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STRUCTURE AND DYNAMIC OF *POPULUS EUPHRATICA* POPULATION ALONG TARIM RIVER

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Abstract

Populus euphratica Oliv. is a common tree species found along the Tarim River and is important for the development of the local economy. We did our study in the upper and lower reaches of the Tarim River during 2.5 months, from September to November. We used the static life table and survivor curve for our investigations, and population dynamics were predicted by time sequence model. According to our results, young individuals were dominant in the upper reaches of the *P.euphratica* population, with the survivor curve belonging to the Deevey C type category. The time sequence model demonstrated that the number of mid-aged individuals in the upper reaches of the river will increase in population over the next 20, 30, to 40 years, when there will be continuous development. In contrast, in the lower reaches, young individuals were rare, and mid-aged individuals comprised the largest proportion of the population. The time sequence model for this population demonstrated that the number of old individuals will increase and young individuals will decrease during the next 20, 30, to 40 years. The main cause of this difference between the upper and lower reaches of the Tarim River is connected mostly to the level of ground water, which played an important role in the determination of age structure. Therefore, the crucial factors for the natural regeneration and restoration of *P.euphratica* were the rising ground water level and improvement in their habitat.

Introduction

The plant population structure is the common result of the survivability of individuals and the impact of environmental conditions (Khan & Shaukat, 1997; Fuchsa *et al*., 2000; Svensson, 2001; Manuel & Molles, 2002), and may also provide important information on the past and present regeneration of species (Agren & Zackarisson, 1990; Chen, 1999). So, the population structure of plant species, especially long-lived ones could be considered as indicators of vegetation succession as well as climate changes along the tree lined ecotone (Begon & Mortimer, 1981; Brubaker, 1986; Johnson, 1989; Camarero & Gutiérrez, 2004). Describing the population structure is a well-known method for analyzing population dynamics. Age is one of the important elements to evaluate the structure of plant populations (Shaukat *et al*., 2012). Although a few authors have recognized the importance of age structure for such studies (Tappeiner, 1991; Huffman *et al*., 1994), the research on age structure is, in fact, the key to population ecology (Jiang, 1992; Chapman & Reiss, 2001). Moreover, the life table and survivorship curve are very important tools for the study of population structures and dynamics (Skoglund & Verwij, 1989), and can intuitively reveal the number in each age class of a population that will survive or die, as well as define the survival trend. The time sequence model, that effectively analyzes the changing processes in the future number of same age individuals, is also used to predict population dynamics.

Populus euphratica Oliv. is the dominant tree species and exclusive germplasm resource in the Tarim Basin, which is an example of an inland river ecosystem in an arid area. This ecosystem plays a very important role in maintaining the delicate ecological balance within the entire Tarim basin, and being especially sensitive to environmental factors; it is a reliable indicator of ecological changes (Wang *et al*., 1996). The importance of *P.euphratica* for the ecosystem is well known (Tian, 1959; Li, 1984; Liu, 1989). However, during the last five decades, intensive human exploitation of the natural resources of Tarim River, especially unsustainable agricultural development of the land and the use of water resources, have led to serious eco-environmental problems. As a consequence, the area of the *P. euphratica* population has been reduced considerably in the upper, and degraded in the lower reaches of the Tarim River. In spite of the fact that a number of researchers from different countries have devoted their investigations to *P.euphratica*, they mostly described the distribution and differentiation of biological characteristics of this species (Zhou, 1959; Huang, 1982; Chen, 1984; Xu *et al*., 2003; Ni & Niu, 2004; Nadja *et al*., 2005); quantitative data defining the structure and dynamics of *P.euphratica* population have been absent. This information is important for the managers of protected areas, who need to know the demographic mechanisms that are responsible for population ageing (Stewart, 1986; Sara *et al*., 2000). The exploration of the population structure, quantitative dynamics, living status and future developmental trends of *P.euphratica* population, through analysis of the age structure, static life table, and time sequence, are the main objectives of our study. Our results can provide useful information for the protection, restoration and further development of *P.euphratica* population along the Tarim River.

