affinis* forest with altitude

2.3 Growth of main bamboo species in different regions of Chishui

2.3.1 Influence of temperature on bamboo growth

Temperature is an important driving factor for plant growth. In this study, the diameter at breast height (DBH) of *P. edulis*, *B. pervariabilis* × *D. daii* and *D. affinis* first increased and then decreased with the increase in temperature, but the temperature at which the maximum DBH occurs differs with species. The maximum average DBH of *P. edulis* (11.3cm) occurs at 19.6 - 20.1°C; the maximum average DBH of *B. pervariabilis* × *D. daii* (4.9cm) occurs at 22.3 - 22.6°C and that of *N. affinis* (5.2cm) occurs at 22.6°C. The average DBH of *D. farinosus* and *B. rigida* showed a rising trend with the increase of temperature. The DBH of *D. farinosus* reached a maximum of 5.8cm at 22.3-22.6°C and the maximum of *B. rigida* (3.8cm) was reached at 22.3 - 23.1°C.

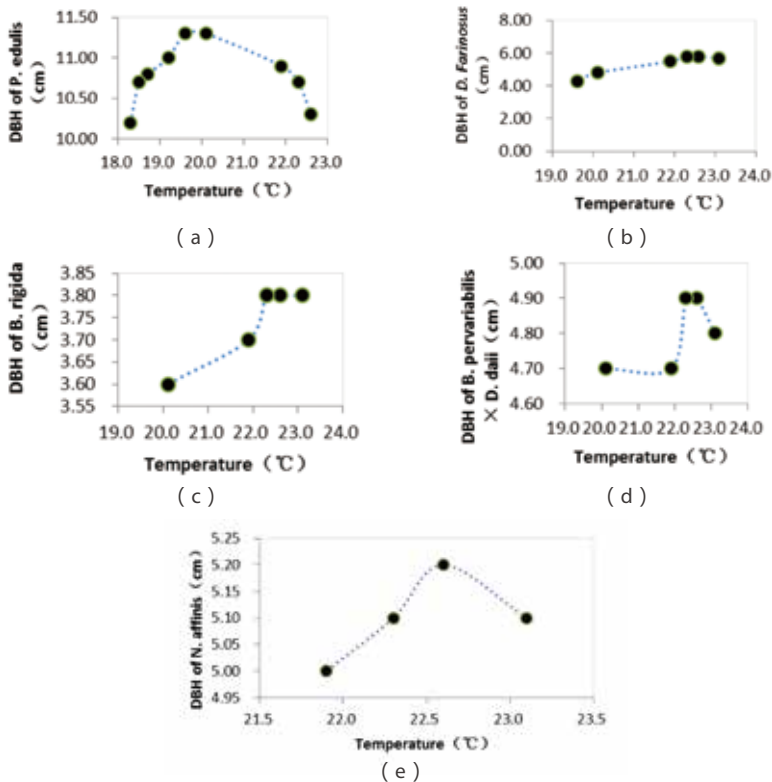


Figure 16 The changes of DBH of *P. edulis* (a), *D. farinosus* (b), *B. rigida* (c), *B. pervariabilis* × *D. daii* (d), *N. affinis* (e) with the elevated temperature

2.3.2 The changes of DBH of several main bamboos species with precipitation

The average DBH of *P. edulis* increased with increasing precipitation, but the DBH of *D.farinosus*, *B. rigida*, *B. pervariabilis* × *D. daii* and *D. affinis* decreased with increasing precipitation.

- As precipitation increased from 1285.2 mm to 1335.4 mm, the average DBH of *P. edulis* increased by 6.8%.
- As precipitation increased from 1278.8 mm to 1322 mm, the average DBH of *D. farinosus* decreased by 7%.
- As precipitation increased from 1278.8 mm to 1314.5 mm, the average DBH of *B. rigida* decreased by 5.3%.
- As precipitation increased from 1278.8 mm to 1314.5 mm, the average DBH of *B. pervariabilis* × *D. daii* decreased by 2.1%.
- As precipitation increased from 1278.8 mm to 1299.1 mm, the average DBH of *N. affinis* decreased by 2%.

