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Phenological changes and effects of Populus euphratica under the background of climate change

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Abstract

Phenology is a key indicator of climate change. We studied the phenological change of *Populus euphratica* during 1960–2019, and investigated the relationships between phenological change and climate change. The results showed that the annual average temperature in the Lower reaches of Heihe River was increased significantly over the past 58years, which directly led to the germination of *Populus euphratica* was advanced, and the leaf yellowing delayed. The growth season of *Populus euphratica* was significantly prolonged after 1990, and the mean growth season length were 230, 236, 245 days in 1960–1969,1990–1999,2010–2019, respectively. Temperature is the major environmental factor affecting phenological change, and the length of growing season was prolonged with the increase of annual average temperature and accumulated temperature. Phenological changes have an important effect on plant growth. Our study showed that the frost days of *Populus euphratica* increasing from 1990 to 2019, and the frost days was increased with the growth season length. The accumulated frost days were 19, 21, 23 days in 1990–1999, 2000–2009, 2009–2019. Our studies also indicated that phenological changes also affect socioeconomic, especially the delay of leaf yellow period maybe has an important impact on tourism due to the best viewing period is postponed. Our study of phenological change law and its relationships with climate changes could guide the government formulates tourism policies and help tourists to arrange best viewing time.

1 Introduction

Plant phenology refers to the long-term adaptation of plant reproductive and growth to the changes of light, precipitation, temperature and other conditions to form the regular seasonal changes (Chen et al., 2017; Piao et al., 2019). Phenology has played a considerable role in promoting science progress in the past few decades (Yu et al., 2017). Many studies indicated that phenology is the simplest process to track the changes of ecological (Parry et al., 2007). However, the phenology is not constant under climate change scenarios, especially climate warming in worldwide, and the plants may experience the phenology delaying or advancing as temperatures continue to increase. Phenological change is the most easily observable plant responses to climate change (Ernakovich et al., 2014, Janet et al., 2020). There have been a number of studies focus on the phenological responses to climate change (Berg et al., 2019; Rafferty et al., 2019). An analysis of phenological change showed that 78% of plants showed phenology advanced because of climate warming (Menzel et al.,2006). Fitter et al. (2002) also found that more than 280 plants flowering period advanced in England. In contrary, several studies have believed that phenology was delayed due to temperature increasing (Han et al. 2014; Yang et al., 2015). Similarly, Tao et al. (2017) also found that shrubs lengthen their flowering period under climate warming. Moreover, timing of phenology is crucial for plants to adapt climatic change. Rafferty et al. (2019) suggested that plants can adjust phenology time to response the change of precipitation and temperature. Although climate change is altering the growth environment experienced by plants (Diffenbaugh,2013), such effects remain unexplored in arid and semi-arid region. An accurately understanding of which environmental factors serve as cues for plant phenology is critical for predicting future responses of arid ecosystems to climate change. In addition, the effects of climate change on phenology mainly focuses on flowering period (Prevéy et al., 2019), the germination period, and leaf yellow period have been relatively less studied, especially the date and the duration of leaf yellowing are rarely reported. But germination period and leaf yellow period is very importance in determining the growing season length of plants, especially leaf yellow period is an important indicator of carbon cycle and biodiversity patterns in arid ecosystem (Garonna et al., 2015).

Phenological Changes have important effect on water-carbon exchanges (Khaine, 2015; Lang et al., 2019), the relationship between animals and plants (Post,2008), and the population reproduction and growth (Inouye, 2008). Such as lengthen of the growing season in winter also caused an increase of the frost risk. Many studies have proved this view. Hänninen (2016) studied found that phenological change in early spring and late autumn caused frost damage in plants, especially in spring, the risk of frost increased due to the premature bud burst. In addition, Phenological changes have important effect on ecosystem productivity and terrestrial carbon budgets (Richardson et al., 2013; Jeong et al., 2009). The changes of spring and autumn phenology is also linked with food availability for herbivores and ecosystem net productivity (Gustine et al., 2017; Park et al., 2016). Moreover, phenological changes have further effect on national economic due to many plants are important in horticulture and tourism. Particular ornamental plants may cause dramatically effect on economy as the proportion of tourism in the national economy has increased in future. Therefore, the formulation of tourism policy has to actively adapted to phenological changes, and an accurate understanding of phenology period may help and improve tourism policy. However, there are few studies on the impact of phenological changes on tourism, which affected the sustainable development of tourism.

Populus euphratica (*P. euphratica*) is a typical species of desert riparian forests in the lower reaches of the Heihe River in northwestern China. It not is one of the main distribution areas of *P. euphratica* forest in China, but is one of the only three *P. euphratica* forest areas in the world. *P. euphratica* forest has created huge tourism income for Ejina due to its unique ornamental value. However, the phenological change law of *P. euphratica* under the background of climate change is still unclear. Understanding phenological changes law in *P. euphratica* and its relationships with climate changes is necessary to guide the government formulates tourism policies and help tourists to arrange best viewing time.

Therefore, we studied the phenological change of *P. euphratica* during 1960–2019, and investigated the relationships between phenological change and climate change. The purposes of this study were (1) to clarify the climate change in lower reaches of Heihe River Basin (2) to explore the Long-term phenological trends of *P. euphratica*; (3) to identify the relationship between phenological change and climate change; (4) to determine the effect of phenological change on growth and tourism. Our findings can provide an important guidance for policy makers to schedule which season are the best viewing period.

