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Static life table and growth analysis of seedlings of Juglans mandshurica in Xinjiang, China

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Keywords: *Juglans mandshurica;* seedlings population; static life table; growth model; altitudinal gradient

Abstract

On the basis of field study, a non-destructive method for the determination of seedling age was proposed. Using this method, the static life table of seedlings of *Juglans mandshurica* in Xinjiang Wild Walnut Nature Reserve, China, was compiled. The life expectancy, age structure, survival curve, mortality curve and plant height characteristics of the seedlings growing in the habitats of different altitudes were analyzed. The growth model was established to analyze the relationship between seedling age and plant height. The result indicated that there were fluctuations in the life expectancy of the seedlings at the same age but different altitudes as well as those at the same altitude but different ages. The seedlings at the age of 1 a accounted for the maximum ratios at three altitudinal gradients, i.e. 39.6%, 43.9% and 46.0% at the gradients H1, H2 and H3, respectively. The ratios of 1~3 a seedlings had absolute advantage, being 89.8%, 93.1% and 93.8% at the gradients H1, H2 and H3, respectively. These seedling populations all showed an expanding age structure. The survival curves were closer to Deevey II type. The mortality of 3 a seedlings was the highest, being 77.9%, 82.1% and 84.4% at the gradients H1, H2 and H3, respectively. For the 1

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a seedlings, only 10.4% could live to 4 a and 1.9% could survive to 7 a. The seedlings of *J. mandshurica* could be considered as r-strategists in their lives. The relationship between seedling age and plant height at three altitudinal gradients can be quantitatively described by exponential function. The increasing rates of seedling height were similar.

1. Introduction

Establishment and growth of plant seedling is an important stage in the process of succession, update or vegetation recovery of plant communities (Zhou et al. 1997; Bai et al. 2012). The number of seedlings of different ages reflects population dynamics and the future development trend (Zhang et al. 2008). Seedling stage is a period which is very sensitive to the environmental condition in a plant‘s life history (Yoshiko and Kudo 2003), and also a period with the greatest change in individual number (Fenner 2000; Clerk et al. 2004). It is a bottleneck affecting the population regeneration (Grubb 1977; Sancher-Coromado et al. 2007). Population dynamics is the core content of evolutionary biology and population ecology (Girod et al. 2011; Coles et al. 2012). Life table of population can provide not only the important parameters of population such as survival rate and mortality in each age class (Begon and Mortimer 1981), but also information on population dynamics such as age structure (Harper 1977; Stewart 1990). While the changes of growth rhythm are triggered by the physiological function of a plant, they are also influenced by the environment. The difference in environmental factors (especially the temperature) due to altitudinal changes will cause changes in seedling growth rate, which will ultimately affect seedling competition, establishment and regeneration.

Juglans mandshurica Dode (Xinjiang, China), classified into *Juglans* genus, *JUGLANDACEAE,* is the relict broad-leaved tree species of the Tertiary Period in Central Asia, and also the north immigrant species in Pleistocene, which is included in the Grade II Endangered Species of China (National Environmental Protection Agency & Institute of Botany, 1987). In the West Tianshan and Pamir-Alai Mountain of the territory of the former Soviet Union, there is a large distribution of natural *J. mandshurica*. In Asia, the large community only exits in the Wild Walnut Ditch of Yili River Valley in Xinjiang, China (Zhang 1973). As the direct ancestor of walnut cultivar (Zhang 1973), *J. mandshurica* has important values in walnut breeding and in revealing the origin and evolution of cultivating walnut (Wang et al. 1997). Xinjiang wild fruit forest of China is formed in the general background of arid desert climate and the particular geologic setting, in combination with warm and humid conditions in local areas. *J. mandshurica* of Xinjiang is distributed in broad and thick and intensively-eroded outer-hills, mountain valleys and canyons (Zhang 1973). The soil in its habitat is mainly the Quaternary loess, with the thickness of 10-30 m (Xu 1989). Apart from the above studies, the present study on *J. mandshurica* also involves phytocoenology (Zhang

1973), forestry characteristics (Wang et al. 1997), resource status (Dong et al. 2012), germplasm resource classification (Wang et al. 1998), phenotypic variation of seed (Zhang et al. 2013), growth of compound leaf and biomass allocation (Zhang et al. 2011; Zhang et al. 2012).

