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Climate Change Effects on Southern Subtropical and Tropical Tree Species in Ganzhou City, China

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Authors' contributions

This work was carried out in collaboration between all authors. FC and CQ designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. All authors managed the analyses of the study, read and approved the final manuscript.

Research Article

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ABSTRACT

Aims: To confirm climate warming changes that have taken place in Gannan Arboretum and Ganzhou City by the expect success of introduced tropical tree species as a response to climatic warming scenarios.
Study Design: Cross-sectional study.
Study Site and Duration: Survey and observational sites were located in 1) Gannan Arboretum and 2) Ganzhou City, Jiangxi Province, China. The survey and observations of introduced tree species were conducted from October, 2009, to November, 2010. Additional growth records were obtained for a period prior to and including the 1970s to assist in the investigation.
Methodology: 1) The meteorological data (1951–2009) record was used to analyse climatic change patterns. 2) Growth and development of introduced tree species were

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examined to evaluate effects of introduction. 3) Climate zone attributes of introduced tree species were determined in order to establish place of origin**.** Effects of introduced tree species were coupled with climatic change scenario data to analyze associative relationships.
Results: 1) A trend in climate warming has been evident in Ganzhou City since the1950s. Based on metrological records from 1951 to 2009, a steady rise in annual average temperature has occurred in the region, increasing from 0.2ºC to 0.3ºC each 20 year period. This trend has been especially evident by changes to average temperature during the coldest month (January) as well as changes in annual minimum temperatures. 2) According to observations and measurements, 39 introduced tropical tree species have successfully established themselves in the Ganzhou region through natural domestication. Among these, 24 tree species were considered basically successful with normal growth patterns while the remaining 15 species achieved preliminary success. 3) Stem analysis data on the five primary introduced tree species indicate that growth patterns were normal and vigorous, suggesting that these tropical tree species have successfully established themselves. It was therefore determined that the successful northward migration of the 39 tree species investigated was chiefly the result of a climate warming trend taking place in the region.

Keywords: Climate change; introduction; Ganzhou; tropical tree species; southern subtropical tree species.

1. INTRODUCTION

Temperatures around the world have increased by 0.74ºC in the last 100 years (from 1906 to 2005) according to the Intergovernmental Panel on Climate Change (IPCC, 2007), resulting in global warming, which today is a concept generally accepted among scientists and state leaders. Although a tendency towards warming is more apparent in high latitudinal regions, similar conditions also occur in lower latitudes. Based on a number of reports, temperatures have been increasing at a rate of 0.26ºC/10a in tropical regions (Qi et al., 2010), and the boundary of the tropics are broadening towards the Polar Regions (Cao et al., 2010). A persistent change in climatic conditions and atmospheric composition may lead to a change in the global distribution patterns of species (Walther et al., 2002). This may even result in an increased risk in species extinction (Pereira et al, 2010). For example, IPCC (2007) suggested that 20% to 30% of all species would be at an increased risk of extinction if the rise in the global average warming trend exceeded 1.5ºC to 2.5ºC, and if it were to exceed an approximate threshold of 3.5ºC, 40% to 70% of all species may become endangered.

Species migration may be an adaptive mechanism of habitat tracking by which species can escape extinction (Woodall et al., 2009). Based on recent forest inventory data from North America collected by the United States Department of Agriculture (USDA), northward migration speed of monitored tree species was $100km\cdot100a^{-1}$ when compared against a distribution map generated in 1971 of 30 tree species (Woodall et al., 2009). Unfortunately, investigating and measuring forests at a species level is difficult when utilizing the general forest inventory of China and is impossible when trying to determine and track tree species distribution changes based on the current forest inventory of southern China. Furthermore, the natural migration of tree species has always been impeded and interrupted by the fragmentation of most forest ecosystems, resulting in difficulties in obtaining reliable data from permanent monitoring plots on the natural migration of tree species. The Anthropocene (Crutzen, 2002) has resulted in maximum changes to tree species distribution patterns. It may therefore be reasonable as well as practicable to utilize cultivated plants instead of natural plants to monitor and provide evidence of climate change.

As far as it can be determined, most literature related to introduced species has concerned itself with the negative impacts to ecological environments. Vitousek et al. (1977) pointed out that biological invasions represent an anthropogenic breakdown of regional distinctiveness of Earth's flora and fauna. Moreover, well-documented examples are available in literature concerning how invading species that degrade human health and welfare also alter the structure and function of undisturbed ecosystems and/or threaten native biodiversity. More than 2,000 alien species have established themselves in the continental United States of America, of which many resulted in various degrees of ecologic and economic degradation (Simberloff, 2000). For example, *Robinia pseudoacccia* (Hunter, 1996a; Peloquin and Hiebert, 1999) and *Ailanthus altissima* (Hunter, 1996b) can greatly interfere with forest restoration processes, and *Paulownia tomentosa* typically outcompetes native tree species in eastern forests in the United States of America (Johnson, 1996), having displaced native pines in a number of national parks. *Sapium sebiferum* invades rainforests, having displaced native forests in the United States of America through self-seeding (Bruce et al.; Miller, 1997) and *Ligustrum sinense* prevents bottomland hardwood (pine forests) regeneration (Miller 1997). However, few reports on the negative impacts of introducing alien tree species to terrestrial regions of China exist even though more than 1,000 alien species have been introduced into the country.