2 Dates And Methods

2.1 Study area

The study area is located in the lower reaches of Heihe River basin which is a typical inland river basin in northwestern China (Fig. 1). The area is controlled by a typical continental arid climate that is severely cold in winter and extremely hot in summer. The mean annual precipitation is only 38 mm, for which 75% of rainfall occurs between June and August. The potential evapotranspiration is more than 3500 mm, which is greater than precipitation by a factor of 90. Soil in the study area derives from fluvial sediment with gray-brown desert sediments (Si et al. 2008). The dominant vegetation types are composed of desert plants, including *P. euphratica*, *Tamatix ramosissima*, *Achnatherum splendens*, *Sophora alopecuroides*, and *Karelinia caspica* (Yu et al., 2013).

2.2 Phenology period and the number of frost days

According to the phenological division method of *P. euphratica* proposed by Wei (1990), that is, the daily average temperature is greater than 5 °C, *P. euphratica* enters the germination stage, greater than 10 °C, *P. euphratica* enters the flowering stage, greater than 14 °C, *P. euphratica* enters the leaf expansion stage, greater than 18.5 °C, *P. euphratica* enters leaf yellowing period, less than 5 °C, and the defoliation stage of *P. euphratica* ends. Thus, the phenology of *P. euphratica* divided into germination period, flowering period, leaf period, leaf yellowing period, leaf fall period, dormancy period. Frost days were defined as the daily mean temperature below 0°C (Meehl et al., 2004).

2.3 Date treatment and statistical analysis

We set statistical significance at $P < 0.05$ by one-way analysis of variance (ANOVA) using SPSS 19.0. We fitted linear functions to observe responses of *P. euphratica* growth season length to temperature using Origin 8.0. We fitted exponential functions to observe the relationship between *P. euphratica* growth season length and the frost days using Origin 8.0. We evaluated differences at a 0.05 significance level. Finally, we plotted data using Origin 8.0.

3 Results

3.1 Change in temperature and precipitation

The annual change of precipitation was not noticeable, records of all stations also showed that there no significant changes in monthly precipitation over the longer term, and the annual average values were 35.37mm (Fig. 2). The annual average temperature was increased significantly over the past 58years. The annual average temperature of the study area was 8.22°C in 1969, and reached 11.26°C in 2017. Average temperatures have increased at a rate of 0.52 °C per decade over the past 58 years. The mean temperatures were highest in 1969, followed by 1995 and again 2015 (Fig. 2). Analysis of periodic changes of temperature and precipitation found that the scale characteristics of precipitation and temperature change obviously in 25 ~ 30 years (Fig. 3). According to the results of M-K test, there is no obvious sudden change in precipitation during the study period. However, there was a sudden change in temperature in 1995, and the temperature increased significantly after 1995(Fig. 4).

3.2 Long-term phenological trends of *P. euphratica*

By separating the entire study period into six subperiods (1960–1969, 1970–1979, 1980–1989, 1990–1999, 2000–2009 and 2010–2019), we found that the growth season of *P. euphratica* was significantly prolonged after 1990, and the mean growth season length were 230, 236, 245 days in 1960–1969,1990–1999,2010–2019, respectively (Fig. 5). A significant prolonged of growth season was found in 2000–2009, and the growth season between the first and last decades increased by 15 days. The germination of *P. euphratica* was advanced, and the earliest germination occur on March 10, March 5, March 1 in 1960–1969, 1980–1989, 2010–2019 respectively (Fig. 5). And the germination date of *P. euphratica* advanced at a relatively rapid rate in recent twenty years. In addition, The *P. euphratica* experienced delayed leaf yellowing in the most recent twenty years (2000–2019) compared with the earliest subperiods (1960–1969), and the earliest leaf yellowing occur on September 1, September 3 in 1960–1969 and 2000–2009, respectively (Fig. 5). The leaf fall of *P. euphratica* also delayed due to the delayed of leaf yellowing.

3.3 Changing climate drives phenological change

To exploring the relationship of growth season length and temperature, we found there was a significantly positively correlation between growing season length and temperature, and the length of growing season was prolonged with the increase of annual average temperature and accumulated temperature. At the long-term scale, temperatures had strongly influenced and predominantly controlled the growth season length from 1960 to 2017. The main reason may be that the high temperature advanced the beginning of the growth season and delayed the end of the growth season (Fig. 6). However, it seems unlikely that changes in growth period growing are a result of changes in precipitation, because our result showed that precipitation has no significant effect on growth season length.

3.4 The effects of phenological change

The frost days of *P. euphratica* decreasing from1960 to 1989, and increasing from 1990 to 2019. The accumulated frost days were 22, 20, 21, 19, 21, 23in 1960–1969, 1970–1979, 1980–1989, 1990–1999, 2000–2009, 2009–2019 (Fig. 7). To exploring the relationship of growth season length and frost days of *P. euphratica*, we found there was a significantly positively correlation between growing season length and frost days, and the frost days was increased with the growth season length (Fig. 8). The main reason may be that the extension of growing season increases the risk of frost.

In addition, the beginning of leaf yellow and the ending of defoliation in *P. euphratica* was all delayed (Fig. 9). There was no significant change in the length of leaf yellow stage (Fig. 10), but the delay of leaf yellow period maybe has an important impact on tourism due to the best viewing period is postponed.

Discussion

Phenology is a key indicator of climate change, and phenological change is the consequence of climate change (Richardson et al., 2013). We found that the annual average temperature was increased significantly over the past 58years, which directly led to the germination of *P. euphratica* was advanced, and the leaf yellowing delayed. Changes in phenology is an important trait of plant which determine the length of growth period. The growth season of *P. euphratica* was significantly prolonged after 1990 due to the timing of the first dates of germination advanced and the last dates of leaf fall delayed. This is consistent with the studies that advanced germination and delayed leaf fall by climate warming extended the growing season (Linderholm 2006; Chung et al., 2013; Prevéy et al., 2019). Moreover, a growing number of studies has indicated that germination is becoming earlier throughout the temperate regions and caused a great impact on plant (Root et al. 2003, Wolkovich et al. 2012, Prevéy et al. 2017). However, some studies found that although spring phenology advanced, the effect is maybe counteracted by decreased chilling (Ma et al., 2018).