Several studies did with physiology and ecology of different plant seedlings, e.g. age structure and height structure of the seedlings of Cryptocarya concinna (Zhou et al. 1997), dynamic life table and survival analysis of the seedlings of *Quercus liaotungensis* (Guo et al. 2011), and the effect of seed size on the growth of the seedlings of *Caragana microphylla* (He et al. 2008). Wang et al. (2010) reported about the effect of light environment on the growth and photosynthesis of the seedlings of J. Mandshurica. The written of this paper focuses on the growth rhythm of the seedlings of *J. mandshurica*. Using the non-destructive age determination method for the seedlings of *J. mandshurica*. We compile static life table of the seedling population of *J. mandshurica* along altitudinal gradients and analyze its growth characteristics, to reveal the population dynamics and individual growth rhythm of the seedlings.

2. Overview of the Study Area

The Wild Walnut Nature Reserve with a total area of 1180 hm² is located in the valley before Kaitemingshan Mountain in Gongliu County of Yili River Valley of Xinjiang, China (82°15'28"~82°17'23"E, 43°22'56"~43°25'40"N). The Reserve is divided into main ditch, east ditch, median ditch and West ditch (Dong et al. 2012). Each ditch extends from north to south, with the altitude gradually increasing and the slope of 30° - 50°. It is rainy in spring and summer and snowy in winter (snow cover of 0.7-1.0 m). The annual average temperature is 7.6 °C, and the average temperatures in January and July are -3.3 °C and 19.7 °C, respectively. The extreme minimum temperatures is -25.3 °C, and ≥10 °C accumulated temperature is 1865.4 °C-2338.9 °C. The average annual precipitation is 580 mm, annual average evaporation 1200 mm, relative humidity 70%-80%, and frost-free period 150 days (Xu and Zhu 1991). Temperature inversion is obvious in the distribution region of *J. mandshurica*. The radiosonde observation by Yili Meteorological Observatory from 1965 to 1969 shows that the inversion intensity in January was 9.5 °C, with the maximum of 22.6 °C; the average thickness of inversion layer in January was 950 m, with the maximum of 2077 m (Xu & Zhu, 1991). The area of existing *J. mandshurica* showing concentrating distribution is about 45 hm², totaling more than 5500 adults with the diameter at breast height (DBH) ≥ 2 cm (Dong et al. 2012; Zhang et al. 2013). They are mainly distributed in the valleys and hillside at the altitude of 1250-1550 m. *J. mandshurica* is dominant species in the Reserve, mainly accompanied by the trees such as *Malus sieversii, Armeniaca vulgaris, Betula tianschanica*, and *Populus tremula*. The auxiliary shrubs mainly include *Spiraea hypericifolia, Lonicera altmannii, Rosa davurica, Berberis heteropoda*, and *Crataegus altaica*. The auxiliary herbaceous plants are mainly *Bromus benekeni, Impatiens brachycentra, Aegopodium alpestre, Brachypodium sylvaticum, Urtica fissa* and *Commelina diffusa*.

3. Study Method

3.1 Field Investigation

From May to September in 2012, belt transects were arranged in the main ditch, east ditch, median ditch and west ditch of the main living region of *J. mandshurica* in the Xinjiang Wild Walnut Nature Reserve, with the width of 20 m and the length of 40-360 m. The length was set from the bottom of valley to the upper boundary of the distribution region. Five belt transects were set in each sunny and shady slopes of the main ditch and the median ditch, and 6 belt transects in each sunny and shady slopes of the east ditch and the west ditch. Quadrats of 20 m×20 m were set in each belt transect, and a total of 149 quadrats were set. Each quadrat was divided into 16 sub-quadrats of 5 m×5 m (2384 sub-quadrats in total). The seedlings of *J. mandshurica* in each sub-quadrat were investigated one by one. The altitude, height, age and number of seedlings were all recorded. At the same time, the quadrats of 20 m x 20 m for other arbors, of 5 m x 5 m for shrubs, and of 1 m x 1 m for herb layer were set in the every valley, and 20 quadrats were randomly sampled for each kind of plants. The species, density, coverage of plants were investigated. and the entire valley habitat conditions were recorded. According to the field survey statistics, there were distinct differences between the tree height, diameter at breast height, density and canopy density of *J. mandshurica* at the altitude of 1380 m and 1490 m. Therefore, according to altitudinal gradient three habitats: 1240-1360 m (H1), 1380-1490 m (H2) and 1520-1670 m (H3), were divided for data grouping and statistics.