Since being founded in 1976, the Gannan Arboretum has from 1978 onwards introduced a large number of alien tree species, most of which originated in South China (Guangdong, Guangxi, Fujian and Yunan) while a few were native to southern Jiangxi forests (Huang et al., 2010). A total of 39 tree species attributable to tropical regions were observed and measured for this study (excluding introduced tree species determined unsuccessful), of which 31 species were from the Gannan Arboretum and eight species were selected from gardens and residential areas within Ganzhou City. In all, 24 tree species were classified as fundamentally successful in introduction and 15 were classified as preliminarily successful in introduction (Table 2). Based on the growth rate and development of these introduced tree species, this study attempted to conduct a preliminary summation and evaluation on the effects of all introduced species as well as to couple these effects with regional climate data from 1951 to 2009 in order to analyze relationships between introduced tree species and climate change in the region. According to an index review of literature, little research on the subject exists with the exception of one PhD dissertation (Song, 2007) that discussed the phenology and growth of introduced tropical plant species and their response to climate change. Phytogeographical principles are the fundamental basis of plant introduction and distribution (Wang et al., 2005), for which biotic and/or floristic homogenization is the important determining factor (McKinney, 2004; Olden, 2006; Olden and Poff, 2003; Olden and Rooney, 2006). However, floristic may in fact be more closely linked to plant introduction as it relates to introduced species that share a place of origin and possess close phytogeographical affinity with the flora of target areas. This may potentially be attributable to their high success rates. Determining initial distribution patterns of introduced tree species and key ecological factors related to original place may therefore be fundamental to the success or failure of introduced species.

2. MATERIALS AND METHODS

2.1 Natural Survey

Situated in the upper region of the Gan River, Ganzhou City comprises an area of 394,000 ha, constituting 23.6% of the total area of Jiangxi Province. Its approximate geographical coordinate is from latitude 24º29' N to 27º09' N and from longitude 113º54' E to 116º38' E (Fig. 1A, 1B). Landform type is hill-basin surrounded by a series of mountain ranges: Yu Mountains to the north, Wanyangshan and Zhuguangshan to the west, Wuyishan to the east as well as Dayuling and Jiulianshan that constitute the eastern Nanling mountain ranges, located in the southern region of Ganzhou City (Fig.1A, 1B). With a distance of only 360 km from Taiwan Strait, Ganzhou City is impacted by monsoon climate conditions. The "local warm habitat" of Ganzhou City area covers an approximate length from 200 km to 300 km from north to south and a similar width from east to west, constituting the geographical basis for the migration and distribution of South China flora and the expect introductory success of species from South China. Gannan Arboretum is the primary site where observations and surveys were carried out for this study. It is located in Ganzhou's Shangyu County, belonging to the hilly moist climatic region south of Changjiang River, situated within the mid-subtropical zone of China (Cheng et al., 2010). According to Ganzhou City meteorological records, the annual average maximum temperature of Gannan Arboretum is 19.5ºC, with a maximum of 29.5ºC in July and a minimum of 8.2ºC in January. The annual average minimum temperature is −1.5ºC; the annual accumulated temperature is 6189ºC ≥ 10ºC; and the annual frost free period is >290 days. Total precipitation is 1444.3 mm.

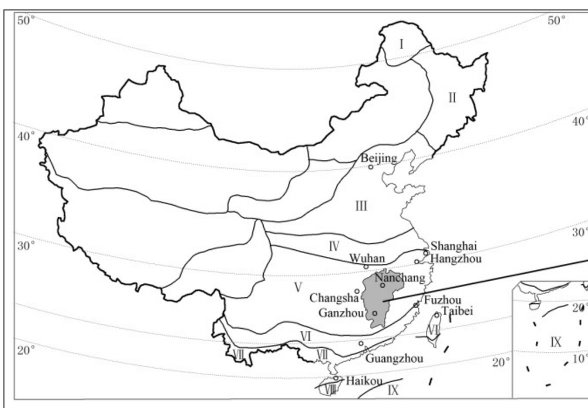


Fig. 1A. Map shows Jianxi Province and it the position in China and the climatic zone division of the eastern part of China

Fig. 1B. A map shows Ganzhou City area and Shangyou county (Gannan Arboretum belong to which), i.e. the study area in this paper

Notes: I. cold temperature zone; II. middle temperature zone; III. warm temperature zone; IV. northern subtropical zone; V.mid-subtropical zone; VI. southern subtropical zone; VII. northern tropical zone;VIII .mid-tropical zone; IX. equatorial zone

2.2 Vegetation and Flora

Native forests of Ganzhou City area belong to the southern evergreen broadleaf subzone of the mid-subtropics for which *Castanopsis fordii*, *C. lamontii*, *Altingia chinensis*, *Tsoongiodendron odorum*, *Semiliquidambar cathayensis*, *Gnetum parviflolium*, and *Rhodomyrtus tomentosa* are representative species ("The Vegetation Atlas of China", published by the Editorial Board of Vegetation Map of China, 2007). Ganzhou City area flora is the typical of the Nanling mountain range, having the transitional characteristics from the floristic region of eastern China to the floristic region of South China (Wu et al., 1983) or from boreal flora to Paleotropical flora (Good, 1964). According to earlier investigations (Yao et al., 2002; Huang et al., 2011), numerous "typical" tropical families and genera are distributed throughout the region but rarely found near its northern boundaries. 55.9% genera of tropical areal-type and 41.8% genera of temperate areal-type among 889 genera of seed plants were recorded within the Jiulian mountains (located in the southernmost region) (Liu et al., 2002). Among the tropical areal-type plants, it was found that tropical Asian areal-type plants (Wu et al., 2006) had closer phytogeographical affinity with Ganzhou area flora, for which most genera comprised dominant elements of its evergreen broadleaf forests. As stated above, there are strong reasons to believe that Ganzhou City area is the northernmost frontier of South China flora. This is probably due to the fact that the potential success rate would likely be higher for tropical tree species introduced from South China under a scenario of a warming climate.