The dominant factor affecting the phenological change still remain debate. Several studies found that temperature is a major environmental factor affecting phenological change (Xie et al., 2015). This is in consist with the results of our study. The field experiments and satellite data also proved that temperature played decisive role in phenological change (Fu et al., 2018). Besides temperature, precipitation has also been reported to effect phenological change (Liu et al., 2016). Some studies found that precipitation was a more dominant factor than temperature on phenology (Ren et al., 2017). Such as precipitation reduce may advance deciduous and delay spring phenology (Misson et al., 2011). Moreover, previous studies found that although the decrease of precipitation leads to the earlier spring phenology (Shinoda et al., 2007), the increase of precipitation had no effect on phenology (Sherry et al., 2007). There also studies show that precipitation has a weaker effect on the change of phenology (Chang,2018). Several studies also found phenology was not changed with the decrease or increase of precipitation (Morin et al. 2010). The reason may be that precipitation not reach the threshold for changing phenology. Other research has shown that temperature and precipitation all effect flowering time (Rafferty et al., 2019). In addition to non-biological, biological factors also affect phenological change (Zu et al., 2018). For example, research has found that grazing would delay the growth phenology (Li et al., 2018).

Phenological changes have an important effect on frost days. Our study showed that the frost days of *P. euphratica* increasing from 1990 to 2019, and the frost days was increased with the growth season length. Consistent with this, previous studies have shown that the warming-induced lengthening of the growing season may induce more frost days (Liu et al.,2018). Frost events increasing can disturb nutrient cycling (Estiarte et al., 2015), inhibit plant growth (beck et al., 2007), reduce carbon uptake (Hufkens et al., 2012), effect species composition of ecosystem (Yang et al., 2010), thus affect the function of ecosystems. Inouye et al. (2008) found that frost have a serious effect on floral abundance. Autumn frost may also result crop yield decrease in late summer (Gallinat et al., 2015). Apart from plant growth, frost events also have a great influence on economy. For example, the 2007 spring freeze in United States was caused over $2 billion in economic losses (Wolf, 2008). Thus, when assessing the effect of phenological changes, the days of frost and time of frost occurred, and the effect of frost events must not be neglected.

Phenological change also affect socioeconomic (Cleland et al., 2012), especially ornamental plants. The *P. euphratica* in Ejina Banner is an intoxicating wonder in the depths of the desert. It is not only a paradise for photographers, but also a paradise for countless travelers. Our results showed that *P. euphratica* experienced delayed leaf yellowing in the most recent twenty years (2000–2019) compared with the earliest subperiods (1960–1969). The delay of leaf yellow period will inevitably lead to the delay of the best viewing period. Thus, Tourists should reasonably arrange travel time due to National Day golden week may not be the best viewing period for *P. euphratica*. In addition, the leaf fall of *P. euphratica* delayed may be extend viewing period, which will increasing tourism revenue. Further research should accurately predict the best viewing period according to climate change, so as to provide basis for tourists' travel and government decision-making.

Declarations

Author contributions Chunyan Zhao designed the study and wrote the manuscript. All authors analyzed data, edited the writing and approved the final manuscript.

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Availability of data and material The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interest The authors declare no competing interests.