Materials and Methods

Study area: The Tarim river basin is situated in the southern Xinjiang Province, northwestern China. This basin covers an area of 1.04×10^6 km^2 and is bordered by the Tian-Shan Mountains in the north and the Kunlun Mountains in the south. The Tarim River stretches from the Aral Sea to Taitema Lake and runs for a total of 1321 km. The upper stream of the Tarim River occurs from the Aral to Yingbazha (495 km) and the lower reaches flow from the Qiala Water Reservoir to Taitema Lake (428 km) (Fig. 1).

Fig. 1. The location of Tarim River.

The upper reaches have a typical climate of an arid zone with a yearly average temperature of 9.8°C. The annual precipitation varies from 42 mm to 76 mm, while the annual potential evaporation rate reaches 1,900-2,800 mm. (Huang *et al*., 2007). Here, the dominant plant species are *P.euphratica* and *Tamarix spp*. Among herbaceous species, *Phragmites australis*, *Apocynum venetum*, *Glycyrrhiza uralensis*, and *Alhagi sparsifolia* are common. The lower reaches are situated in the area of a warm arid climate with a yearly average temperature of 10.8°C. Annual precipitation varies from 20-50mm, but the annual potential evaporation rate is as high as 2500-3000mm. Among trees, the dominant species is *P.euphratica*; among shrubs, *Tamarix spp*., *Lycium ruthenicum* and *Halimodendron halodendron* are often noted; and among herbaceous species, *Phragmites australis*, *Alhagi sparsifolia*, *Karelinia caspica* and *Glycyrrhiza inflata* are common (Liang & Liu, 1990; Liu & Dai, 1981).

Field sampling: Our field investigations were carried out along the upper and lower reaches of the Tarim River from September 18 to November 18, 2007. Six transects perpendicular to the main channel were laid with an interval of every 25-30km along the river. Each transect consisted of 8 sampling plots, each plot 25m × 25m in size and set at 100m intervals, starting from the riverbank. All individuals found inside of every sampling plot were recorded. We measured the stem base diameter, coverage, height, crown diameter and number of individuals, which were bigger than 2.5cm in diameter at breast height (DBH). If DBH of *P. euphratica* individuals were less than 2.5cm, only the number of trees was recorded.

Age structure: Population age structure analysis is one of the main methods to discover a population's living status and update strategy (Zhang, 1991). The tree age is closely correlated with a tree's DBH; therefore we estimated the age of each individual by the age-height relationships for seedlings or saplings and the age-DBH (diameter at breast height) relationships for big trees. In this paper, we classified every ten years in age as one class (e.g. trees at the age of 1-10 years were defined as the first age class, 11-20 years as the second age class, etc). We recorded the number of individuals of every age class for determining the age structure of the population. Taking the age class as the *x*-axis and the percentage of trees as the *y*-axis, we built the age structure graph (Crawley, 1986; Jiang, 1992). Four categories of population age structures are generally well known: (1) Pyramid; (2) Inverted pyramid; (3) Nearly column; and (4) Irregular shape (Li *et al*., 2000).

Static life table and survivorship curve: There are two kinds of life table forms, an age life table and a particular time life table, which we used for the population dynamic estimation. Using life tables is a widely used practice, since it is not feasible to trace the whole life history, from birth to death, of long-lived species (Jiang, 1992; Yang *et al*., 1991). So, in this paper, the static life table was constructed according to age structure data of the *P.euphratica* population (Armesto et a1., 1992; Wu *et al*., 2000; Hong *et al*., 2004).

We also used the survivorship curve for describing the specific age mortality rate. This curve has three basic categories: upward concavity (Deevey A), straight line (Deevey B) and downward concavity (Deevey C) (Li *et al*., 2000). The categories for this paper were created by using the survival number of standardization (l_x) as a horizontal coordinate and the age class (x) as a vertical coordinate (Han *et al*., 2007).

Time sequence model: We used the time sequence model for predicting population development trends for the future, and made calculations based on the following formula:

$$M_t = M_{t-1} + \frac{X_t - X_{(t-n)}}{n}$$

where, M_t is the average value in t moment of n observations; in this study we took the number of individuals in every age class as the n value and M_t was calculated for populations in 20, 30, and 40 years (Xie, 1999).

