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Dynamics of Canopy Tree of Riparian Forest, *Populus euphratica*, and Their Relationship with Environmental Conditions in Ejina Oasis, Inner Mongolia, China

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Abstract: In order to elucidate the ecological mechanisms sustaining the riparian forest under unreliable environmental conditions, replicate censuses were conducted to clarify the structure and dynamics of *Populus euphratica* forest in Ejina Oasis. Judging from the changes in stem length, the leaf biomass remained at the same level under different weather conditions. Dieback phenomenon is common in Ejina Oasis and spatial distribution of well growing and dieback canopy trees indicated some aspect of canopy dynamics with frequent dieback was not caused by the shortage of water supply but by the competition for water among canopy trees.

Key Words: Canopy tree, Ejina Oasis, Forest dynamics, *Populus euphratica*, Spatial distribution

1. Introduction

There are many kinds of ecosystems in dryland characterized by small biomass under a lack of water. Therefore, if sufficient amount of water is supplied, a highly productive ecosystem can be established even in dryland. Oasis is an unique habitat superabundant in water resource and can support diverse and a fertile ecosystem in it. As water in oasis is mainly supplied by river and/or groundwater coming from outside water reservoirs, the vegetation in oasis is vulnerable to irregular hydrological conditions, especially the amount of rainfall and its temporal distribution. Therefore, most of plants being able to grow in arid and semi-arid regions have high drought tolerance in physiological and/or ecological traits. However, some oasis species, such as *Populus euphratica* Oliv, are not markedly drought-tolerant and are able to persist only in riverine sites with high water availability.

P. euphratica is a famous deciduous arbor in *Salicaceae* as a riparian forest in arid and semi-arid regions between Morocco and Mongolia, and between 30 and 47 degrees northern latitude. Heihe River originated from Qilian Mountains and reached the west and east Juyanhai Lake has the second largest inland river basin in the arid region of Northwestern China. In the most lower reach of Heihe River (Ejina Oasis), large riparian *Populus euphratica* forests are established, which have an important role to support ecological conditions of Ejina Oasis. It is also the first barrier to sandstorms in the middle of Heihe River valley and Northwestern China (Xu *et al*., 2003). As the population along Heihe River basin had been increasing in recent decades, river water and groundwater coming from the mountains has been overused. Especially, as lots of reservoirs had been built in the middle reaches, the amount of water supply in Ejina Oasis decreased year by year, and even was cut off. As the environmental conditions had changed as above, most of the *P. euphratica* forest were damaged in Ejina Oasis and led to land desertification (Wang and Cheng, 1999; Qi and Luo, 2007; Zhao *et al*., 2004).

To protect and restore the *P. euphratica* forests in Ejina Oasis, Ecological Water Conveyance Project (EWCP) had been carried out since 2000 by the Chinese government. After the project, the groundwater and the vegetation have a favorable change in a small scale (Guo *et al*., 2009; Wang *et al*., 2011). But how *P. euphratica* forests maintain themselves in this unreliable condition is not clearly understood.

To promote protection and restoration of *P. euphratica* forests in Ejina Oasis, we undertook a study to examine the dynamics of forest structure and also determined the effects of site conditions on the spatial structure of these riparian stands at the canopy level.

2. Materials and Methods

2.1. Study area

Study area is an oasis in the lower reaches of Heihe River in the county of Ejina, Inner Mongolia Autonomous Region, China (39°52’-42°47’N, 97°10’-103°7’E) (**Fig. 1**). It is a typical hyper-arid desert with the mean annual precipitation of 42 mm and the mean annual potential evaporation of 3,755