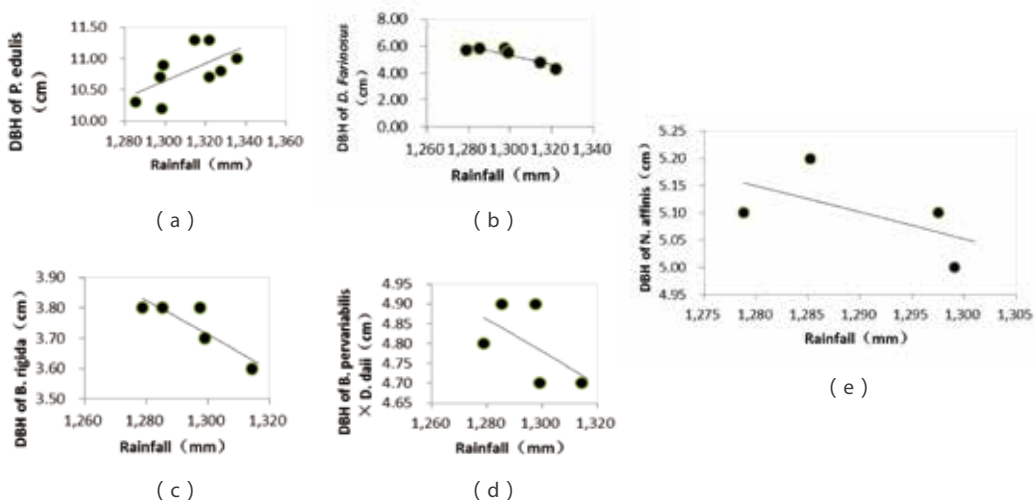


Figure17 Changes of DBH of *P. edulis* (a), *D. farinosus* (b), *B. rigida* (c), *B. pervariabilis* × *D. daii* (d), *D. affinis* (e) with increasing rainfall

2.3.3 The changes of DBH of several main bamboos with the altitude

Altitude has important influence on temperature and humidity. With the increase of altitude, the temperature decreases and the rainfall increases. The DBH of *P. edulis*, *B. pervariabilis* × *D. daii* and *D. affinis* increased firstly and then decreased as the altitude increased, while the DBH of *D. farinosus* and *B. rigida* showed a decreasing trend as altitude increased. The characteristics of several main bamboo species show that different bamboo species have their own normal region for growth, and also provides a reference for understanding the growth of bamboo in the context of climate change.

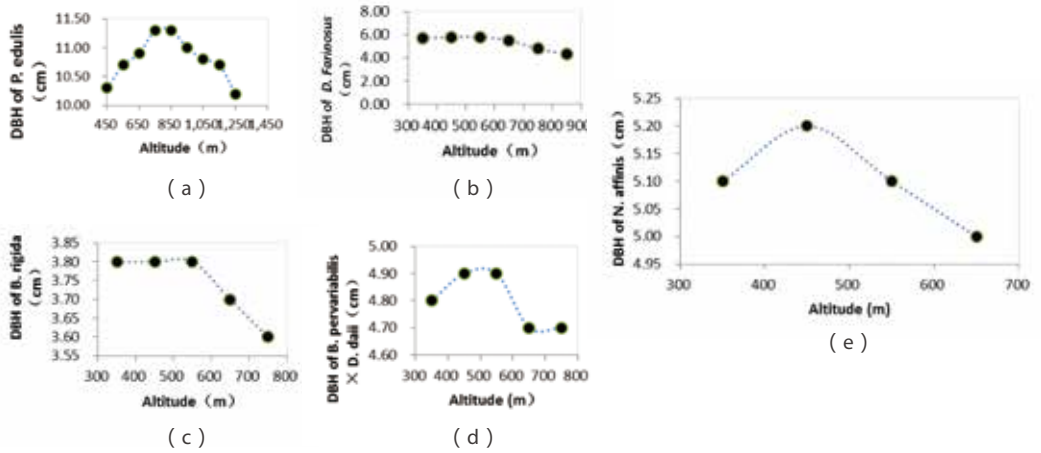


Figure18 Changes of DBH of *P.edulis* (a), *D.farinosus* (b), *B.rigida* (c), *B.pervariabilis* × *D.daii* (d), *N.affinis* (e) with altitude

2.3.4 Bamboo forest diseases and insect pests in Chishui

(1) The occurrence of bamboo forest diseases and insect pests in Chishui since 2009

The main disease found on bamboos in Chishui was blight, which affected *B. pervariabilis* × *D. daii*. Insect pests, including bamboo locust, bamboo tussock moth, bamboo leaf roller, bamboo stick insects were found on several bamboos. In 2012, the area infested by insect pests and diseases was the largest, at 40,755 mu (2,717 ha), with disease predominating at 92% - in other years disease accounts for just 18-30% of the area suffering from pests and diseases combined.