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Figures

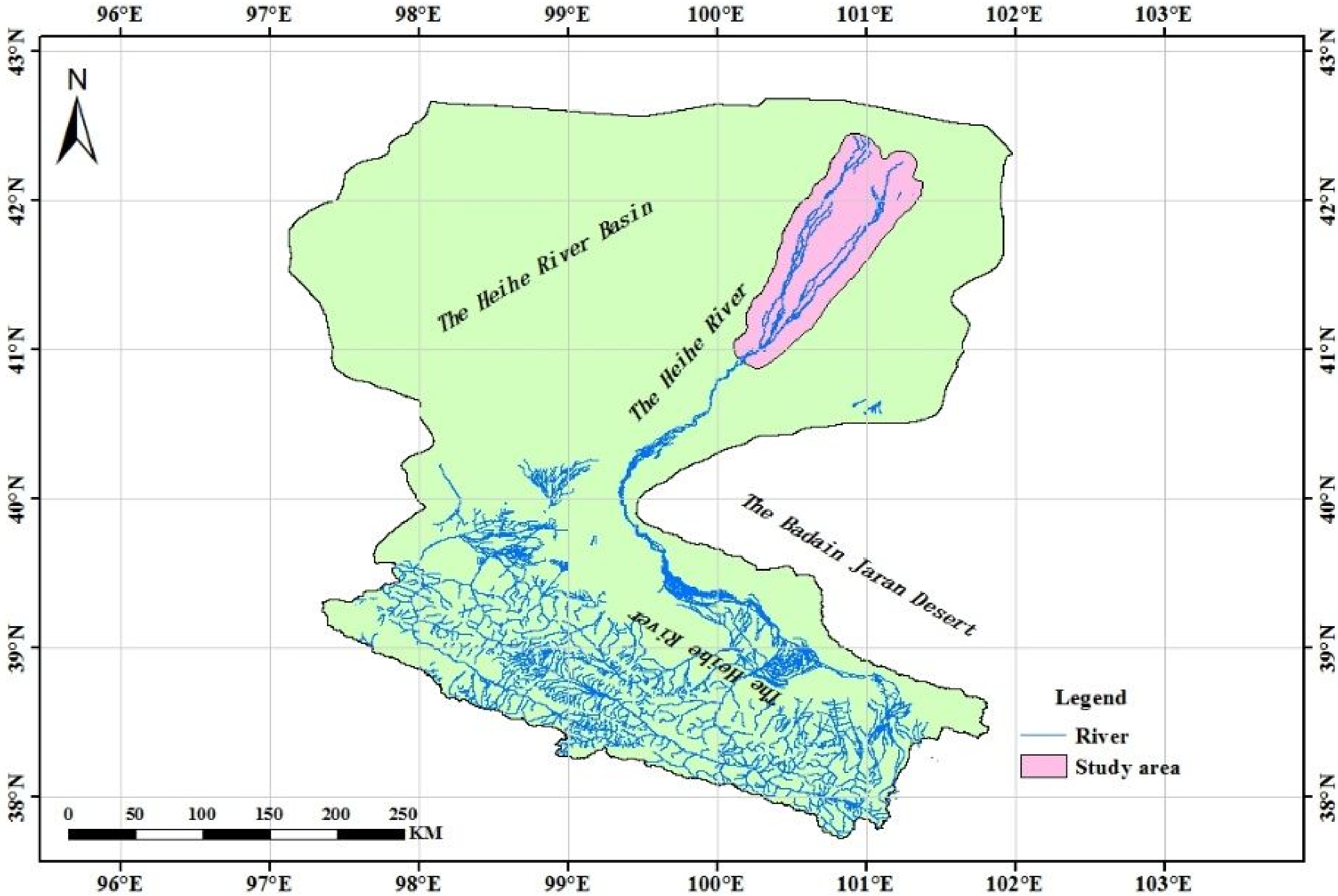

Figure 1

The study area

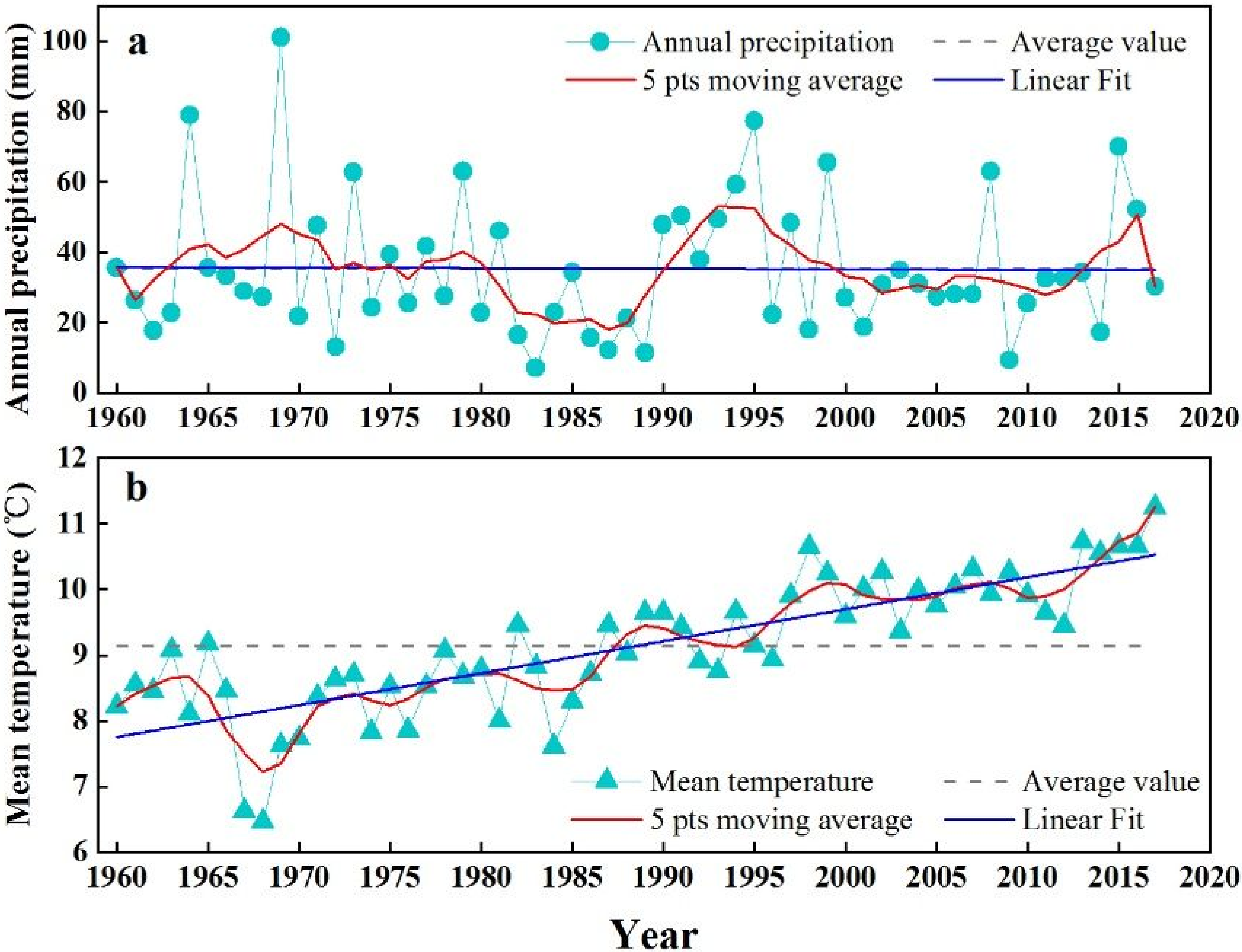

Figure 2

Change in temperature and precipitation from 1960 to 2018

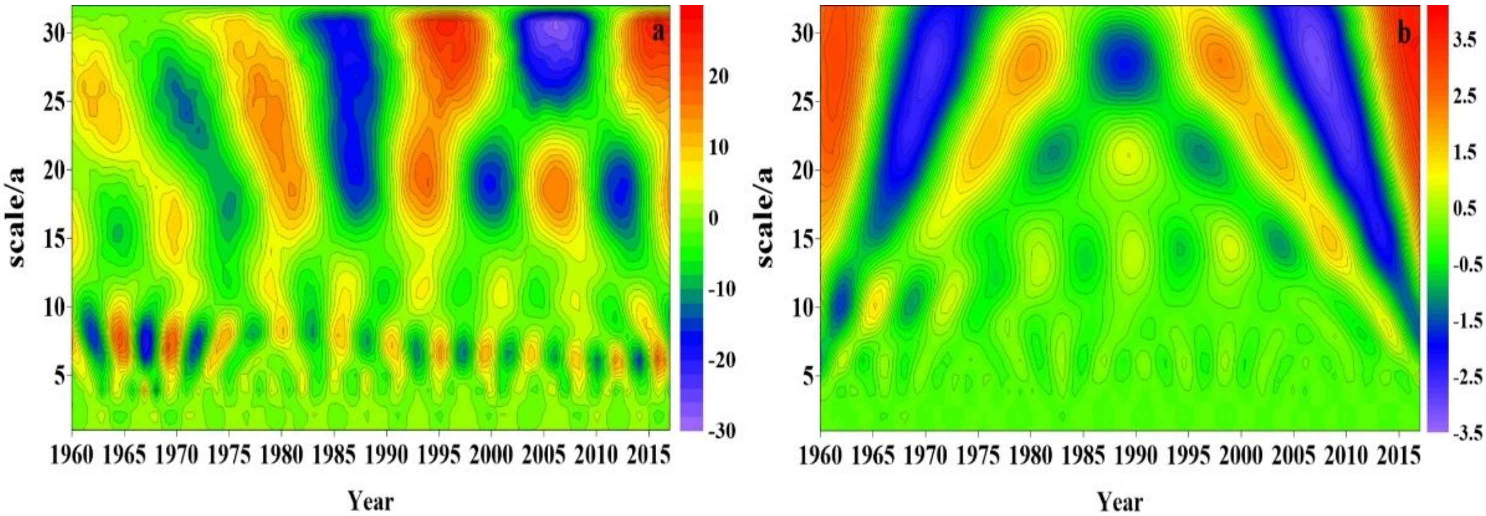

Figure 3

Contour map of wavelet coefficient of temperature and precipitation

