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Characteristics and dynamics analysis of *Populus euphratica* populations in the middle reaches of Tarim River

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Abstract: *Populus euphratica* Oliv. is widely distributed along the Tarim River. Maintaining stability of *P. euphratica* population is important to local development. This study explored the static life table, survivorship curves and four function curves (survival rate, cumulative mortality rate, mortality density, and hazard rate), and development index of *P. euphratica* population in the middle reaches of Tarim River. The results indicated that the age structure of *P. euphratica* population belonged to positive pyramidal type, which meant young age-class individuals occupied most populations. The number of Ⅰ–Ⅱ age classes accounted for 66.2% of whole population, and this indicated that there were abundant subsequent seedlings resources to support the growth of *P. euphratica* population in the middle reaches of Tarim River. The survivorship curve of *P. euphratica* belonged to the Deevey Ⅲ (concave-type) and the development index was 47.72%. Four function curves revealed that the individuals of *P. euphratica* sharply decreased at the initial stage and then leveled off at the late stage of survival curve. Time sequence prediction models predicted that the number of midlife individuals would increase in future 10, 20, 30 years, and *P. euphratica* population grew steadily as a result of rich saplings.

Keywords: *Populus euphratica*; population; static life table; survivorship curve; survival analysis; development index; time sequence

1 Introduction

Population dynamics of plant species, especially those of long-lived species, could be considered as an indicator of vegetation succession as well as climate changes on treeline ecotone (Brubaker, 1986; Camarero and Gutie´rrez, 2004), and the research on the population dynamics is the core of population ecology (Jiang, 1992; Chapman and Reiss, 2001). As it is generally infeasible to trace the whole life history, from birth to death of a long-lived species, a static investigation on age structure of population was often accepted in population dynamic estimations (Stewart, 1986; Johnson and Fryer, 1989; Svensson and Jeglum, 2001). Age structure of population usually has a significant change in response to subtle changes of environmental conditions, and the research on age structure and dynamic of population make us not only know the current situation of population but also analyze foregone structure and interference state, and reflect the suitability between plants and environmental factors to some extent (Xie *et al.*, 1999). A few authors have recognized the importance of age structure in studies of vegetation dynamics (Huffman *et al.*, 1994; Tappeiner, 1999).

Populus euphratica Oliv. plays a very important role in maintaining delicate ecological balance along the Traim River (Wang, 1996). It is a dominant tree species and precious germplasm resources of Tarim River Basin. However, over-utilization of natural resources, especially water resources, in the last half century, has led to a drastic change in ecological process of Tarim River. Expanding farmland, overgrazing pasture and setting up hydrologic dams and reservoirs deeply impacted on local ecosystem, espe-

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cially the underground water level, which dropped down considerably. As a consequence, the natural vegetation is degraded in the lower reaches of Tarim River.

The importance of *P. euphratica* for ecosystem in the middle reaches of the Tarim River is well documented (Tian, 1959; Li, 1984; Liu, 1989). It is an important barrier for defending sandstorm and controlling desertification in local area. The study on *P. euphratica* population has been attracting the attentions of researchers from many countries for a long time; especially its geographic distribution and biological characteristics have been intensively investigated (Zhou, 1959; Huang, 1982; Chen, 1984; Xu, 2003; Ni, 2004). However, only a few studies have quantitatively examined the population dynamics and structure. In this paper, the population structure, quantitative dynamic, living status and future development trend of *P. euphratica* in the middle reaches of Tarim River were explored through analyzing static life table, population life table, survivorship curve, time sequence and development index. The objectives of this study is to evaluate the population development of *P. euphratica* in the middle reaches of Tarim River and provide a reference for making appropriate environmental management measures in this area.

2 Study area

This study was conducted in the middle reaches of Tarim River, located in the Bayingolin Mongol Autonomous Prefecture, Xinjiang, China. The study area has a typical climate of arid zone with yearly average temperature of 10.7°C. The temperature maximum is 43.6°C and minimum is –30.9°C. The annual precipitation varies from 17.4 mm to 42.8 mm while the annual potential evaporation reaches 2,500–3,000 mm. Wind speed can reach 70–140 km/h (Liu *et al*., 2007). The dominant plant species of the study area are *P. euphratica*, *Tamarix ramosissma* and *Calligonum mongolicunl*. Among herbaceous species, *Phragmites australis*, *Apocynum venetum*, *Glycyrrhiza*. *Alhagi sparsifolia* are predominant. So, the vegetation of the study area is composed of tree–shrub–grass zones. The groundwater table varies from 2 m to 4 m depth in the study area.