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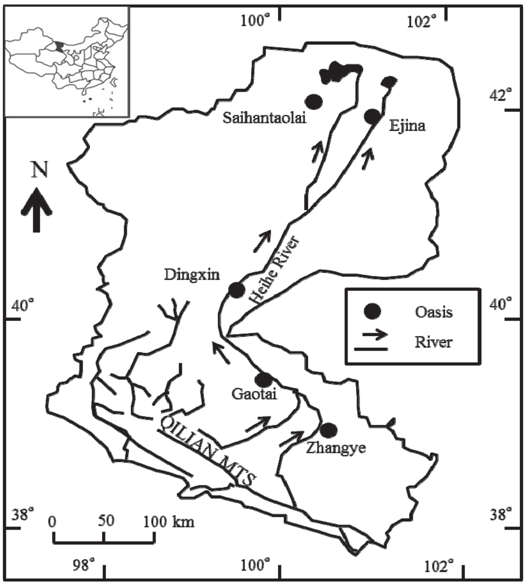

Fig. 1. Study area.

mm. More than 60% of the rainfall occurs during July to September. The basin elevation ranges from 898 m to 1598 m above sea level (Wen *et al*., 2005). Three types of groundwater (young groundwater, regional background water and groundwater in Gurinai) were found in this area by Qin *et al*. (2012).

2.2. Tree census

A permanent experimental plot with the size of 100 m × 100 m was established in the western part of Ejina Oasis in 2005. All trees were numbered and the location, height of dead and living top, and DBH and crown width, were measured every year from 2009 to 2012. Topography and soil EC were measured by mini compass and EC meter respectively in 2010.

2.3. Data analysis

Index of aggregation (I_a) was used to analyze spatial distribution pattern of canopy trees (contagious, random and uniform distribution, if I_a was greater than, equal to and smaller than unity) and spatial associations of trees and environmental conditions (ground level and soil EC) were analyzed by using index of local association (X) (negative, independent and positive association, if X was smaller than, equal to and greater than zero). Both indices were calculated by Spatial Analysis by Distance IndicEs (SADIE) (Perry, 1998; Perry and Dixon, 2002) and significant difference from unity and zero for I_a and X, respectively, was determined by $\alpha = 0.05$.

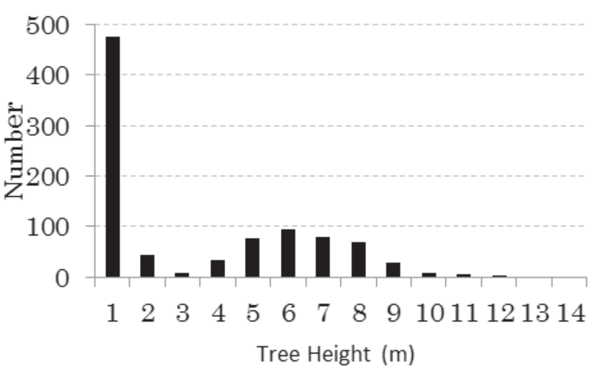

Fig. 2. Frequency distribution of tree height.

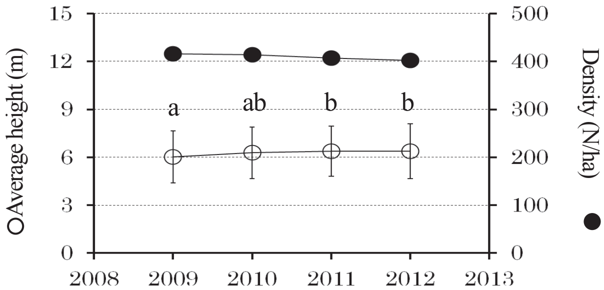

Fig. 3. Temporal changes in height and density of canopy trees. Height values are means ± SD. Different letters indicate the significantly differences (P<0.05).

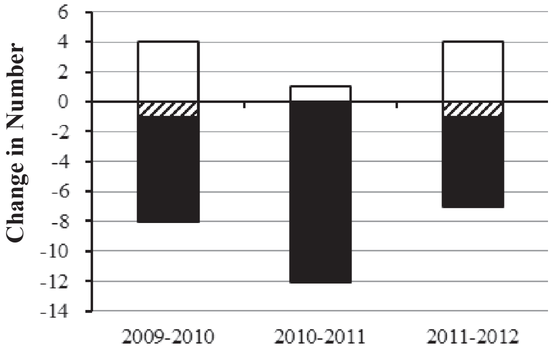

Fig. 4. Changes in number of canopy trees. □ : recruit to canopy; ▨: dieback; ■:dead.