3.2 Determination of Seedling Age of J. Mandshurica

Based on the long-term field observation by our research group, there are few branches in the seedlings of *J. mandshurica* under 7 years old. The non-lignified parts on the top cannot overwinter, and new branches will grow from the newly-lignified leaf bud in the next year. As a result, a visible knot will be formed after each year growth. Therefore, the seedling age can be determined by counting the knots. This non-destructive investigation method can accurately determine the 1~7 a seedlings of *J. mandshurica*. For the plant above 7 years old, the knot gradually blurred or disappeared.

3.3 Compilation of Static Life Table

The static life table is based on the sampling and analysis of the age distribution of the population at a given time, and it can represent a specific time in the dynamic aging course of the many overlapping generations of the population. The present study described the number of the seedlings of *J. mandshurica* at specific time, therefore, the static life table could be compiled according to the seedling number in the seedlings statistics during the quadrat field investigation (Jiang 1992; Manuel and Molles 2002). The parameters used in the table are explained as follows: x: age; a_x:

number of seedlings at the age of X; l_x: standardized number of survived seedlings; d_x: standardized number of seedlings dying from the age of x to the age of x+ 1; q_x: mortality in the interval of x ~ x_{+1}; L_x: number of survived seedlings from the age of x to the age of x+ 1; T_x: total number of seedlings surviving from the age of x to the age of x+1; e_x: life expectancy of the seedling at the age of x; K_x: the rate of disappearance.

3.4 Date Processing

The values of parameters in the static life table were achieved through the calculation using the following equations.

$$l_x = (a_x / a_0) \times 1000 \quad (1)$$

where a_0 refers to the number of one-year seedlings, and the standard base is set at 1000.

$$d_x = l_x - l_{x+1} \quad (2)$$

$$q_x = d_x / l_x \quad (3)$$

$$Lx = (l_x + l_{x+1}) / 2 \quad (4)$$

$$Tx = \sum Lx \quad (5)$$

$$K_x = ln l_x - ln l_{x+1} \quad (6)$$

The survival curve of plants could be classified into three categories according to the Deevey division (Jiang, 1992). The survival curve of the seedling of *J. mandshurica* were determined using the mathematic models shown as Equations 7, and 8.

$$y=ae^{bx} \quad (7)$$

$$y=a^{xb} \quad (8)$$

The models were simulated and analyzed using the statistics software SPSS 13.0, and the category of the survival curve of the seedling of *J. mandshurica* was tested using F test and correlation coefficient R^2.

In order to explore the growth pattern of seedlings at different altitudes, scatter diagram was plotted for average plant height and age, respectively. Linear function, logarithmic function, power function and exponential function were used for simulation, and the fitting equation with the highest correlation was selected to quantitatively describe the relationship between seedling height and age. Goodness-of-fit test for the equations was achieved with the correlation coefficient (R^2), and the significance of the equation was assessed by F test.

4. Result and Analysis

4.1 Analysis of Static Life Table

The 1~7 a seedlings of in each quadrats were surveyed. There were 1092 seedlings at 3 altitudinal gradients, i.e. 508 in H1, 360 in H2, and 224 in H3. The static life table was compiled by these data (Table 1). This table can reflect the survival and development state of the seedlings to some extent.