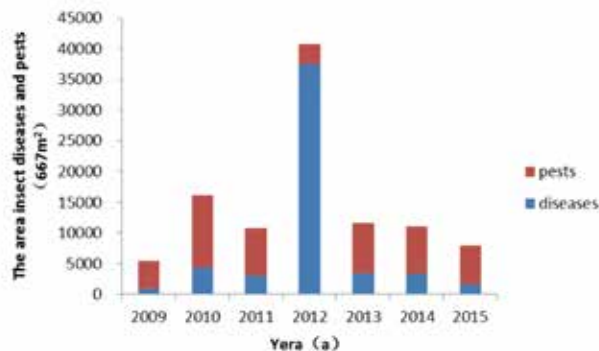


Figure19 Bamboo forest diseases and insect pests in Chishui

(2) The relationship between the occurrence of diseases and insect pests and the climatic factors

A correlation analysis of the combined area of plant diseases and insect pests, and the area of disease and insect pests alone in Chishui with precipitation, minimum temperature, maximum temperature and effective accumulated temperature showed only that the area of total occurrence and disease occurrence was significantly negatively correlated with the effective accumulated temperature – years with lower accumulated temperature see higher incidences of disease. No other correlations of insect pests occurrence and climatic factors were found – it is thought that reproductive rate of insects may be more important than precipitation and temperature.

Table 4 Correlation coefficients between area of pest occurrence and climatic factors

	Rainfall (mm)	Minimum temperature (°C)	Maximum temperature (°C)	Effective accumulated temperature (°C)
Total area	-0.27	-0.43	-0.20	-0.887*
Area of diseases	-0.29	-0.35	-0.28	-0.917*
Area of pests	0.21	-0.13	0.47	0.58

2.4 Ecological vulnerability assessment of bamboo forest in Chishui based on the comprehensive index method

2.4.1 Hierarchy building

An Analytic Hierarchy Process (AHP) method was applied to assess the vulnerability of bamboo forests. It consists of an overall goal, three criteria and six alternatives for reaching the goal. The overall goal is defined as the vulnerability assessment index of bamboo forest in Chishui. The stand vitality, stand structure and interference response are the three criteria. The six alternatives (indicators) are change of bamboo area, DBH changes, density change, biomass change, incidence of pests and incidence of disease.

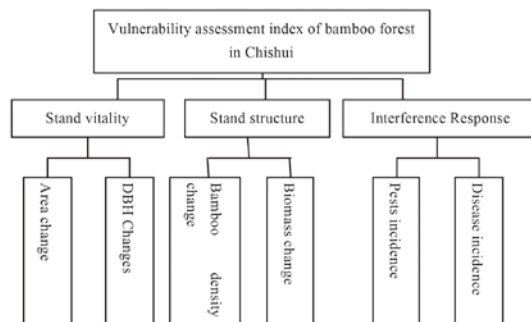


Figure20 Vulnerability assessment index of bamboo forests in Chishui

2.4.3 Establishment of numerical weight of the vulnerability assessment Hierarchy

In order to avoid using too many subjective factors, the three criteria are given equal weight, as per Feng, 2014 (Table 5).

Table 5 The weight of targeted criteria layers

Evaluation of Basic	Stand vitality	Stand structure	Interference Response	Total weight
Weight value	0.517	0.359	0.124	1.0

2.4.4 Classification of ecological vulnerability assessment criteria of bamboo forest

According to work by H.T. Odum, the threshold levels of vulnerability of different ecosystems can be categorised appropriately (Zhao *et al*, 2007). In this study, the vulnerability index of bamboo forest is divided into 5 levels - ecosystem collapse (80 - 100), severe (60 - 80), medium (40 - 60), low (20 - 40), and slight (0 - 20).