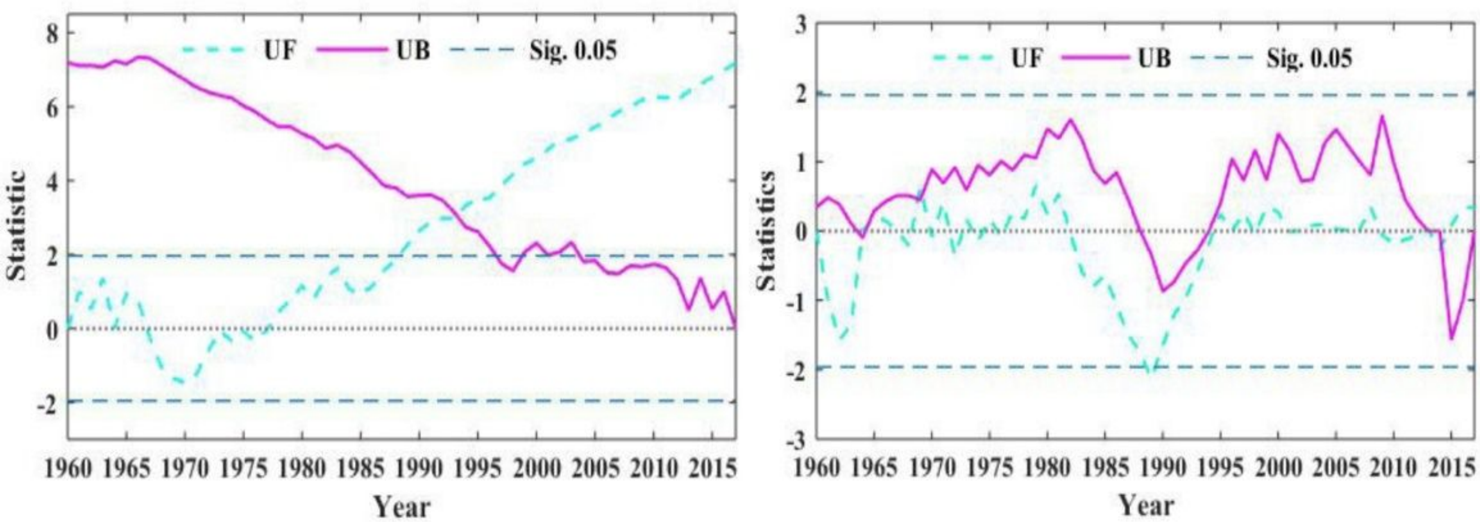

Figure 4

Manner-Kendall statistic curve of temperature and precipitation

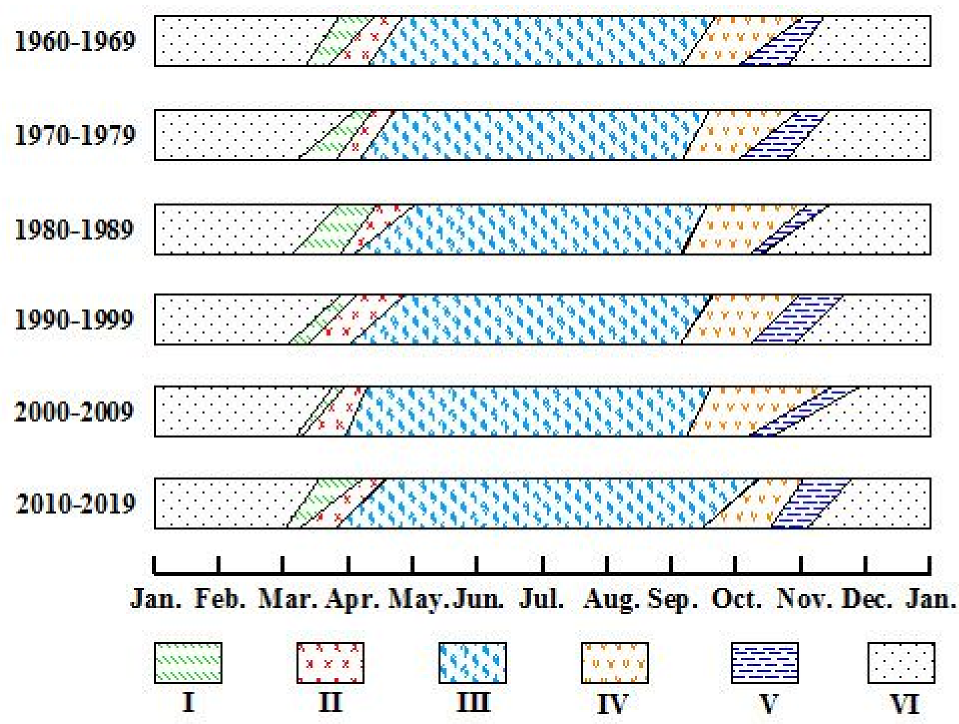

Figure 5

The changes of phenology of *P. euphratica* from 1960 to 2019 (-germination period, - flowering period, - leaf period, -leaf yellowing period, -leaf fall period, -dormancy period)