Results

Age structure: The age structure of *P.euphratica* populations was quite different in the upper and lower reaches of our study. In the upper river area, the age structure of the *P.euphratica* population had a positive pyramidal type with a wide base and narrow top (Fig. 2). The number in age class 1 accounted for over 83% of the population, while old individuals were rare and individuals over 60 years were not found at all. In contrast, in the lower reaches of the Tarim River, we found a bell-shaped age structure with only a few young and old trees but a lot of mid-aged individuals. Young individuals were rare and only 19.88% of individuals, with weak growth, were less than 10 years old.

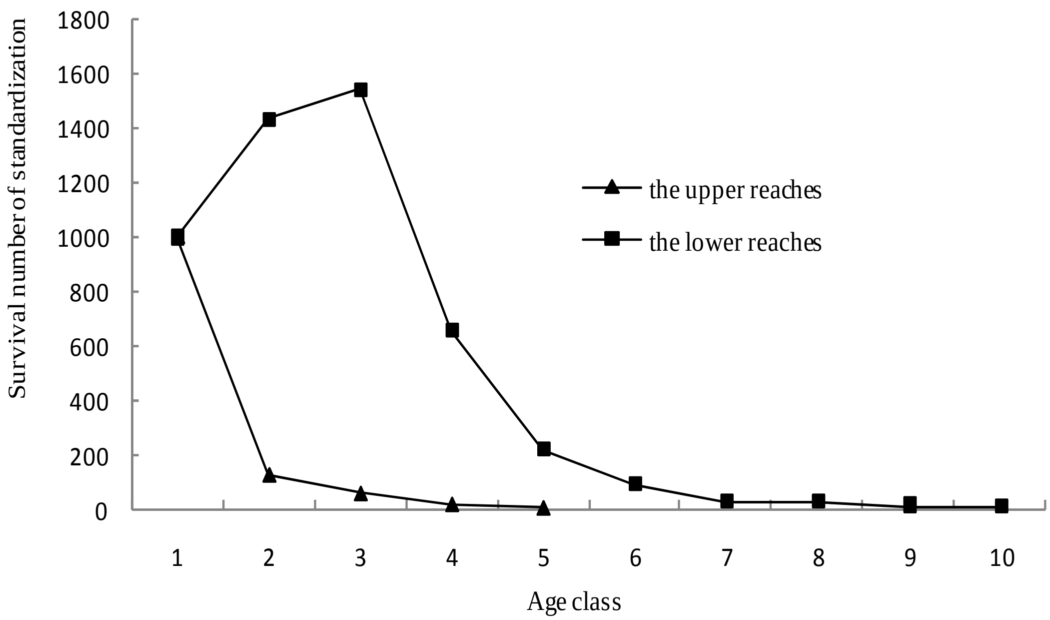

Fig. 2. Age structure of the *P. euphratica* population in upper and lower reaches of Tarim River.

Static life table and survivorship curve: We calculated the survival number of standardization (l_x), number of deaths (d_x), longevity (T_x), expected longevity (e_x), and periodical longevity (L_x), for every age class to determine *P.euphratica* population's static life table of both the upper and lower reaches of the Tarim River (Table 1). As we can see in this table, the oldest trees of the *P.euphratica* population in the upper stretch of the river were 50 years. The sapling mortality rate was high there, though the proportion of living saplings reached 83.12%. Life expectancy was maximized for age class 3, and then began to decrease. In spite of a different mortality rate for each age class, we found a tendency for the number of surviving individuals to gradually decrease with an increase in plant age. The mortality rate was highest for the first age class (Table 1). The survivorship curve belonged to category type Deevey C, but the slope of this curve was quite steep, which meant that the survival level of *P.euphratica* population dropped sharply and the death rate was highest at the beginning of the growth period. When the age of the individual was above 10 years, the declining range of survival started to diminish (Fig. 3). In contrast, there were only a few young individuals and a lot of mid-aged individuals in the lower stretch of the Tarim River. The proportion of young individuals was low here, and the rarity of young trees was typical for an inferior regeneration type of population.

Table 1. Static life table of *P.euphratica* population in the upper and lower reaches of Tarim River.