2.3 Weather Data

Meteorological data used in this study were taken from China's Weather Bureau, including the consecutive annual average temperature (from 1951 to 2009) of Ganzhou City, the average temperature in January, the average temperature in July, annual minimum temperature, and annual precipitation. In order to analyze climate change accurately, relevant climate dynamic curve and trend line graphs were generated based on the original weather data from the aforementioned source.

2.4. Growth and Developmental Observations of Introduced Tree Species

Introduced tree species investigated for this study came from two sources: Gannan Arboretum (Shangyou Xian) and from gardens and residential areas situated within the Ganzhou City. For this study, tropical tree species that originated from South China were the primary items of investigation, and observations and measurements taken from introduced tree species focused on the following items: site and time of introduction, plant size (stem number or area), tree height and diameter at breast height (DBH), flower and fruit behaviour, introduction evaluation, etc. For a number of cultivated tree species with larger plant sizes (such as *Illicium verum*, *Mytilaria laoensis*, *Canarium album*, *Reevesia thyrsoidia*, and *Podocarps wallichiana*), plots were established to carry out further investigation in order to better understand growth processes. This included measuring each stem in the plot and the selection of one stem as an analytical tree sample by which to carry out stem analysis.

2.5 Climate Zone Attributes of Introduced Tree Species

Introduced tree species originated from various climatic zones and regions (Xi et al. 1984; Cheng et al. 2010). It became necessary to classify them into respective zone types according to their original distribution area. The following is a list of the classification zone types established: (a) South China southern subtropical zone; (b) Chinese marginal tropical zone; (c) Chinese mid-tropical zone–southern tropical zone; (d) northern region of the Indochina peninsula and southern region of the marginal tropical zone of the Himalayas–Chinese southern subtropical zone; (e) Indochina peninsula zone–South Asia and

Philippines–Chinese southern subtropical zone; (f) Indonesia-Malaysia equatorial tropical zone–Chinese southern subtropical zone; (g) Oceania tropical zone–Chinese southern subtropical zone; and (h) American tropical zone–Chinese southern subtropical zone.

3. RESULTS AND DISCUSSION

3.1 Analysis of Climate Change

Weather records from Ganzhou City between 1951 and 2009 can be divided into four separate 10 year intervals (1950s, 1970s, 1990s and 2000s) for the convenience of comparing differences and changes among timeframes. The following results were ascertained (Table 1): 1) Annual average temperatures experienced a steady rise over time, increasing by 0.7ºC from the 1950s to the 2000s. Specifically, temperatures rose by 0.2ºC every consecutive 20 year period in the latter half of twentieth century. 2) Minimum monthly average temperatures rose by 0.9ºC, from 7.3ºC in the 1950s to 8.2ºC in the 1990s, after which they dropped slightly to 8.1ºC in the 2000s. 3) Annual minimum temperatures rose from −3.1ºC in the 1950s to −1.2ºC in the 1990s; however, they then dropped to −2.0ºC owing to the unusually cold winters experienced in the region in the latter part of the 2010s. 4) Similar to the warming trend experienced in winter, records show that it also became increasingly warmer during summer. The average temperature of the hottest months of the year rose from 29.2ºC in the 1950s to 29.8ºC in the 2000s, for which 31.9ºC measured in 2003 and 31.5ºC measured in 2007 were the peak values recorded in the meteorological record (from 1951 to 2009).

Table 1. Comparison between key climatic factors from the 1950s, 1970s, 1990s and 2000s in Ganzhou City

Age (10a)	Annual average temperature (ºC)	Coldest month average temperature (ºC)	Hottest month average temperature (ºC)	Annual average minimum temperature (ºC)	Annual average precipitation (mm)
1950s (1951-1960)	19.1	7.3	29.2	−3.1	1404
1970s (1970-1979)	19.4	7.8	29.4	−2.3	1423
1990s (1990-1999)	19.6	8.2	29.1	−1.2	1497
2000s (2000-2009)	19.8	8.1	29.8	−2.0	1404

The origin of data and how data were calculated (as shown in Table 1) are as follows: Ganzhou City meteorological data between 1951 and 2009 was supplied by the China Meteorological Data Sharing System (MDS), stored by the China Meteorological Bureau, and climatic data pertaining to standard month (IM) and standard year (IY) was downloaded from its website based on an agreement between the China Meteorological Bureau and the project team of this study. IM includes monthly average temperatures, coldest monthly average temperatures, and hottest monthly average temperatures. IY includes annual average temperatures, annual minimum temperatures, annual maximum temperatures, and annual precipitation. Annual average temperatures for the 1950s were calculated by the total value of annual average temperatures from 1951 to 1960 divided by 10. Calculations of annual average temperatures for the 1970s, 1990s, and 2000s were carried out in the same manner. Average temperatures of the coldest month (January) for the 1950s, 1970s, 1990s, and 2000s were calculated by the total value of average temperatures of the coldest month (January) from 1951 to 1960, 1970 to 1979, 1990 to 1999, and 2000 to 2009, divided by 10. Other calculation methods, including average temperatures of the hottest month (July), annual minimum temperatures, and annual average precipitation, were carried out in the same manner.

Climate change in the twenty-first century has varied from extreme cold to extreme hot. As shown in Fig. 2 and Fig. 3, a rising trend in the variance curve and variance trend line of annual average temperatures as well as the variance curve and variance trend line of annual minimum temperatures have been observed throughout 1951 and 2009.