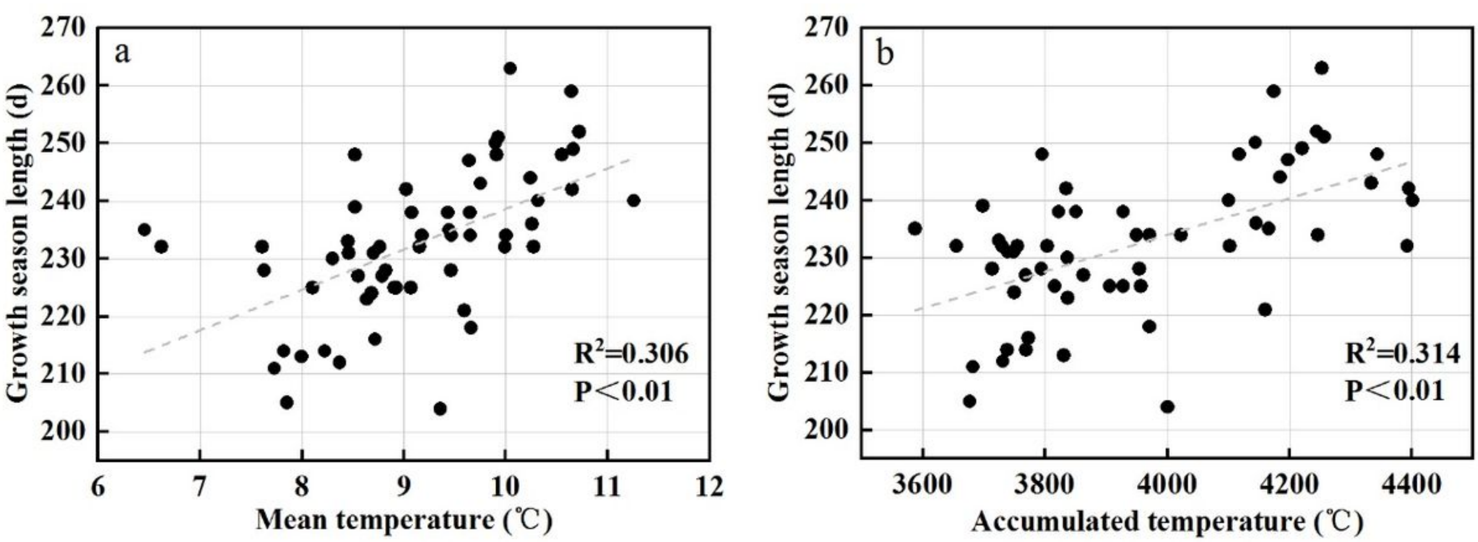

Figure 6

The relationship between growth season length and temperature

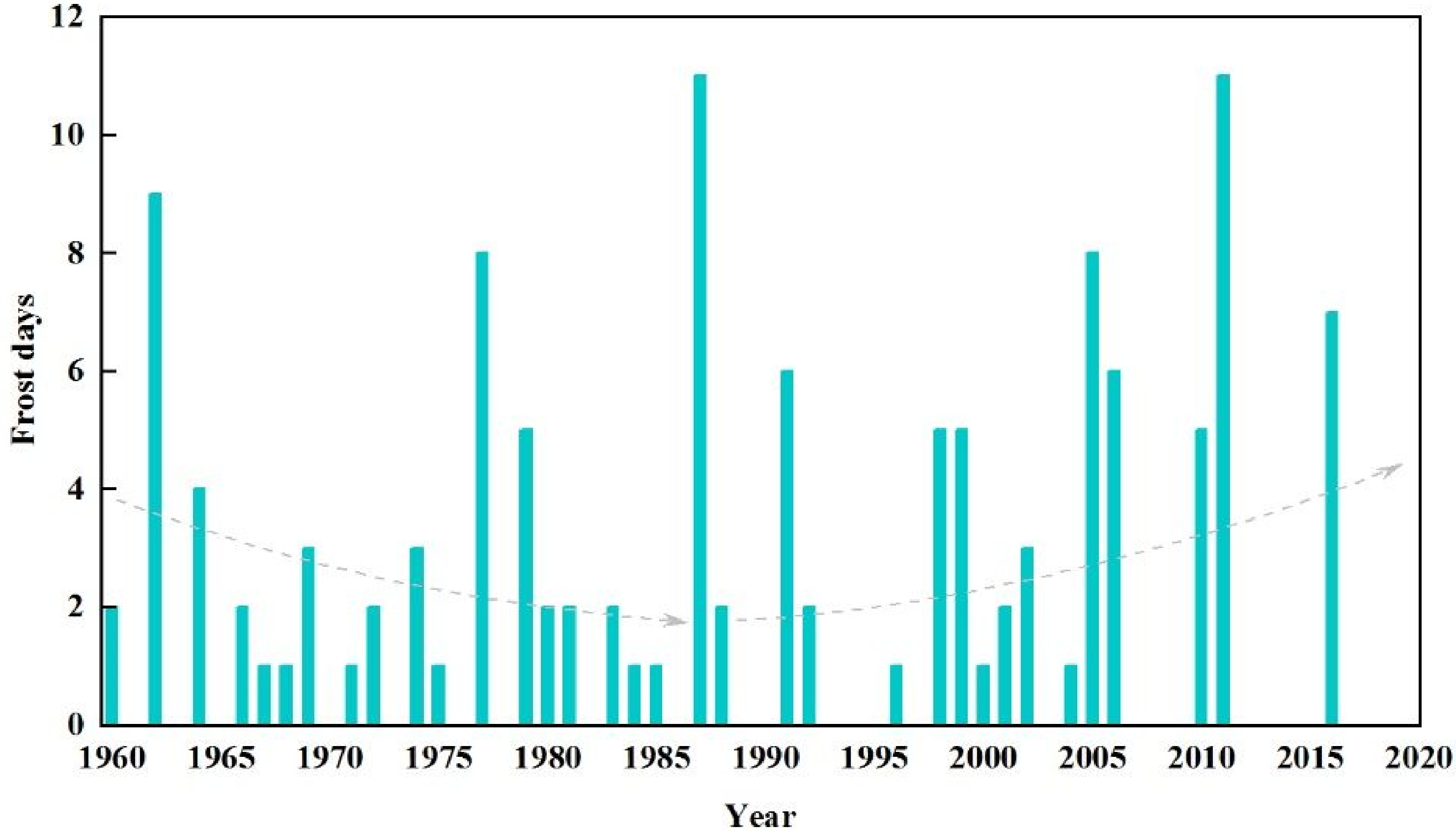

Figure 7

The frost days of *P. euphratica*