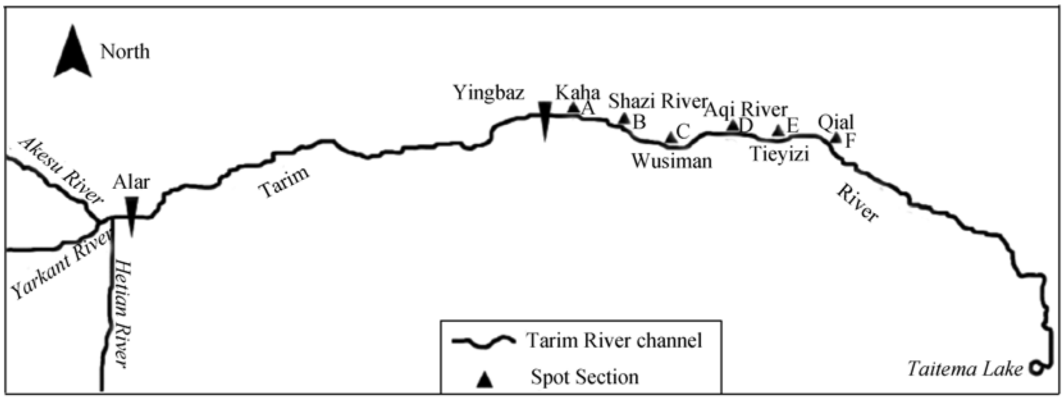

Fig. 1 The investigation sections in the middle reaches of Tarim River

3 Materials and methods

3.1 Field investigation

The field works were carried out from September 18 to November 2, 2007 along six transects, each of which was perpendicular to local water flow and start from the water channel and extend 400 m through both sides of the river bank. There were 8 to 12 plots along each transect and each plot was 25 m × 25 m. Within each plot, diameters at breast height (DBH) of each tree were measured. If DBH was less than 2.5 cm, the number of individuals was only recorded. Otherwise, the stem base diameter, coverage, height, crown diameter and number of individuals were measured and recorded for the tree with DBH greater than 2.5 cm.

3.2 Methods

3.2.1 Age structure

All trees were grouped into 10 age classes according to DBH (Han *et al*., 2007). The interval of every class was 4 cm diameter, and 0–4 cm of DBH trees were defined as saplings. Because the age of trees was highly correlated with the diameter, the class of DBH of each tree was able to be transformed to the age class (Frost and Rydin, 2000). The age structure was determined after knowing the number of tree in each age class. In this study, the population age structure was grouped into four categories, namely (1) Pyramid; (2) Inverted pyramid; (3) Nearly column; (4) Irregular shape (Li *et al*., 2000).

3.2.2 Static life table and survivorship curve

Static life table was constructed using the data of all individuals during a specific period of time. It didn't trace the whole life history of cohort, from birth to death but reflected a specific time among age dynamics course of multi-generation overlap (Harcombe, 1987). The analysis for life table structure was prerequisite for explaining the change of population (Armesto *et a1*., 1992; Wu *et al*., 2000; Hong *et al*., 2004). Moreover, a static life table was a very important tool to study population demographic and population dynamics (Skoglund and Verwij, 1989). Static life table are gained by Eqs. (1)–(7), where x is age class; a_x survival number; l_x standardized survival number; d_x death number; q_x standardized mortality rate, p_x standardized survival rate; L_x span life; T_x total life and e_x life expectancy.

$$l_x = a_x / a_0 \times 1000, \quad (1)$$
$$d_x = l_x - l_{x+1}, \quad (2)$$
$$q_x = d_x / l_x \times 100\%, \quad (3)$$
$$L_x = (l_x + l_{x+1})/2, \quad (4)$$
$$T_x = \sum l_x, \quad (5)$$
$$e_x = T_x / L_x, \quad (6)$$
$$p_x = 1 - q_x. \quad (7)$$

Survivorship curve was made for describing specific age mortality rate and it has three basic categories: upward concavity (Deevey Ⅰ), straight line (Deevey Ⅱ) and downward concavity (Deevey Ш) (Li and Yang, 2000). The categories are created through using survival number (l_x) as a horizontal coordinate and age class (x) as a vertical coordinate in this paper.