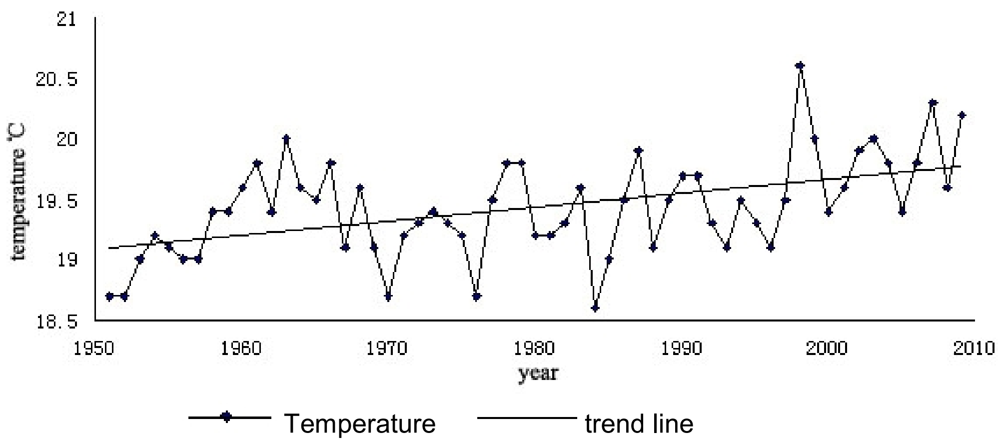


Fig. 2. Variance curve and variance trend line of annual average temperature (1951–2009)

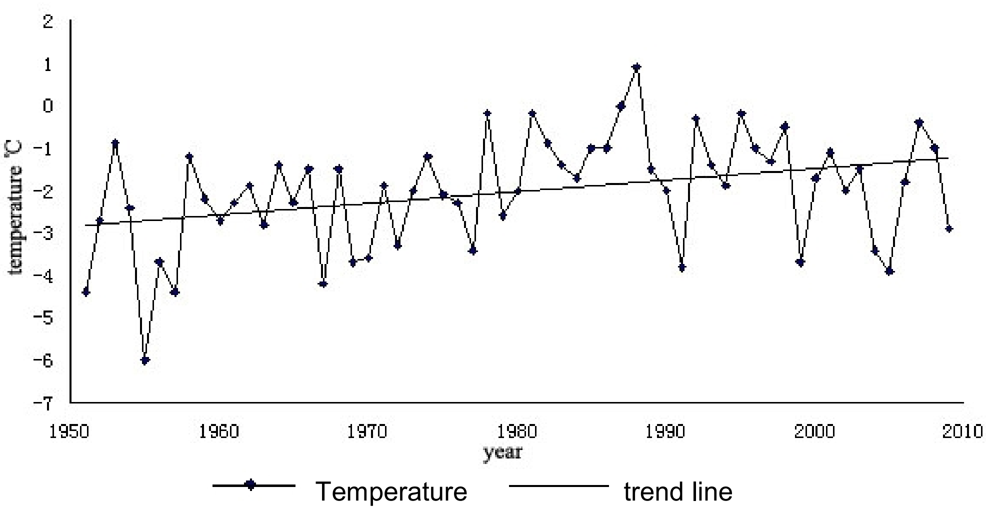


Fig. 3. Variance curve and variance trend line of annual minimum temperature (1951–2009)

Fig. 4 and Fig. 5 show a slight rise in the variance curve and variance trend line of average temperatures during the coldest month of the year (January) as well the variance curve and variance trend line of average temperatures during the hottest month of the year (July). In addition (as shown in Fig. 6), a trend towards a slight drop in both the variance curve and the trend line of annual precipitation took place from 1951 to 2009. There is evidence that suggests that the trend in climate change may be heading towards hotter and drier conditions for the region.

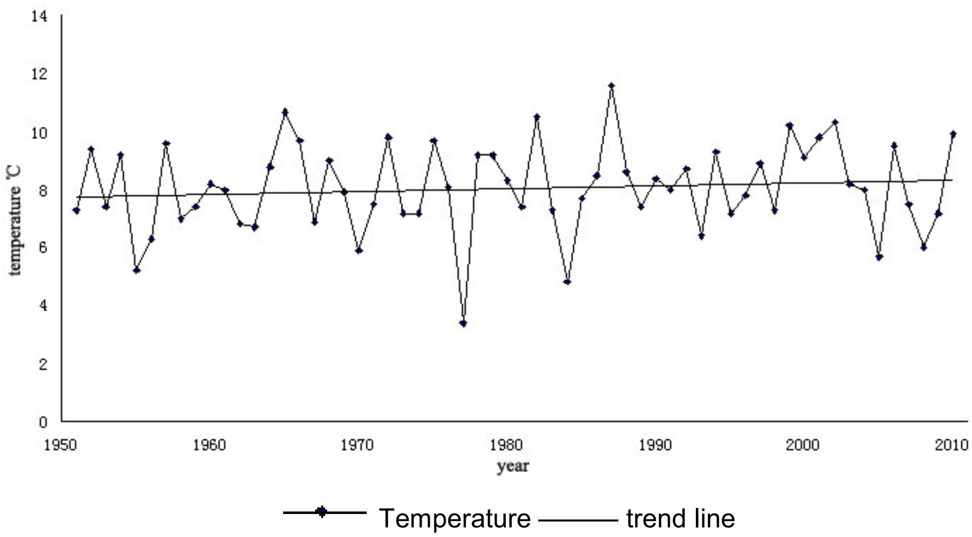


Fig. 4. Variance curve and variance trend line of the average temperature of the annual coldest month (1951–2009)