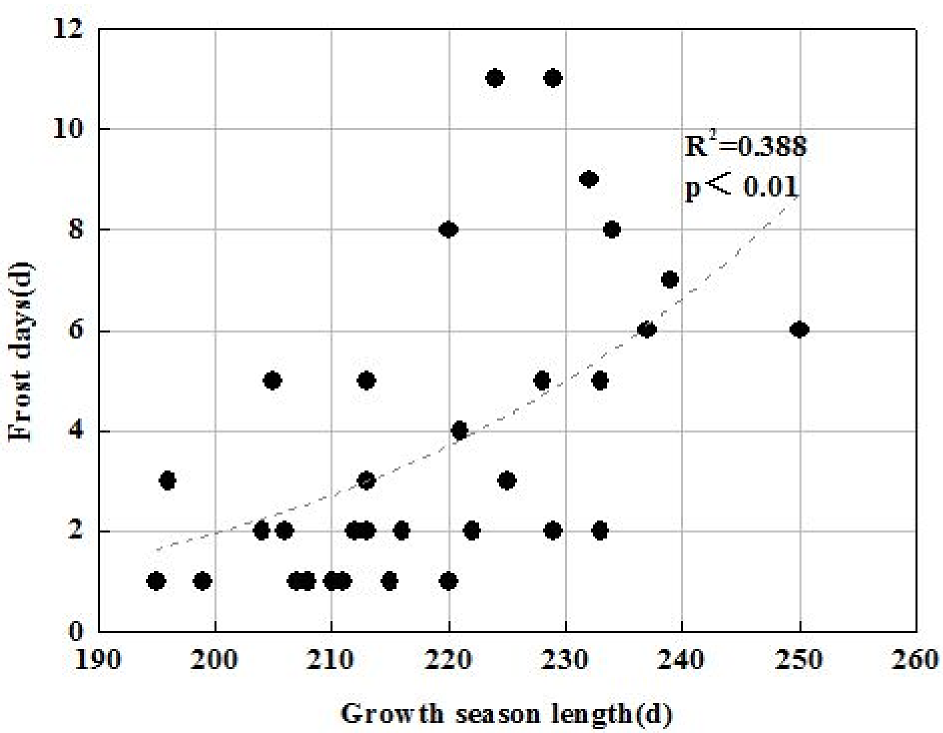

Figure 8

The relationship between growth season length and the frost days

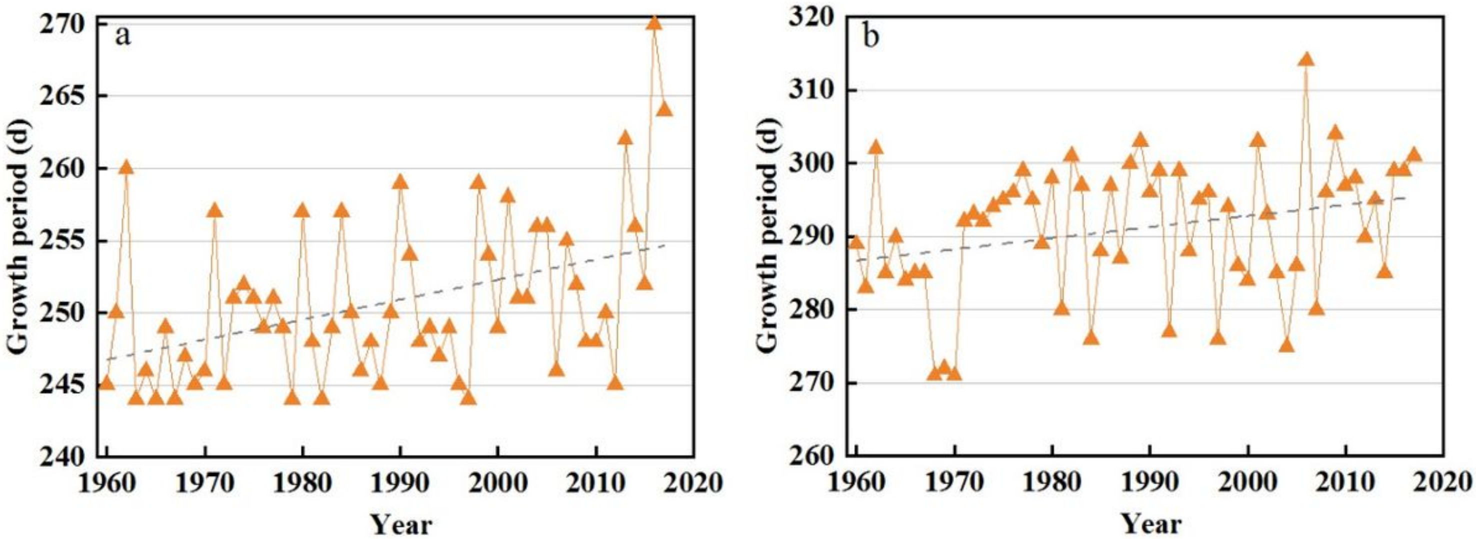

Figure 9