	Age class	**a_x**	**l_x**	**d_x**	**q_x**	**L_x**	**T_x**	**e_x**	**ln_{ax}**	**ln_{lx}**
the upper reaches	1	4416	1000	875	0.88	563	703	0.70	8.39	6.91
	2	552	125	68	0.54	91	141	1.12	6.31	4.83
	3	253	57	40	0.70	37	50	0.87	5.53	4.04
	4	75	17	13	0.76	11	13	0.74	4.32	2.83
	5	17	4	4	1.00	2	2	0.50	2.83	1.39
the lower reaches	1	405	1000	-432	0.00	1216	4530	4.53	6.00	6.91
	2	580	1432	-111	0.00	1488	3314	2.31	6.36	7.27
	3	625	1543	886	0.57	1100	1826	1.18	6.44	7.34
	4	266	657	435	0.66	440	726	1.11	5.58	6.49
	5	90	222	128	0.58	158	287	1.29	4.50	5.40
	6	38	94	69	0.73	60	129	1.37	3.64	4.54
	7	10	25	-5	0.00	28	69	2.76	2.30	3.22
	8	12	30	15	0.50	23	42	1.38	2.48	3.40
	9	6	15	4	0.27	13	19	1.27	1.79	2.71
	10	5	11	11	1.00	6	6	0.55	1.61	2.40

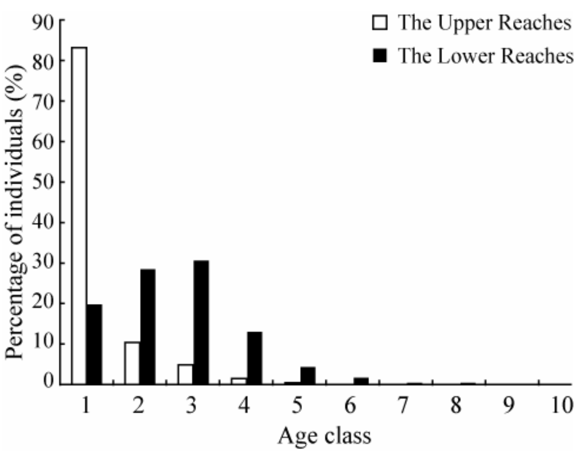

Fig. 3. The survivorship curve of *P. euphratica* population in the upper and lower reaches of Tarim River.

Time sequence: Based on the number of trees in each age class of the *P.euphratica* population in the different regions of Tarim River, we calculated the number of surviving individuals for each age class for the next 20, 30, and 40 years (Fig. 4). According to our data, the number of mid-aged individuals will increase over the next 20, 30 and 40 years in the upper reaches (Fig. 4). This result coincided with the data of the static life table, which demonstrated that *P.euphratica* population has a rich sapling bank for maintaining steady development in the upper areas of Tarim River. In contrast, the number of individuals in the lower reaches continues to decline in mid-aged classes. Our data showed that the number of trees in the young-aged classes was not sufficient for maintaining long-term stable development and will lead to the destruction of the population in this area of the river if special measures against these processes are not undertaken.

Discussion

On the basis of our data analysis, life table, time sequence and age structure we found that the *P.euphratica* population dynamic had a big differences between the upper and lower reaches of the Tarim River. This difference was the result of impacts from different biological factors, ecological characteristics and habitat peculiarities. Among them, the groundwater table was the key factor for the quality of the ecological conditions (Ye *et al*., 2009).

In the upper reaches, the groundwater table is relatively close to the surface and the floodwaters frequently reach this area. In addition, the floods occur often during the time of *P.euphratica*'s seed dissemination. So, the upper area of Tarim River is suitable for disseminating *P.euphratica*'s seeds, for survival of seedlings and for population regeneration, especially in the area within 100 m of the main river. There were many saplings in this region, with a large population density of up to 83%, indicating that the population will develop continuously here. The survivorship curve in the upper river belonged to the Deevey C category type, which signifies a high rate of sapling mortality during the early stages of growth, but only the mortality level gradually stabilized later in the growth cycle (Table 1). A high rate of sapling mortality is a consequence of a too high plant density and an increase in competitive self-thinning, environmental filtering, and the allelopathy phenomenon of plants, resulting in decreasing fecundity and the survival rate of individuals (Chou, 1987; Ma, 1998; Ma & Dong, 1996; Liao, 2000). The time sequence model indicated the same conclusion for the upper reaches: the population has a stable continuous development due to a rich sapling bank (Fig. 2).