3. Results

3.1. Tree height distribution

Frequency distribution of tree height in 2009 (**Fig. 2**) shows a bimodal distribution indicating two height groups classified at 2 m height, namely canopy trees and saplings.

3.2. Dynamics of canopy trees

The density of canopy trees showed a gradual decrease in the last four years (**Fig. 3**) because the number of dead trees was greater than that of recruit trees in every year (**Fig. 4**). Meanwhile the average height of canopy trees gradually increase in this period (Fig. 3) as the height in 2011 and 2012 were significantly higher than that in 2009.

Dieback phenomenon is common in our research area. **Figure 5** shows changes in stem length of well growing (open circle) and dieback (solid circle) canopy trees and the heights

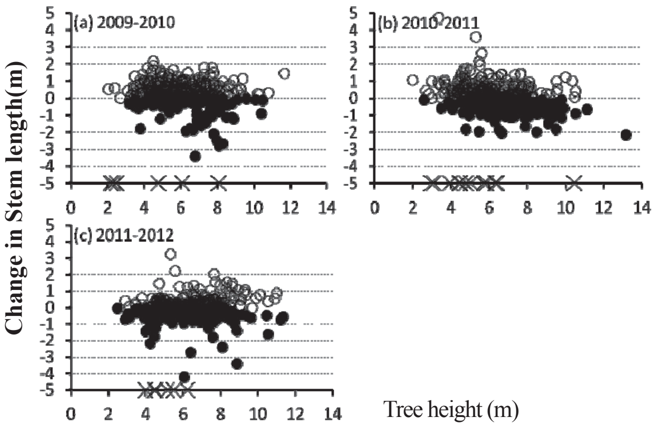

Fig. 5. Relationship between stem lengths and heights of canopy trees in 3 years. ○: well growing trees; ●: dieback trees; ×: dead trees.

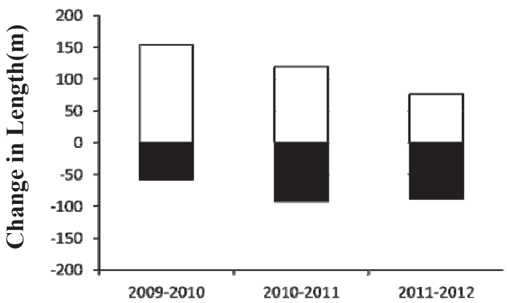

Fig. 6. Total growing length and dieback length of canopy trees. □: growth of stem; ■: dieback length.

of dead trees are shown on the abscissa axis with cross marks. As shown in this Figure 5, most of dead trees' heights were shorter than those of living trees, resulting in a gradual increase in average height of canopy trees as shown in Figure 3. No significant relationships were detected between tree height and both growth and dieback length.

Figure 6 shows the total growth length and dieback length of canopy trees. Although growth length was longer than dieback length in 2009 to 2010, the total growth length and dieback length were almost balanced from 2010 to 2012, and no were not related to weather conditions, namely 11.2 mm, 26.2 mm and 40.7 mm of annual precipitation from 2009 to 2012, respectively.

3.3. Spatial distribution

Although both well growing and dieback trees show significant contagious distribution of their spatial arrangement as shown in **Figure 7**, trees with dieback (Fig. 7**b**) had the higher degree of aggregation (I_a = 1.94), indicating spatial unevenness of site conditions under which dieback occurs. Heights of well growing trees increased gradually; these individuals became significantly taller than trees with dieback in 2012 (**Table 1**). Therefore, the taller trees grew well and