Table 6 Bamboo ecological vulnerability assessment criteria ines

Target layer	Index	Ecosystem collapse (80- 100)	Severe (60- 80)	Medium (40- 60)	Low (20- 40)	Slight (0-20)
Stand vitality	Area change	decrease > 30%	decrease 20-30%	decrease 10-20%	decrease 0-10%	≥0
	DBH Changes	decrease > 30%	decrease 20-30%	decrease 10-20%	decrease 0-10%	≥0
Stand structure	Bamboo density change	decrease > 30%	decrease 20-30%	decrease 10-20%	decrease 0-10%	≥0
	Biomass change	decrease > 30%	decrease 20-30%	decrease 10-20%	decrease 0-10%	≥0
Interference Response	Pests incidence	pest incidence >40%	pest incidence >30%	pest incidence, 10 - 30%	pest incidence, <10%	Almost no influence pest
	Disease incidence	disease incidence >40%	disease incidence >30%	disease incidence, 10 - 30%	disease incidence, <10%	Almost no influence disease

2.4.5 Partition of distribution area of bamboo forest in Chishui

The bamboo forests in Chishui can be divided into eastern, central and western areas, according to the terrain and the growth of bamboo. See Table 7.

Table 7 The main bamboo forest distribution area in Chishui

	Bamboo species	<i>P. edulis</i>	<i>D. farinosus</i>	<i>B. rigida</i>	<i>B. pervariabilis</i> × <i>D. daii</i>	<i>N. affinis</i>
East	Altitude (m)	700-1300	340-700	340-700	340-700	340-700
	Average temperature (°C)	21.5	17.6	17.5	17.5	17.2
	Soil thickness (cm)	65	75	70	70	75
Central	Altitude (m)	650-1350	350-700	350-700	350-700	350-700
	Average temperature (°C)	21.7	17.1	17.3	17.3	17.3
	Soil thickness (cm)	70	80	75	75	85
West	Altitude (m)	650-1400	350-700	350-700	350-700	350-700
	Average temperature (°C)	22.1	18.5	17.2	17.2	17.2
	Soil thickness (cm)	70	90	85	85	90

2.4.6 Vulnerability assessment index of several major bamboo forests in Chishui

According to the average temperature of bamboo growth in different regions, the bamboo forest in Chishui can be divided into 3 areas. Using the different INES indexes and the values of the actual survey index changes, the comprehensive scores of the main bamboo forests can be calculated. Each index is calculated by taking the vulnerability assessment value from the highest value of each category. e.g. the "slight (0-20)" index score is calculated as: $S=20$ minus the calculated vulnerability assessment value for the "slight" category. The results show that the change of vulnerability of the bamboo species was not consistent with increase of temperature.

- The vulnerability index of *P. edulis* is slight (less than 20), and showed a decreasing trend with an increase of temperature - the stability of *P. edulis* improved as the temperature increased.
- The vulnerability index of *D. farinosus* showed a different pattern, first increasing and then decreasing at the temperature of 17.6°C was in low vulnerable state.
- The vulnerability index of *B. rigida* showed a rising trend with the increase of temperature, changing from slight fragile state to low-level vulnerability.

- The vulnerability of *B. rigida* increased as the temperature increased.
- The vulnerability index of *B. pervariabilis* × *D. daii* was higher than 20. With the increase of temperature, the vulnerability of *B. pervariabilis* × *D. daii* increases, and so rising temperatures may have a negative impact on *B. pervariabilis* × *D. daii*.
- The vulnerability index of *N. affinis* showed an increasing trend with increasing temperature, but in general only at the “slight” level, which indicates the system is stable and adaptable to climate change.