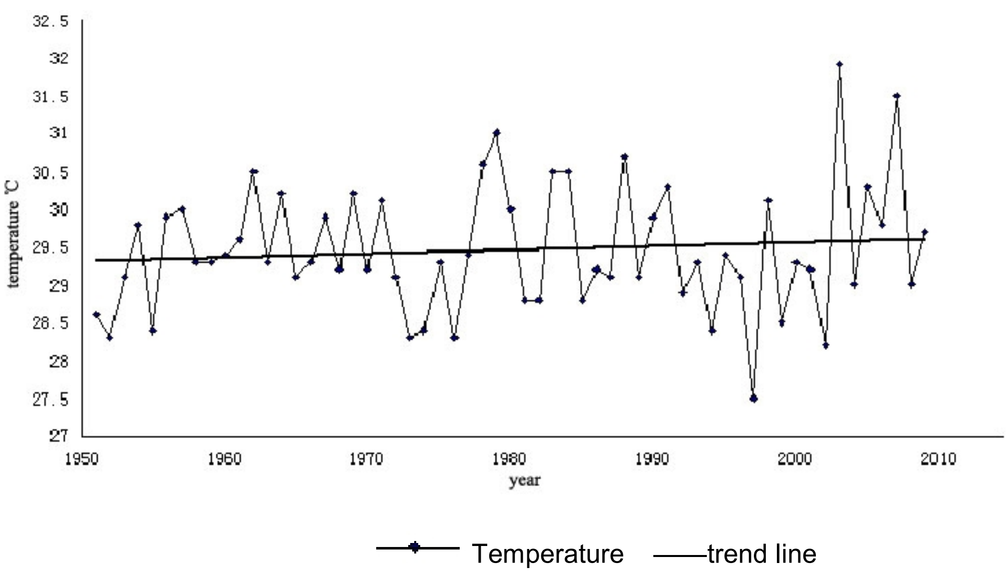


Fig. 5. Variance curve and variance trend line of the average temperature of the annual hottest month (1951–2009)

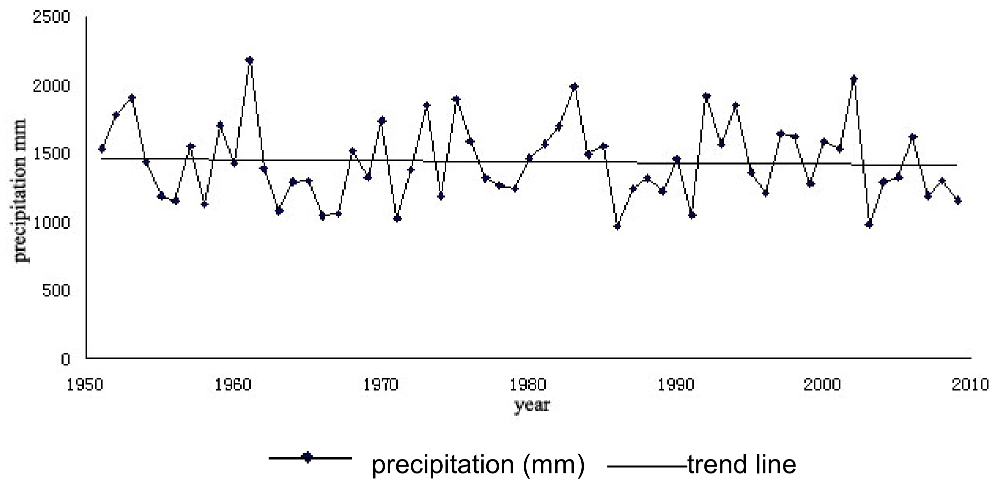


Fig. 6. Variance curve and its annual precipitation trend line (1951–2009)

The origin of data and how data was calculated (as shown in Fig. 2, Fig. 3, Fig. 4, Fig. 5 and Fig. 6) are as follows: All meteorological data was supplied by the China Meteorological Data Sharing System (MDS), and climatic data pertaining to standard month (IM) and standard year (IY) was downloaded from its website, including data related to annual average temperatures, annual minimum temperatures, annual average temperatures of the coldest month (January), annual average temperatures of the hottest month (July), and annual precipitation, wherein all data refers to the entire study period (1951–2009). This data were the basis on which the two-dimensional graphs were generated and variance curves and tread lines were drawn.

3.2 Outcome of Tropical and Subtropical Trees Species Introduction

The outcome of tropical and southern subtropical trees species introduction into the Gannan Arboretum as well as into Ganzhou City gardens and residential areas are listed and summarized in Table 2. Among these, 24 species are considered as fundamentally successful, exhibiting normal growth and developmental patterns while producing flowers and bearing fruit, which are listed as follows: *Podoarpus. wallichiana, Michelia alba, Parakmeria yunnanensis, Illicium verum, Bauhinia variegata, B. purpurea, Cassia suffruticosa, Leucaena leucocephala, Mitilaria laoseensi, Altingia chinensis, Ficus virens, Ficus altissima, Ficus elastica, Callistemon rigidus, C. salignus, Evodia austrosinensis, Canarium album, Chukrasia tabularis* var*. Velutina, Trichilia connaroides* var*. microcarpa*, *Aglaia odorata, Reevesia thyrsoidea, Hibiscus rosasinensis, Duranta repens,* and *Jacaranda mimosifolia*. Another 15 species that have achieved preliminary success are: *Araucaria cunninghamii, A. hetrophylla, Podocarpus fleuryi, Erythrophleum fordii, Acacia richii, Erythrina corallodendron, Adenanthera pavonina, Casuarina equisetifolia, Castanopsis kawakamii, Cratoxylum cochinchinense, Syzygium cumi, Psidium guajava, Canarium pimela, Bombax malabaricum,* and *Gmelina arborea* (Table 2).