3.2.3 Development index

Development index was used for characterizing population dynamics (Chen, 2007). The number variations of individuals (V_{pi}) between adjacent age classes were analyzed.

$$V_n = (S_n - S_{n+1}) \times 100\% / \max(S_n, S_{n+1}), \quad (8)$$

$$V_{pi} = \frac{\sum_{n=1}^{k-1}(S_n \times V_n)}{\sum_{n=1}^{k-1} S_n}. \quad (9)$$

Where, V_n is changing of number from n to $n+1$ age class. V_{pi} is dynamic index, which is the changes of total population structure; S_n and S_{n+1} are the population of n and $n+1$ age class respectively. The value of V is less than 1, and more than −1. When V is positive, negative and zero between two adjacent age classes, it means the population increasing, recessionary and steady respectively. The external interferences are not taken into account when above equations are used. If external interference is considered, V_{pi} is related to the number of age classes (K) and number of individuals in age class (S_n). So, the Eq. 9 can be modified as:

$$V_{pi}' = \frac{\sum_{n=1}^{k-1}(S_n \times V_n)}{k \times \min(S_1, S_2, S_3 \ldots S_k) \times \sum_{n=1}^{k-1} S_n}. \quad (10)$$

3.2.4 Survival analysis

In order to analyze population structure and expound the law of survival of *P. euphratica* population, four functions are introduced for population survival analysis: survival rate function $S_{(t)}$, accumulative mortality rate function $F_{(t)}$, mortality density rate function $f_{(t)}$, hazard rate function $\lambda_{(t)}$, and the formula are listed as follows (Feng, 1983).

$$S_{(t)} = p_1 p_2 \ldots p_t, \quad (11)$$
$$F_{(t)} = 1 - S_{(t)}, \quad (12)$$
$$S_{(t)} = (S_{(t)} - S_{(t-1)}) / h_{(t)}, \quad (13)$$
$$\lambda_{(t)} = 2(1 - S_{(t)}) / h_{(t)} (1 + S_{(t)}), \quad (14)$$

where, p_t is survival rate and $h_{(t)}$ is age-class interval.

3.2.5 Time sequence model

Time sequence model was constructed for predicting population development trend in the future, and it is expressed as following equation (Xie, 1990):

$$M_t = \frac{1}{n} \sum_{k=t-n+1}^{t} X_K. \quad (15)$$

Where, n is the year that we used to forecast the future; M_t is the population size in the nth year; X_k is the population size at present time. Population development trend in future 10, 20 and 30 years are predicted.

4 Results

4.1 Age structure of *P. euphratica* population

Age structure of *P. euphratica* population showed a positive pyramidal type with wide base and narrow top (Fig. 2), indicating a progressive population. The populations of Ⅰ–Ⅱ and Ⅹ age class accounted for 66.2% and 4.0%, respectively, and this indicated that *P. euphratica* reproduced well and its population will grow stably in the middle reaches of the Tarim River.

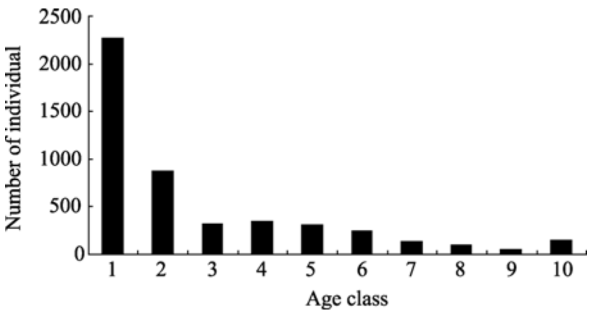

Fig. 2 Age structure of *P. euphratica* population in the middle reaches of the Tarim River

4.2 Static life table and surviorship curve

Although the proportion of saplings was up to 62.64% in the middle reaches of the Tarim River, the saplings mortality rate was high. The life expectancy reached the highest at the age class Ⅲ, then it began to level off. In spite of different mortality rate in each age, the number of survival individuals decreased gradually as plant grew, and the mortality rate became largest at age class I (Table 1). The survivorship curve belonged to the type of Deevey III, which also indicated that there was abundance of saplings. In addition, the slope of this curve was quite steep, which indicated that the survival number of *P. euphratica* decreased sharply as saplings grew during earlier stage (Fig. 3).