Table 8 The bamboo forest ecological vulnerability index in Chishui

Forest types	Average temperature	Stand vitality	Stand structure	Interference Response	Composite score
<i>P. edulis</i>	21.5	7.77	10.28	2.52	17.48
	21.7	8.51	6.28	2.52	14.21
	22.1	7.22	2.05	2.52	8.70
<i>D. farinosus</i>	17.10	6.15	10.28	2.52	15.86
	17.60	6.63	17.97	2.52	24.02
	18.50	4.24	2.60	2.52	6.27
<i>B. rigida</i>	17.20	6.15	10.28	2.52	15.86
	17.30	6.15	10.57	2.52	16.15
	17.50	6.83	17.43	2.52	23.68
<i>B. pervariabilis</i> × <i>D. daii</i>	16.80	10.34	10.28	2.66	20.18
	17.00	10.87	22.89	2.66	33.32
	17.90	10.87	24.56	2.66	34.99
<i>N. affinis</i>	17.20	5.64	5.14	2.52	10.20
	17.30	5.64	13.30	2.52	18.36

Conclusions and recommendations



3.1 Conclusions

- (1) According to the analysis of the temperatures in the past 20 years, there were an increasing trend of the mean annual temperature and a decrease of the effective cumulative temperature in Chishui. The mean temperature in the 21st century was 0.4°C higher than in the 1990s. The mean lowest temperature in 2010-2014 was 1.02°C lower than in 1995-1999. The highest maximum temperature increased by 2.4°C. The effective cumulative temperature decreased by 1.1% over the period.
- (2) Mean annual precipitation in Chishui decreased between the first and last penenniums by 133.32mm, a drop of 10%. There were increasing amounts of rainfall in January-March, and October-December of the year, and a drop in April-September, the growth periods of the year. The effect of the changing distribution of rainfall on seasons varies with bamboo species with different phenophase.
- (3) The vulnerability assessment indexes of the major bamboo species in Chishui are all below 40, showing that bamboo forests in Chishui in general have low vulnerability to climate change, and can adapt to it. Though the wide scale of altitude diversify changes of temperature and humidity, bamboo forests have high self-adjustment to adapt to. In general, the overall climatic changes in Chishui are expected to be slight, and there won't be obvious changes of the vulnerability of the bamboo forest ecosystems.
- (4) Different bamboo species have different adaptation capacities to environmental changes and warming trends. The DBH, density and biomass of *P. edulis* and *D. farinosus* have increased with the increase of temperature, and the vulnerability of the bamboo forests decreased and stability increased. The warming trend has a positive effect on *P. edulis* and *D. farinosus*. However, the DBH, density and biomass of *B. rigida*, *B. pervariabilis* × *D. daii* and *D. affinis* decreased with the increase of temperature, indicating higher vulnerability and lower stability, but still in the range of "slight" or lower levels of vulnerability, showing that the bamboo forests are relatively stable and can adapt to warming trends.
- (5) The response of several main bamboo forests to the temperature and rainfall in Chishui is different. The DBH of *P. edulis*, *B. pervariabilis* × *D. daii* and *N. affinis* first first and then decreased with the increase of temperature; the average DBH of *D. farinosus* and *B. rigida* showed a decreasing trend with the increase of temperature. With the increase in rainfall, the average DBH of *P. edulis* showed an increasing trend, and *D. farinosus*, *B. rigida*, *B. pervariabilis* × *D. daii* and *N. affinis* showed a decreasing trend with the increase in rainfall. Rising temperatures in Chishui may promote the growth of several main bamboo species, but the decrease of rainfall may have a negative effect on some bamboo species.
- (6) The terrain in Chishui is diverse, with bamboo forests found at different altitudes. Grove forming bamboos are found at higher altitudes, such as *P. edulis* and *C. quadrangularis*, and clump forming ones predominate at lower altitudes, such as *D. farinosus*, *B. rigida*, *B. pervariabilis* × *D. daii* and *N. affinis*. All these bamboo species grow well in areas of 600-800m.