Table 2. Observational and measurement records on the growth status of introduced tree species in Ganzhou City
*(Survey Location**:** Gannan Arboretum and Ganzhou City**;** Investigation period: 2010/11)*

Species name	Introduction time and location	Cultivated location and its site	Climate zone of original distrib.	Size of cultivated trees (stem n.)	Freeze damage in seeding time	Aver. age (a)	Aver. height (m)	Aver. DBH (cm)	Initial flowing time (a)	Initial fruit time (a)	Evaluation degree
Araucaria cunninghamii	1950s，Guangdong 2002，Guangdong	Park, Ganzhou I Park, Ganzhou Ⅱ	g	1 3	D1	>60 9	22.0 5.0	59.9 6.0	No note	No note	V2
A. hetrophylla	2002，Guangdong	Arboretum Ⅰ	g	1	D3	8	8.0	10.5	No note	No note	V2
Podocarpus fleuryi	2004，Guizhou	Arboretum Ⅱ	d	200	D1	6	2.5	3.0	No note	No note	V2
P. wallichiana	1991，South China Botanical Garden	Arboretum Ⅲ	e	15	D1	21	15.0	19.5	15	16	V1
Michelia alba	1985，Guangdong	Park, Ganzhou II	f	1 big tree Others small	D2	25	23.0	43.6	10	14	V1
Parakmeria yunnanensis	2006，Yunnan	Arboretum Ⅱ	a	70	D1	5	1.5	3.5	Young t.	Young t.	V1
Illicium verum	1980，Guangxi Botanical Institute	Arboretum I	a	$35hm^2$	D1	33	13.0	12.4	12	15	V1
Bauhinia variegata	2006，Guangdong	Community, Ganzhou I	e	5	D1	5	2.5	5.0	3	No note	V1
B. purpurea	2006，Guangdong	Comm. Ganzhou I	e	6	D1	5	2.5	5.0	3	No note	V1
Cassia suffruticosa	2005，Guangdong	Street, Ganzhou I	F	>200	D1	6	2.5	6.0	3	3	V1
Erythrophleum fordii	1982，Nanning, Guangxi	Arboretum III	d	6	D3	28	12.7	22.0	24	25	V2
Acacia richii	1981，Guangzhou	Arboretum III	f	3	D3	31	3.8	18	No note	No note	V2
Leucaena leucocephala	1983，South China Botanical Garden	Arboretum Ⅱ	h	30	D1	27	4.5	10.3	25	26	V1
Erythrina corallodendron	2006，South China Botanical Garden	Arboretum I	h	9	D3	5	3.5	5.0	2	2	V2

Table 2 continues…….

Adenanthera pavonina	1980, Forestry Research Institute of Guangxi	Arboretum II	f	5	D3	31	11.7	10.0	No note	No note	V2
Mitilaria laoseensi	1979, Nanning, Guangxi	Arboretum I	d	4.5hm^2	D1	22	17.0	18.0	10	11,	V1
Altingia chinensis	1985, Dayu County, Kiangxi	Arboretum II	d	3.5hm^2	D1	16	10.5	12.5	10	11	V1
Casuarina equisetifolia	1986, Fuzhou Arboretum	Arboretum III	g	3	D1	15	6,0	9.0	No note	No note	V2
Castanopsis kawakamii	1980, Fujian	Arboretum II	c	10		31	12.0	16.0	20	No note	V2
Ficus virens	2000, Guangdong	Street trees, Ganzhou II	f	>100	D1	10	12.0	28.0	6	6	V1
Ficus altissima	2004, Guangdong	Street trees, Ganzhou II	f	>100	D1	8	4.2	15.8	6	6	V1
Ficus elastica	2004, Guangdong	Ganzhou II	f	1 big tree Others small	D2	8	6.0	68.0	No note	No note	V1
Cratoxylum cochinchinense	1986, South China Botanical Garden	Arboretum II	f	20	D2	24	7	8.1	11	11	V2
Callistemon rigidus	1978, Forestry Re search Institute of Guangxi	Arboretum I	g	2	D1	33	5.0	12.0	15	15	V1
C. salignus	1979, Forestry Research Institute of Guangxi	Arboretum II	g	3	D1	32	6.5	15.2	16	16	V1
Syzygium cumi	2005, Guangdong	Parks,Ganzhou II	f	>10	D1	6	3.5	8.0	No note	No note	V2
Psidium guajava	1984, South China Botanical Garden	Arboretum II	h	3	D3	26	3.5	5.6	14	14	V2
Evodia austrosinensis	1978, Nanning, Guangxi	Arboretum II	a	3	D1	27	8	26	15	15	V1
Canarium album	1985, South China Botanical Garden	Arboretum III	a	6	D1	26	15.0	21.0	16	20	V1

Table 2 continues…….

Canarium pimela	1985， South China Botanical Garden	Arboretum II	e	4	D3	26	10.0	10.0	No note	No note	V2
Chukrasia tabularis var. velutina	1983， South China Botanical Garden	Arboretum II	c	1	D1	27	15	44.9	22	22	V1
Trichilia connaroides var. microcarpa	1998， South China Botanical Garden	Arboretum III	d	20	D1	13	4.0	4.4	8	10	V1
Aglaia odorata	1990s， Guangdong	Cummunity, Ganzhou I	e	>200	D1	8	2.5	2.0	3	No note	V1
Reevesia thyrsoidea	1979， Shicheng County, Jiangxi	Arboretum II	e	25	D1	32	24.5	18.5	13	14	V1
Bombax malabaricum	1960，Guangdong	Park, comm. Ganzhou II	f	3	D2	50	32.0	130	10	No note	V2
Hibiscus rosasinensis	2004，Guangdong	Street trees Ganzhou II	e	>100	D2	7	2.0	3.0	2	No note	V1
Duranta repens	2000s， Guangdong	Park, commnity Ganzhou I	h	>1000	D1	5-10	1.0	2.0	3	No note	V1
Gmelina arborea	1979， Forestry Research Institute of Guangxdong	Arboretum I	f	5	D2	32	5.5	12.5	No note	No note	V2
Jacaranda mimosifolia	Absent note	Street tree Ganzhou I	h	1	No note	ca.80	15.0	48.7	10	No note	V1
Caryota ochlandra	1985， South China Botanical Garden	Arboretum I	e	1	D3	15	4.5	14.5	No note	No note	V2