the phenology period of *P. euphratica* (a- the beginning of defoliation, b-the terminal stage of defoliation)

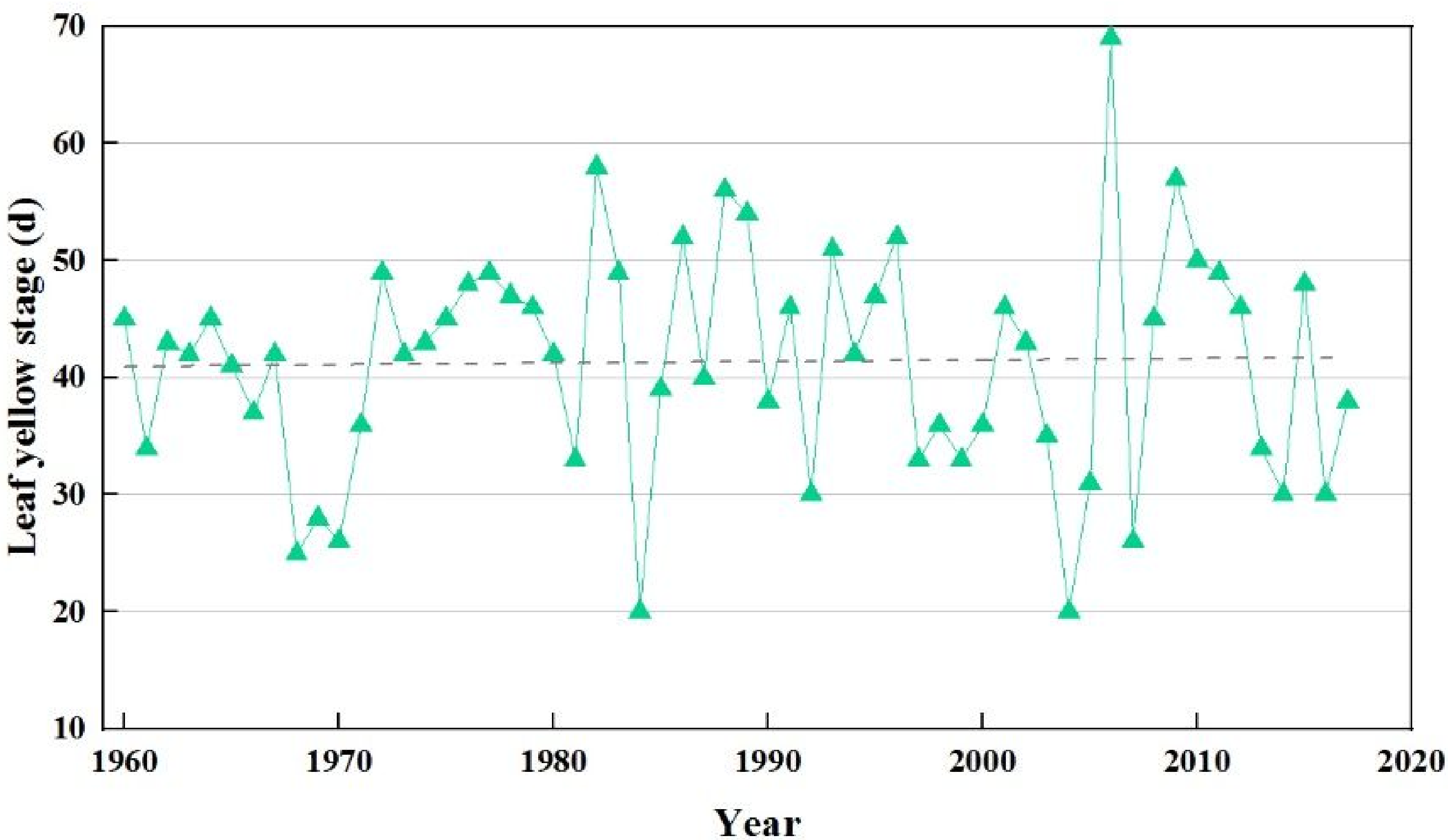

Figure 10

The length of leaf yellow stage in *P. euphratica*