3.2 Recommendations

The findings of this study are expected to be of particular relevance for forestry planners and implementers, both in Chishui and other similar parts of China, and more broadly in other mountainous bamboo-growing regions of the world. The following recommendations are made:

Recommendation 1: Expand the area of *P. edulis* and *D. farinosus* at lower altitudes, and the area of *B. rigida* and *N. affinis* at higher altitudes. The increase of temperature can make bamboos shoot early and extend the growing season, but it may have different effects on different bamboos. *P. edulis* is a grove-forming bamboo that produces shoots in March or April. It is obviously affected by warming. In addition, the decreased precipitation from April to September may indicate more sunshine hours. As *P. edulis* can tolerate precipitation of 800-1800 mm, a slight decrease in precipitation and an increase in temperature can promote the rapid growth of bamboo shoots and young bamboos, which may be the reason that *P. edulis* vulnerability decreases as the temperature increases. *D. farinosus*, *B. rigida*, *B. pervariabilis* × *D. daii* and *N. affinis* are clump-forming bamboos. They have higher demand for precipitation and heat. The decrease of summer rainfall may have an adverse effect on the growth of these species. The tolerance range of precipitation of *D. farinosus* and *N. affinis* is wide (1000-1400mm) and the tolerance range of precipitation of *B. pervariabilis* × *D. daii* and *B. rigida* is narrow (1100-1200mm), so *D. farinosus* and *N. affinis* may be less affected by the seasonal drought. This may be the reason why the vulnerability of *B. pervariabilis* × *D. daii* and *B. rigida* increased with the increase of temperature. In addition, the distribution of *D. farinosus* and *N. affinis* overlap, but the distribution of *N. affinis* (altitude 300-700m) is lower than that of *D. farinosus* (300-900m). If *D. affinis* is grown on higher altitudes, there will be more competitive pressure. This is probably the reason that the vulnerability of *N. affinis* increased with increasing temperature.

Recommendation 2: Reduce the area of *B. pervariabilis* × *D. daii*, gradually replacing it with *P. edulis* and *D. farinosus* to optimize the landscape structure. Data analysis showed that the occurrence of pests and the effective accumulated temperature was negatively correlated, and as the effective temperature gradually reduces, the incidence of plant diseases and insect pests may gradually increase. Further analysis found that diseases and insect pests mainly occurred in *B. pervariabilis* × *D. daii* forest - this may be one of the negative impact of climate change on *B. pervariabilis* × *D. daii*.

Recommendation 3: Maintain optimal numbers, ages, sizes and density of bamboo culms to enhance productivity of the forests. With the increase of temperature, the vulnerability of *P. edulis* and *D. farinosus* reduced, but the vulnerability of *B. rigida*, *B. pervariabilis* × *D. daii* and *N. affinis* increased. This was mainly manifested as decreases in DBH and stand density, leading to a poor structure of the bamboo forest, reducing stand yield and limiting the ecosystem benefits it can bring.

- **For *B. rigida*** Stand density of 2000-3000 clumps per hectare, keeping 2-3 productive culms per clump to ensure productivity of new shoots, with less than 30% of one year old productive culms in the forest. The average DBH of the productive culms should be 4.0 cm.
- **For *N. affinis*** stand density of less than 12 000 culms per hectare, keeping 6-15 productive culms per clump, with average DBH of 4-5 cm, and 50-70% of one year old productive culms.

With the rapid increase of the management costs of bamboo forests and a reduction in the bamboo industry, the economic benefits of bamboo forest have been significantly reduced. As the productivity of *P. edulis* and *D. farinosus* increased with the increase of temperature, an increase the economic benefits of bamboo and farmers' willingness to manage them can be predicted. In addition, the large scale of the bamboo resources in Chishui can provide the basis for the mechanization of harvesting, and with the modernization of the technology, can limit the rise of management costs, and thereby promote farmers' willingness to manage the forests.

4

Future work



4.1 Suggestions for future work

In this study, the main data was sourced from the local statistics departments, and there is a lack of continuous monitoring data of long-term growth for different bamboo species. As there is no time-related data, the study used data for different locations to clarify the growth and vulnerability of bamboo under different temperatures, rainfall and altitude, and make indicative suggestions based on this. However, differences in site conditions may have some effect on the results – in particular, the limited numbers of indexes used may affect the accuracy of the vulnerability score.

The assessment focused on the productivity of bamboo forests, their structure and the incidence of pests and diseases. Changes in vulnerability of bamboo forests also include changes in the animal and microbial communities. In order to study more comprehensively the health conditions of forest ecosystems, research on the animal and microbial communities should be strengthened. In addition, the change of vulnerability of bamboo forest is a long-term dynamic process. When considering the long-term changes of bamboo forests, a long-term monitoring and evaluation system should be established.

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