Table 1: Static life table of seedlings of *J. mandshurica* in different habits

Habitat	x	a_x	l_x	$\ln l_x$	d_x	q_x	L_x	T_x	e_x	K_x
H1	1	201	1000	6.908	338	0.338	831	2030	2.030	0.413
	2	133	662	6.495	55	0.083	635	1199	1.812	0.086
	3	122	607	6.408	473	0.779	371	564	0.929	1.508
	4	27	134	4.900	75	0.556	97	193	1.437	0.811
	5	12	60	4.089	20	0.333	50	96	1.608	0.405
	6	8	40	3.684	15	0.375	33	46	1.156	0.470
	7	5	25	3.214	-	-	13	13	0.523	3.214
H2	1	158	1000	6.908	373	0.373	814	1782	1.782	0.467
	2	99	627	6.440	133	0.212	561	968	1.545	0.238
	3	78	494	6.202	405	0.821	292	407	0.824	1.718
	4	14	89	4.484	51	0.571	64	115	1.298	0.847
	5	6	38	3.637	19	0.500	29	51	1.343	0.693
	6	3	19	2.944	6	0.333	16	22	1.159	0.405
	7	2	13	2.538	-	-	6	6	0.474	2.538
H3	1	103	1000	6.908	398	0.398	801	1677	1.677	0.508
	2	62	602	6.400	165	0.274	520	876	1.455	0.320
	3	45	437	6.080	369	0.844	253	356	0.815	1.861
	4	7	68	4.219	39	0.571	49	103	1.516	0.847
	5	3	29	3.372	10	0.333	24	54	1.854	0.405
	6	2	19	2.966	0	0.000	20	30	1.545	0.000
	7	2	19	2.966	-	-	10	10	0.515	2.966
Total	1	462	1000	6.908	364	0.364	818	1863	1.863	0.452
	2	294	636	6.456	106	0.167	583	1045	1.642	0.182
	3	245	530	6.273	426	0.804	317	462	0.871	1.630
	4	48	104	4.643	58	0.563	75	145	1.396	0.827
	5	21	45	3.817	17	0.381	36	70	1.540	0.480
	6	13	28	3.337	9	0.320	24	34	1.208	0.368
	7	9	19	2.969	-	-	10	10	0.513	2.969

Life expectancy. The relationship between age (abscissa) and life expectancy (E_x, ordinate) of seedlings at different ages (Table 1) is plotted as shown in Figure 1. With the increase of altitude, the life expectancy of 1~3 a seedlings decreased gradually; the life expectancy of 4~6 a seedlings was the largest at the gradient H3; the life expectancy of 7 a seedlings was the largest at the gradient H1. At the same altitudinal gradient, the life expectancy first decreased (1~3 a), then increased gradually (3~5 a), and decreased again (5~7 a) with the age. This showed that the seedlings at different altitudinal gradients experienced different intensities of environmental screening, and fluctuation exits in the life expectancy of seedlings at different ages.

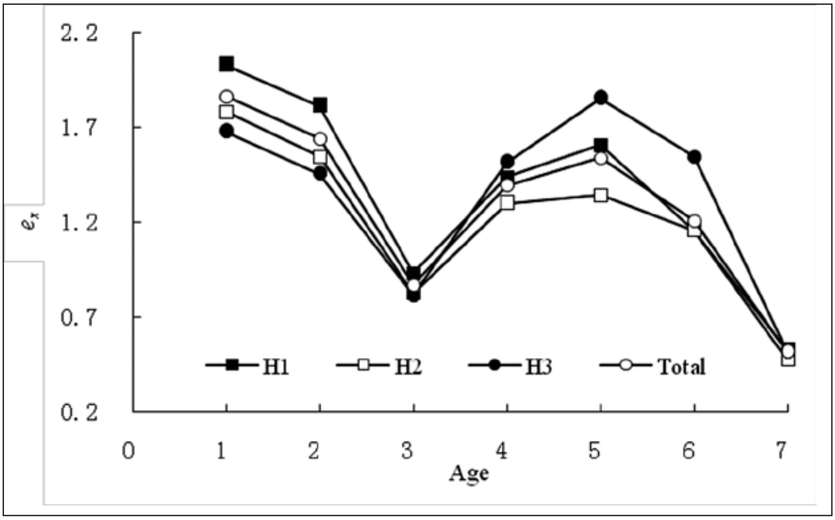

Figure 1: Life Expectancies in seedling populations of *J. mandshurica* in different habitats

Age structure. The age structure diagram of seedlings of *J. mandshurica* is plotted with age as the abscissa and percentage of the number of seedlings of each age (a_x) as the ordinate (Figure 2). The ratio of 1 a seedlings was always the largest at different altitudinal gradients, being 39.6%, 43.9% and 46.0% at gradients H1, H2 and H3, respectively. The ratio of all 1 a seedlings in the study area was 42.3%. The seedlings of 1~3 a had absolute advantage, with the ratios of 89.8%, 93.1% and 93.8% at gradient H1, H2 and H3, respectively. The ratio of all 1~3 a seedlings in the study area was 91.6%. With the increase of age from 4 a to 7 a, the ratio of seedlings at corresponding age decreased in a large amplitude. This demonstrated the expanding age structure at different altitudinal gradients or on the whole.