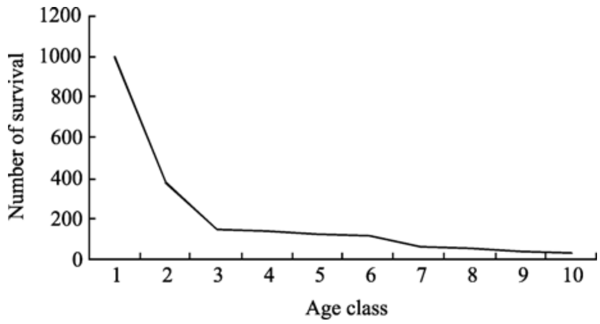

Fig. 3 The survivorship curve of *P. euphratica* population in the middle reaches of the Tarim River

4.3 Dynamic index

Although the values of development index (V) were negative at age classes of Ⅲ and Ⅸ, the value of V_{pi} was greater than 0, indicating that it was a progressive population. When external circumstance interference is considered, the value of $V_{pi'}$ was 0.11%, which is also greater than 0 and indicated a stable state of *P. euphratica* population (Table 2). This result agreed with the result from age class structure analysis.

4.4 Survival analysis

It was clear that the survival rate of *P. euphratica* decreased, meanwhile, the cumulative mortality rate increased. The amplitudes of decreasing in survival rate and increasing in cumulative mortality rate were

Table 1 The static life table of *P. euphratica* population in the middle reaches of the Tarim River

Age class	a_x	$a_{x'}$	l_x	d_x	q_x	L_x	T_x	p_x	e_x	Ln ($a_{x'}$)	Ln (l_x)
1	2,276	2,276	1,000	616	0.62	692	1,592	0.38	1.59	7.73	6.91
2	873	873	384	236	0.61	266	900	0.39	2.35	6.77	6.91
3	310	337	148	11	0.08	142	634	0.92	4.28	5.82	5.00
4	343	311	137	12	0.09	131	492	0.91	3.60	5.74	4.92
5	297	285	125	12	0.10	120	361	0.90	2.88	5.65	4.83
6	240	259	114	52	0.46	88	241	0.54	2.12	5.56	4.73
7	136	141	62	11	0.18	57	153	0.82	2.48	4.95	4.13
8	97	117	51	11	0.21	46	97	0.79	1.88	4.76	3.94
9	45	93	41	11	0.27	36	51	0.73	1.24	4.53	3.71
10	142	69	30			15	15		0.49	4.23	3.41

Table 2 Dynamic indices of *P. euphratica* in the middle reaches of the Tarim River

V_1	V_2	V_3	V_4	V_5	V_6 (%)	V_7	V_8	V_9	V_{pi}	$V_{pi'}$
61.64	64.49	–9.62	13.41	19.19	43.33	28.68	53.61	–68.31	47.72	0.11

greater in the earlier stage than those in the later stage. The variations of survival and accumulative rate curves were not significant for age class Ⅱ. Trends of mortality density rate were nearly consistent with hazard rate functions except for small fluctuation (Table 3).

Table 3 Estimated values of survival analysis function of *P. euphratica* in the middle reaches of the Tarim River

Age class	$S_{(t)}$	$F_{(t)}$	$F_{(t)}$	$\lambda_{(t)}$
1	0.384	0.616	0.059	0.153
2	0.148	0.852	0.003	0.019
3	0.137	0.863	0.003	0.022
4	0.125	0.875	0.003	0.024
5	0.113	0.887	0.013	0.114
6	0.061	0.939	0.003	0.044
7	0.050	0.950	0.003	0.053
8	0.040	0.960	0.003	0.067
9	0.029	0.971	0.007	0.250
10	0.000	1.000	0.000	0.000

4.5 Time sequence

The number of mid-age individuals will increase in next 10, 20 and 30 years (Fig. 4). This result was consistent with the result of static life table, which showed that *P. euphratica* population had rich saplings banks in the middle reaches of the Tarim River.