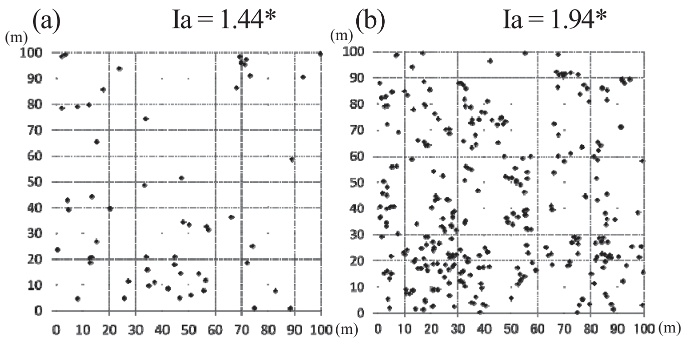

Fig. 7. Spatial distribution of well growing canopy trees; (a) Well growing trees for all census period, (b) Dieback trees.
*: significant for contagious distribution.

Table 1. Average height (m) of well growing trees and dieback trees.

	Well growing trees	Dieback trees
2009	6.15 ± 1.58 a	6.09 ± 1.58 a
2010	6.45 ± 1.52 a	6.32 ± 1.63 a
2011	6.66 ± 1.55 a	6.38 ± 1.52 a
2012	7.04 ± 1.72 a	6.42 ± 1.67 b

Height values are means ± SD. Different letters in the column indicate the significant differences (P<0.05).

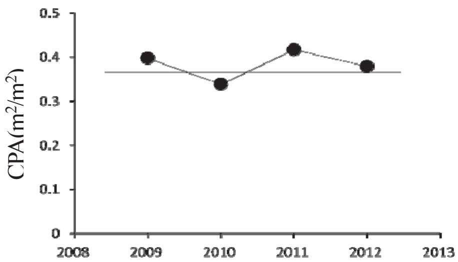

Fig. 8. Changes in canopy projection area (CPA) of canopy trees.

Table 2. Index of local association (X) among canopy tree of *P. euphratica*, soil salinity and ground undulation.

	EC	Topography
Topography	0.4663*	
Well growing trees	0.2581*	0.3685*
Dieback trees	0.1592	0.3461*

*: Significantly positive association, P<0.05.

increased in height, while smaller trees suffered some environmental stress, which resulted in dieback. Changes in total CPA (canopy projection area) of canopy trees are shown in **Figure 8** indicating almost sustainable canopy cover for four years.

To analyze the spatial association among canopy trees, soil salinity and ground undulation, index of local association (X) were calculated by SADIE (**Table 2**). Well growing trees were positively associated with increasing soil salinity and elevation, and dieback trees were positively associated with elevation. Thus, elevated ground promoted tree survival, and tree growth became well even under high soil salinity.

4. Discussion

Although the dieback phenomena is the effective response to drought stress, the total length of height growth in this forest balanced with the sum of dieback length from 2010 to 2012 irrespective of changes in weather conditions (Fig. 6). The stable canopy area (Fig. 8) with immediate replacement of dieback top canopy by equivalent stem growth (Fig. 6) suggests that the leaf biomass has remained almost at the same level in the study area.

If the water shortage is the main cause of dieback, high rate of dieback trees are expected in the area of high tree density. However, the degree of aggregation of dieback trees was higher than that of well growing trees indicating that some aspect of canopy dynamics with frequent dieback was not caused by the shortage of water supply but by the competition for some environmental factor(s) among canopy trees. As the average height of healthy trees was higher than that of dieback trees (Table 1), it seems that taller individuals likely had competitive advantages over smaller conspecifics.

On the other hand, high mortality of smaller trees (Fig. 5) without any remarkable increase in newly joined trees (Fig. 4) resulting in gradual increase in the average height (Fig. 3) suggests a gradual change in forest canopy structure from the matured forest with wide range of tree size to the over-matured forest with a small number of giant trees as reported by Monda *et al*. (2008).

Death of some small canopy trees and high proportion of dieback trees in bigger trees suggested the effects of soil water condition. Gries *et al*. (2003) suggested that *P. euphratica* can maintain a contact with stable groundwater by deep tap root and wide spread lateral root system. Thus, monitoring the changes in groundwater level is necessary for our further research.

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