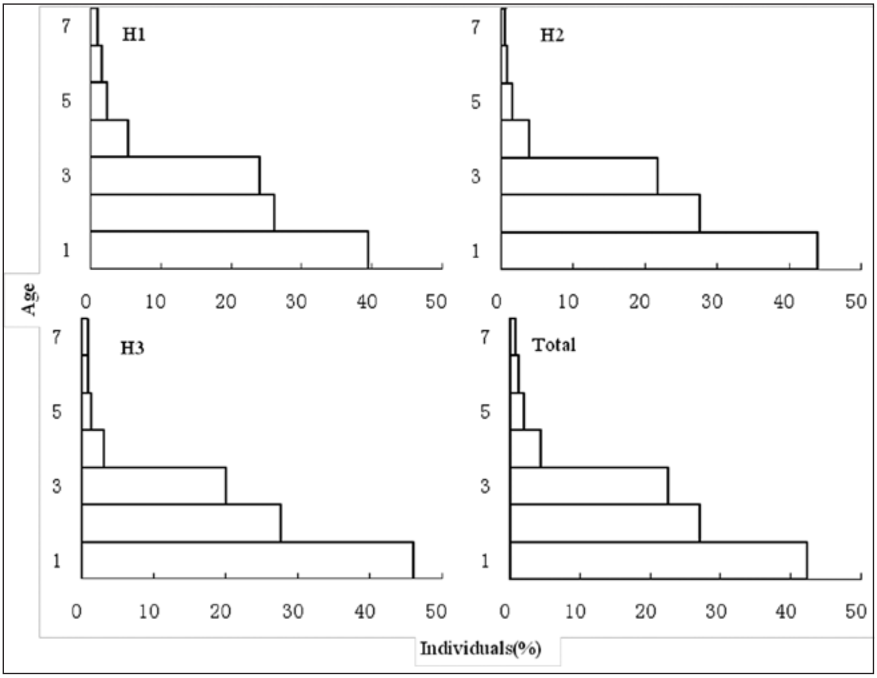

Figure 2: Age structures in seedling populations of *J. mandshurica* in different habitats

Survival curve. With age as the abscissa, the logarithm of survival number ($\ln l_x$) is taken as the ordinate to draw the survival curves (Figure 3). Comparing with the classical survival curve, the three altitudinal gradients were all between Deevey I and II type. The test by mathematic model (Wu et al. 2000) indicated that for the F-test value and coefficient of determination (R^2) of the models of 3 altitudinal gradients and total population, exponential functions were all larger than power functions (Table 2). This means that the survival curve of seedlings of *J. mandshurica* is closer to Deevey II type. Figure 3 shows that the survival rates of 1~3 a seedlings in 3 altitudinal gradients were relatively high, with a slow gradient. The survival rate decreased greatly in the seedling above 3 a. The survival rates of 2~5 a seedlings showed a tendency of H1>H2>H3, i.e., the survival rate of seedlings decreased with increasing altitude during this period. For the whole population, 10.4% 1 a seedlings could live to 4 a, and only 1.9% could live to 7 a. This means that each plant of young *J. mandshurica* survives at the cost of high mortality of seedlings in the population.