In contrast to *P.euphratica* population in the upper river area, the lower river population had the opposite situation, where we found only a few young individuals and a lot of older individuals, and the age structure demonstrated the lack of young seedlings. The time sequence model of *P.euphratica* population indicated that the number of old individuals initially would increase, but gradually drop later. Additionally, the lack of young trees for restoration of the population was the distinctive characteristic of the lower reaches population. The main reason for this situation was the high degree of agricultural development and an irresponsible use of water resources in the upper and middle stretches of Tarim River (Song *et al*., 2000; Feng *et al*., 2005). This, in turn, caused a decrease in the level of the groundwater table (up to a depth of 8-12 m) and severe damage to the riparian forest, where *P. euphratica* was dominant (Song *et al*., 2000). Since 2000, a project to create eight water diversions has been implemented, from the upper reaches of the Tarim River and the neighboring Kaidu-Kongque River, for the protection and restoration of natural vegetation (Zhang & Yao, 2004). As a result, the ecological degradation in the lower reaches of the river has been slowed down to some extent. However, our data demonstrates that these measures are not enough. The present method of an impulsive linear water diversion along the riverbed cannot radically change the local eco-environment. Only a sustainable water utilization and ecosystem protection scheme is effective for the restoration of the degraded ecosystem.

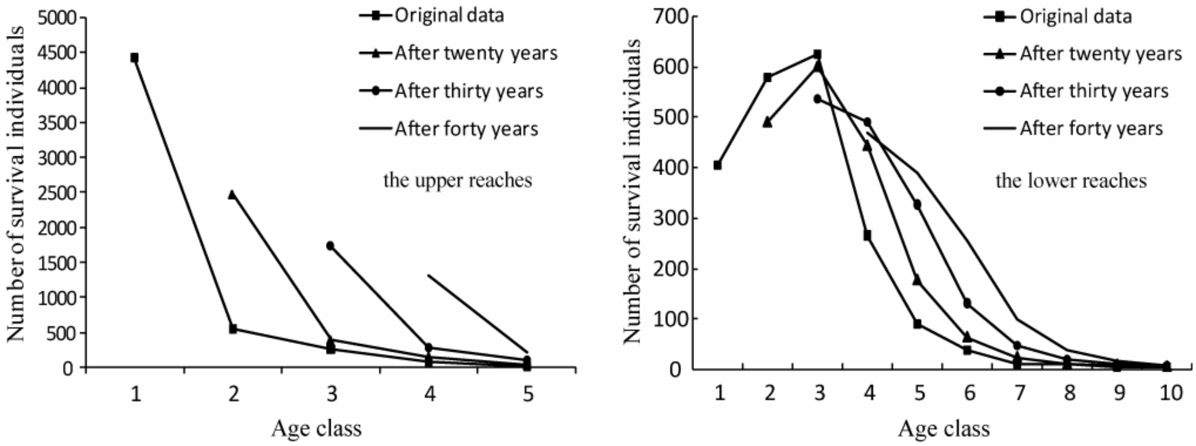

Fig. 4. Time sequence prediction of *P.euphratica* population in the upper and lower reaches of Tarim River.

From the analysis above, optimal environmental conditions could enable a well-developed population, and limiting ecological factors will result in poor growth of plant individuals, as well as problems in the regeneration process of the local population. Earlier studies have also stressed that the native vegetation in arid and semi-arid areas is closely dependent on the groundwater table, which is supported by adjacent streams (Groeneveld & Griepentrog, 1985; Michael *et al*., 1999; Jenifer *et al*., 2004; Richard & Mark, 2004). So the natural restoration of the *P. euphratica* population in the upper reaches of Tarim River is very strong, putting the population into the progressive category on the survivorship curve. But, the area of the *P.euphratica* forest that depends on the groundwater level has had great degradation at present due to the extensive agricultural development in the region (Feng *et al*., 2005): many individuals of *P.euphratica* were felled in the study area, and local livestock often enter these regions, which has an unfavorable impact on the growth of saplings.

Thus, we think that strictly controlled human exploitation of the natural resources and scientifically based management of the *P.euphratica* population in the upper reaches, would be enough to maintain the steady development of virgin forest, with its important ecological functions, in the upper end of the Tarim River. In contrast, the population in the lower river needs additional effective actions for the restoration of the severely degraded ecosystem, specifically the implementation of artificial floods and sustainable use of water resources.

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