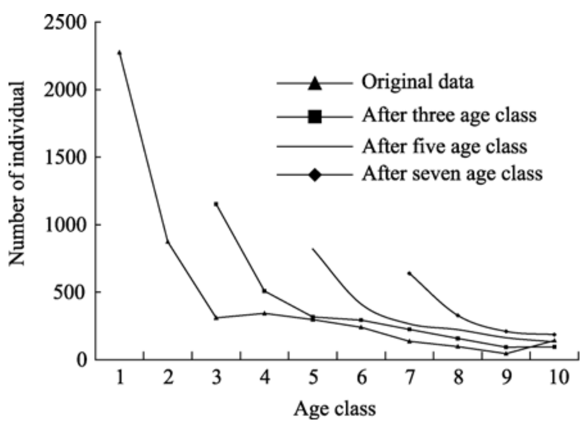

Fig. 4 Time sequence prediction of *P. euphratica* population in the middle reaches of the Tarim River

5 Discussion and conclusions

P. euphratica is one of the most dominant tree species in the riparian forest ecosystem, which develops along the inland rivers in arid areas. The population of *P. euphratica* is sensitive to its environment around and can be a reliable indicator to eco-environmental changes.

5.1 Characteristics of *P. euphratica* population

The static life table, survivorship curve and dynamic index of *P. euphratica* population in the middle reaches of Tarim River show that the number of Ⅰ–Ⅱ age class individuals is abundant and this implied the *P. euphratica* is progressive population. The survivorship curve belonges to the type of Deevey III, indicating that the saplings mortality rate was high in early stage and gradually stabilized later. $V_{pi'}$ is 0.11% (Table 2), which also reflectes that *P. euphratica* population is stable in the region. The time sequence prediction indicated that the number of mid-age individuals will increase in next 10, 20 and 30 years due to rich saplings bank (Fig. 4) and the population will develop steadily.

The middle reaches of the Tarim River is suitable for disseminating *P. euphratica* seed, seedling survival and population regeneration, especially for the area less than 100 m away from the main river course, where groundwater table is relatively shallow and flood water can frequently reach. There were many saplings here and population density was considerably large (2,169 individuals/hm^2). However, with the increase of plant density, the fecundity and survival of population decrease as a result of increasing competitive self-thinning effect, environmental filtering and allelopathy of plants (Chou, 1987; Dong, 1996; Ma, 1998, 2000). More than half of the saplings died because saplings were highly sensitive to environment at early stage (Table 1). Besides, livestock often enteres these areas and has an unfavorable impact on the growth of saplings.

5.2 Effect of Integrated Management of the Tarim River Basin on *P. euphratica* population

Tarim River was a meandering river, especially in the upper and middle reaches where large amount of overflow happened frequently. The program of Integrated Management of the Tarim River Basin was implemented in 2000. This program considerably changed meandering characteristics of Tarim River and nearly erased overflow events. Overflows, however, was beneficial to the seedlings establishment and germination of the *P. euphratica* population. Also, after overflow disappeared, salts accumulated in the top soil could not be leached and this has a negative impact on *P. euphratica*'s growth and seedling (Zhang and Yao, 2004; Li *et al*., 2008). The results from this study also demonstrated the effects mentioned above. Outside the embankment for confining flood, the root-sprouting was the main style of regeneration and the number of saplings individuals (younger than 4-year) was much less than the place within the embankment. Only 8 saplings individuals were found in some plots. Within the embankment area, the number of regeneration seedlings was much more than that of outside embankment area, and up to 148 saplings individuals existed in some plots. Here the saplings appeared through both seedling and root-sprouting. Therefore, there are still some questions on how to manage Tarim River water resource for effective use and to maintain a stable development of *P. euphratica* population in the middle reaches of Tarim River. At the same time, the effective use of the river course and water gates to control drainage could be also benefit for the growth of *P. euphratica*.

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