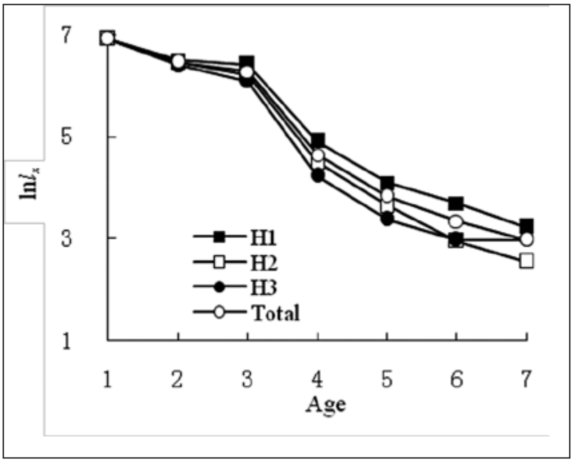

Figure 3: Survival curves in seedling populations of *J. mandshurica* in different habitats

Table 2: Test models of survival curves in seedling populations of *J. mandshurica* in different habitats

Habitat	**Equation**	***R^2***	***F***	***Sig.***
H1	$y=8.031x^{-0.405}$	0.750	23.156	0.005
	$y=8.535e^{-0.139x}$	0.933	112.089	0.000
H2	$y=8.458x^{-0.531}$	0.714	22.631	0.005
	$y=9.189e^{-0.182x}$	0.928	126.371	0.000
H3	$y=8.158x^{-0.501}$	0.769	28.028	0.003
	$y=8.631e^{-0.167x}$	0.931	70.871	0.000
Total	$y=8.131x^{-0.452}$	0.754	25.147	0.004
	$y=8.654e^{-0.153x}$	0.934	102.782	0.000

Curves of mortality and disappearance rate. The relationship between age (abscissa) and the ratio of mortality (Q_X) to disappearance rate (K_x) (ordinate) is plotted as shown in Figure 4. Along the altitudinal gradients, the maximums of mortality were 77.9% in H1, 82.1% in H2 and 84.4% in H3, all occurring in 3 a. The total mortality was 80.4% in 3 a. In addition, the mortality curves of 1~4 a seedlings showed similar increasing trend with the altitude. Starting from 5 a, there is fluctuation in mortality at 3 altitudinal gradients. It means that the mortality caused by the selection pressure of local altitudinal variation is far less than the synchronous mass death caused by regional environment. The curves of mortality and disappearance rate showed consistent changing trend, which reflects the correspondence between great environmental selection pressure and high mortality.

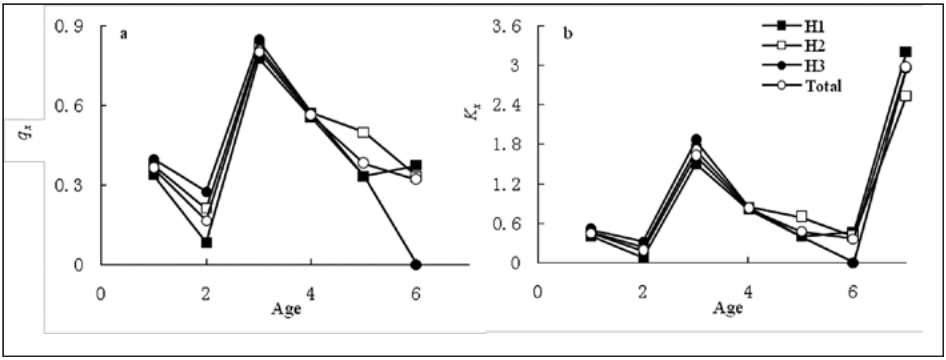

Figure 4: Curves of mortality (a) and disappear rate (b) in seedling populations of *J. mandshurica* in different habitats

4.2 Growth Analysis

Height characteristic of seedlings. Statistical analysis showed that although the height of seedling of *J. mandshurica* at different altitudes has some fluctuations at different ages, there was no significant difference (Table 3). For the seedlings of different ages (except for the 7 a seedlings in H3), the coefficient of variation at one altitudinal gradient was larger than that between gradients. It showed that the height of seedlings of the same age showed less variation at 3 altitudinal gradients, but the height was more affected by the microenvironment in its community. Therefore, the seedling populations along different altitudinal gradients can be treated as the same samples.