Note: Degree of site conditions: I – good site condition; II – acceptable site condition; III – poor site condition
Evaluation degree: V1 – growth and development normal; V2 – growth normal and flowers bloom without fruit production (with the exception of certain ornamental tree species); V3 – growth and development poor overall (information not included in the table).
Freeze damage during seeding period: D1 – no frost damage; D2 – light frost damage; D3 – considerable frost damage
Climatic zone types of original distribution – see Section 3.2

3.3 Growth Processes of Key Introduced Tree Species

3.3.1 *Mitilaria laoensis*

Mitilaria laoensis, a marginal tropical zone to Chinese southern subtropical zone tree species (d) was distributed throughout China's southern provinces, that is Guangxi, Guangdong and Yunan as well as northern Vietnam and Laos. The stem sample used for analysis was obtained from a 22 year old tree of 17.2 m height, 23.2 cm DBH, and 0.33 m^3 volume. Results of the analysis indicated rapid growth in height and DBH. Moreover, height (Fig. 7A), DBH, and volume growth curves (Figs. 7B and C) exhibited a vigorous rising trend. Forest structure and dynamics of the species were stable with more natural seedling production occurring under the forest canopy, confirming that the introductory experiment of this species was successful.

3.3.2 *Illicium verum*

The *Illicium verum* stand (a: South China southern subtropical zone) planted in 1980 originated from the south and southwest of Guangxi Province. According to the survey carried out on the 20×30 m plot, an average height of 10.0 m was measured for the 102 stems with an average DBH of 12.4 cm and an average volume of 133.6 $m^3 \cdot ha^{-1}$. The stand produced approximately 250kg·0.1 ha^{-1} of fruit. The sample taken showed that the stem was 30 years old, 10.8 m height, 16.0 cm DBH and 0.11 m^3 volumes. Fig. 7 illustrates a normal rising tendency for all growth curves (height growth curve (A), DBH growth curve (B), and volume growth curve (C)). Fruit production commenced at the age of 15 years (1986). According to the criteria established by this study, the introduction of *Illicum verum* has been successful.

3.3.3 *Reevesia thyrsoidia*

Reevesia thyrsoidia belongs to the marginal tropical zone to Chinese southern subtropical zone(d). Its original area of distribution was in the Chinese provinces of Guangdong, Guangxi, and Fujian as well as Vietnam and Cambodia. It has rarely been seen naturally occurring in native forests of Ganzhou City. The sample stem (retrieved as a coppiced stem) was collected from a 24 year old plantation forest, 20 m height, 18.4 cm DBH and 0.26 m^3 volumes. Figures 7A, 7B & 7C show that height growth, DBH growth and volume growth occurred rapidly. Growth curves suggest a vigorous growth tendency.

3.3.4 *Podocarps wallichiana*

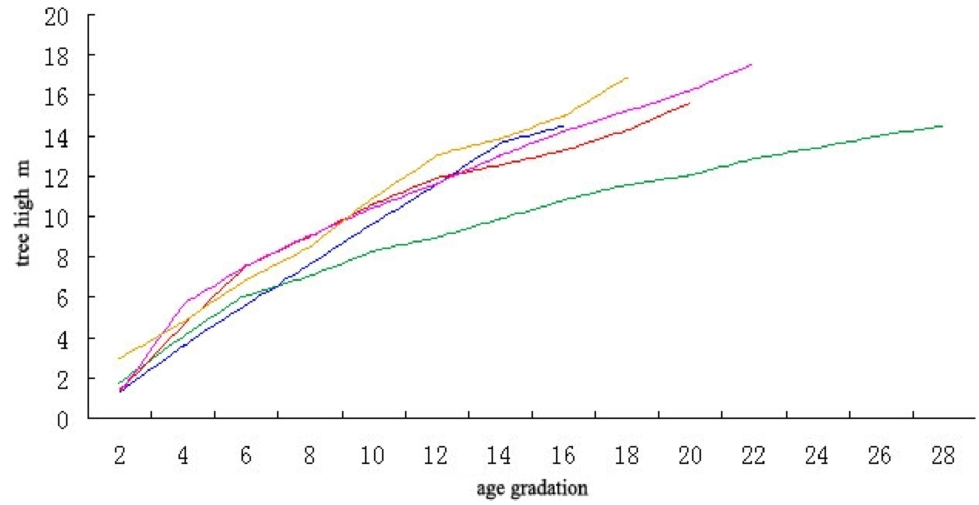
Podocarps wallichiana, whose original area of distribution was in Xihuangbanna (Yunnan Province, China) and Vietnam and India, belongs to the mid-tropical and southern subtropical zone (e) (delet "mid-tropical -Chinese southern subtropical zone"). Sample age was 20 years old, 17.9 m height, 16.5 cm DBH, and 0.22 m^3 volume. Growth curves were identical to the aforementioned tree species, indicating it grew rapidly and exhibited a trend towards vigorous growth.