Table 3: Quantitative characteristics in seedling height of *J. mandshurica* in different habitats

Habitat	Parameter	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7
H1	*M±SD*(cm)	15.4±5.5	20.9±5.8	25.4 ±6.7	30.9 ±9.0	41.3±21.3	53.1±31.2	72.4±28.3
	CV(%)	35.7	27.8	26.4	29.1	51.6	58.8	39.1
H2	*M±SD*(cm)	13.6±5.2	19.2±6.8	24.1±8.9	30.6±11.6	32.0±18.9	58.0±15.6	61.5±30.4
	CV(%)	38.2	35.4	36.9	37.9	59.1	26.9	49.4
H3	*M±SD*(cm)	14.7±4.9	21.8±6.5	26.2±6.7	37.6±11.4	47.3±19.4	56.0±2.8	84.0±11.3
	CV(%)	33.3	29.8	25.6	30.3	41.0	5.0	13.5
Total	*M±SD*(cm)	14.6 ±0.9	20.6 ±1.3	25.2 ±1.1	33.0 ±4.0	40.2± 7.7	55.7 ±2.5	72.6±11.3
	CV(%)	6.2	6.3	4.4	12.1	19.2	4.5	15.6

Growth model of seedlings. Linear regression analysis indicates that the height of seedlings of *J. mandshurica* showed exponential growth with the age. The correlations of regression equations all reached significant level (*P<0.01*), suggesting that the seedlings at different altitudinal gradients all had the same growth pattern. It can be seen from the shape of fitting curves and the parameters of the equation that (1) the seedlings grew slowly before 3 a or 4 a, showing a flat growth curve. Afterwards, the growth rate increased; (2) along different altitudinal gradients, the growth rates of seedlings were similar basically.

5. Discussion and Conclusion

Non-destructive study is an ideal study approach highly recommended in ecology due to the great difficulty in determining individual age. In the past study on age structure of tree populations, age structure is often replaced by DBH structure. Although the DBH with small grade division can also reflect the situations of individuals in different life histories (Duan et al. 2009; Zhang et al. 2009), it is less ideal to study the population dynamics compared with actual age. The age determination method for the seedlings of *J. mandshurica* created in this study can also be used to study the seedlings of similar broad-leaved species in Alpine area or mountains.

Based on the quadrat investigation on the seedlings of *J. mandshurica*, Xingjiang, China, the established static life table for the seedling populations could show: (1) the survival number and its dynamic variation of the seedling at present. For example, the number was about 78/hm^2 for the 1 a seedlings, 8/hm^2 for the 4 a seedlings, and 2/hm^2 for the 7 a seedlings; (2) the life expectancies of the seedlings at different ages located at various altitudinal gradients and its trend (Figure 1); (3) the age structures of the seedlings in different habitat conditions (Figure 2); (4) the survival rates (Figure 3), mortality (Figure 4), etc. of the seedlings at different ages. Therefore, the static life table provide information about the life expectancies, survival rates and mortality at different ages.

With the increase of altitude, the number of *J. mandshurica* at each stage decreased (Table 1). The reasons may be as follows: (1) the population of *J. mandshurica* at high altitude region has less fruiting trees and low seed setting rate, resulting the lack of provenance and less seedling number; (2) The higher the altitude (exceeding the height of inversion layer in this area), the lower the average temperature and extreme low temperature in winter will be. As *J. mandshurica* is broadleaf thermophilic species and the seedlings have low degree of lignifications, many seedlings die of extreme low temperature.

At different altitudinal gradients, the mortality peaks of seedlings of *J. mandshurica* all occurred in 3 a (Figure 4). Guo (2011) reported that the cotyledons of the seeds of *Quercus liaotungensis* can provide nutrition for the growth in early seedling stage, which enables the seedlings to safely live through the first 2 growing seasons. The field survey showed that the cotyledons of germinated seeds of *J. mandshurica* in the Reserve were in good condition in the first year; only 40%-60% of the cotyledon was left in the second year, and the cotyledon disappeared in the third year.

The forest light environment constantly changes in space and time. The adaptability of seedlings to the light heterogeneity determines the survival, growth, distribution and abundance to some extent (Messier and Bellefleur 1988; Zhu et al. 2003). The 1 ~ 3 a seedlings of *J. mandshurica* accounted for more than 89.8% (Figure 2), and grew slowly. If these seedlings are treated as the seedling bank of *J. mandshurica* in the nature reserve, it reflects the development strategy to some extent that the population achieves the continuous regeneration at the cost of mass mortality.

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