3.3.5 *Canarium album*

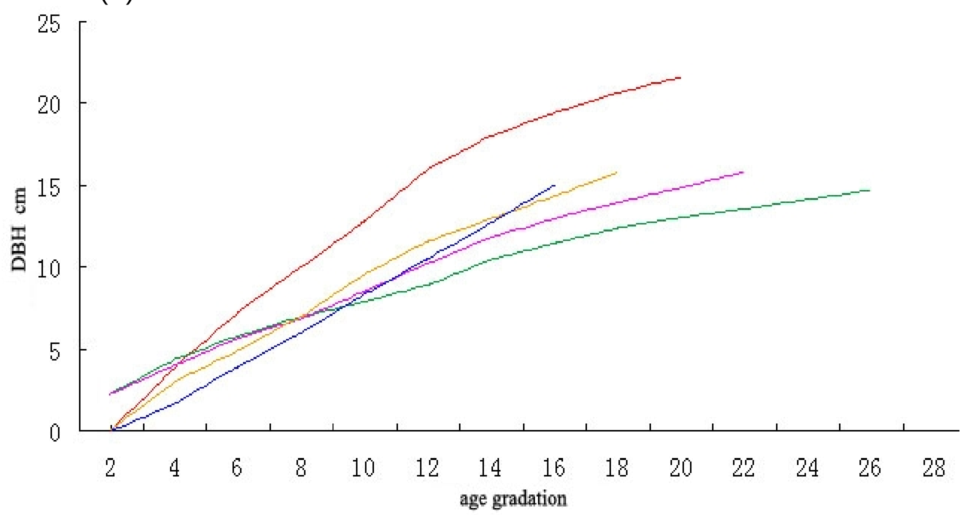
Canarium album was originally distributed throughout southern China and into Vietnam. It belongs to the marginal tropical to Chinese southern subtropical zone (d). Sample age (retrieved as a coppiced stem) was nine years old, 15.2 m height, 17.4 cm DBH, and 0.157

m^3 volumes. Growth curves (such as it was for *Podocarps wallichiana*) were identical to the aforementioned tree species, indicating it grew rapidly and exhibited a rising trend for all growth indexes.

(A) Height Growth



(B) **DBH Growth**



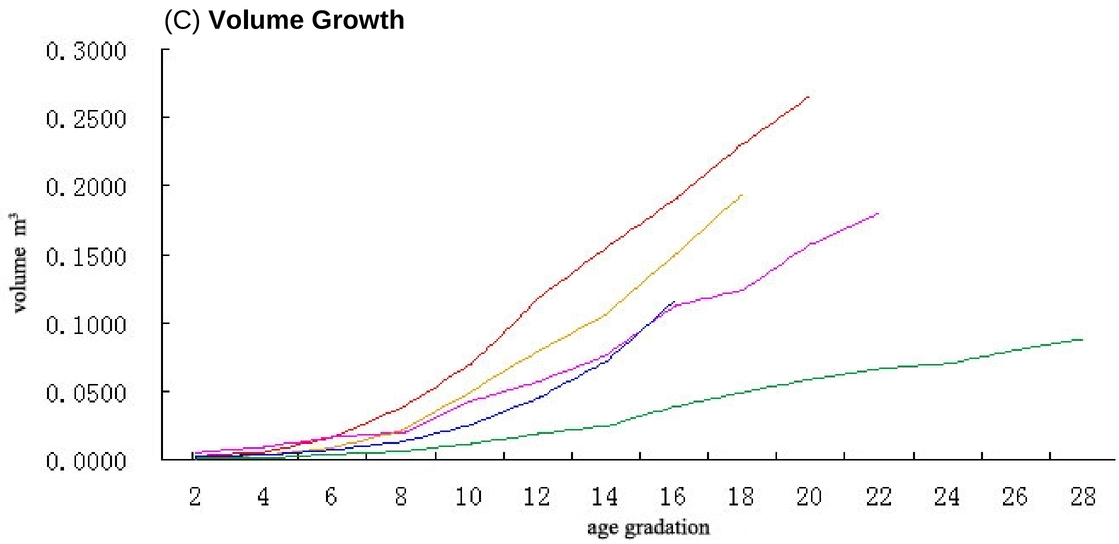


Fig. 7. *Mitilaria laoensis* curves relating to (A) height growth, (B) DBH growth, and (C) volume growth.

Note pertaining to line designation: Mitilaria laoensis: Illicium verum: Reevesia thyrsoidea: Podocarps wallichiana: Canarium album

Stem analysis results from all five species indicated that the growth rate of these tropical and southern subtropical species was rapid and vigorous. The outcome of these introduced tree species suggests that the overall natural condition of Ganzhou City is suitable for the growth of thermophilous tree species introduced from tropical and southern subtropical regions. It also serves as confirmation to the climate warming taking place in the region.

4. CONCLUSION

Since the late 1970s, the introduction of tree species from tropical and southern subtropical regions into Gannan Arboretum and Ganzhou City gardens has become increasingly successful. Among the 39 introduced tree species, 24 are listed as basically successful and 15 are considered preliminarily successful. Other introduced and cultivated tree species that exhibited a lower success rate may be the result of issues relating to plantation technology and mismanagement. Introduction success are likely attributable to three factors: 1) It has been established through the existing meteorological records that the climate of the local region has been experiencing an increasingly warming trend since the 1950s, and this trend has been especially prevalent since the 1970s. Since most introductory experiments were initiated in the late 1970s, during a time when a concurrence of tree species introduction and climate warming was taking place, it is reasonable to attribute introduction success to climate warming. 2) The effectiveness of the local warm habitat likely played a role in the introductory success of tree species from tropical and southern subtropical zones. 3) The potential ecological niche of tree species can be extended by means of a change in natural conditions (Wang et al., 2005). Abundant intrinsic tropical floristic behaviour has taken place in Ganzhou. In addition, more new tropical floristic behaviour from introduced tree species has been added to this region in recent years. It can therefore be safely concluded that Gannan Arboretum may become “the South China in the northern part of Nanling” under the impact of global warming.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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