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Demographic Study of *Juniperus communis* L. on Mishu-Dagh Altitudes in North West of Iran

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Abstract: Age structure and seed characteristics of a *J. communis* population in Mishu-dagh situated in Azerbaijan province were investigated as indicators for the viability of the species. The entire study area (ca. 25 ha) was surveyed and ages of all junipers were determined by counting the annual rings and measuring the main stem diameter. The age-specific life table was then constructed from detailed observations on mortality and recruitment. In addition, different seed characteristics including length, diameter, weight, average number of seeds per cone and percentage of filled seeds were assessed. Based on the results obtained, production of relatively good quality seeds by individuals is the most important basis for maintenance of natural regeneration. Present study suggests that the juniper population in Mishu-dagh survives due to not only good seed features but also individual longevity, inertias which partially counteract losses to unfavorable environmental conditions delays the possible extinction course. These inertias would maintain populations through the critical regression period imposed by the present climate with continual drought period.

Key words: *Juniperus communis*, Mishu-dagh, demography, age structure, seed characteristics, global warming

INTRODUCTION

Iran is situated on the cross-roads of four floristic regions i.e., Irano-Turanian, Hyrcanian relating to Euro-Siberian, Zagros and Khalijo-Ommanian (Willis, 2001; Zehzad *et al*., 2002). This privilege provides ecological context for growth and development of plenty plant species belonging to various vegetation zones. In this miscellaneous habitat *Juniperus communis* L. (Cupressaceae), like its fellow-creatures in Mediterranean mountains and other southern habitats, which are away from their home in taiga-tundra limitation (Garcia *et al*., 1999, 2001), distributed in some mountainous areas mostly on northern and northwest altitudes of the country such as Alborz ranges, Sabalan, Ghara-dagh and Mishu-dagh (Korori and Khoshnevis, 2000). Similar to the insular habitats of *J. communis* in Europe (Clifton *et al*., 1997), almost all of the *J. communis* populations in Iran also endure harsh environmental conditions and try to survive through morphological changes (Korori and Khoshnevis, 2000). Because of unfavorable life conditions over past decades, populations of *J. communis* in Mishu-dagh are faced with the possibility of extinction.

The juniper populations have a high ecological value, mainly in relation to their soil retaining ability, as well as their associated flora and fauna (Molero *et al*., 1992). However, despite the increasing protection of juniper habitats, population sizes have continued to decline, very often due to the deficiency of regeneration (Verheyen *et al*., 2005). Two factors that are often mentioned as responsible for the insufficient regeneration of *J. communis* are the absence of microsites suitable for seed germination and establishment (Ward, 1982) and limited seed viability (Garcia *et al*., 2000). Bare ground microsites have become rare due to a combination of some ecological factors such as soil erosion and the abandonment of traditional management practices such as grazing and mowing (Barton, 1993). It is also well documented that under unfavorable conditions female plants may decrease reproductive efforts resulting in less level of viable seed sets (Block and Treter, 2001; Marion and Houle, 1996). The analysis of the production

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of healthy seeds throughout the distribution area of a given species is thus crucial for determination of population viability at a geographical scale (Garcia *et al.*, 2000). A reduction in reproductive ability would be expected due to genetic drift and inbreeding depression in those populations situated in marginal area of the range under unfavorable condition (Kärkkäinen *et al.*, 1996; Nantel and Gagnon, 1999). Decrease in the production of viable seeds due to genetic reasons can also occur in small fragmented populations (Aizen and Feisinger, 1994). Reduction in seed viability among populations in a stressful area can lead to regeneration failure and, eventually, extinction (Woodward, 1990; Pigott, 1992).

Age structure investigations could also give insights into the processes determining population structure over time and can help in tracing past history (Andrzejczyk and Brzeziecki, 1995; Svensson and Jeglum, 2001). In addition, estimation of age structure is necessary for monitoring future trends in population structure (McCartney *et al.*, 2006). Quantitative studies of age structure could serve as a basic point of reference central to conservation status of a population and management of ecosystems (Fule *et al.*, 1997; Mast *et al.*, 1999; Wang *et al.*, 2004). The analyzing of age structure are therefore prerequisites for understanding ecological processes and restoration of natural habitats.

So far, few studies have quantified demographic changes in juniper populations (Rosen, 1995; Clifton *et al.*, 1997). No study has yet evaluated the dynamics of juniper populations in Iran and there is lack of primary information concerning age of plants, extent of regeneration, grazing pressure and management practices. This is perhaps not surprising given the difficulties of access and the fact that plants are often scattered over large areas in small numbers. The present study was performed to investigate age structure and seed characteristics of the common juniper population in Mishu-dagh. This information, reflecting the reproductive ability of the population, enables us to reconstruct regeneration dynamics in the past and thereby predict the future viability of the species.

MATERIALS AND METHODS

Study area: The study was conducted in the northern slope of Mishu-dagh (3150 m asl, 44°44'-45°55' E, 38°15'-38°30' N) situated in the north side of Urmia lake in Azerbaijan province in northwest of Iran (Fig. 1). The mean annual precipitation is 269 mm and the mean annual temperature is 12.5°C. The relative humidity is

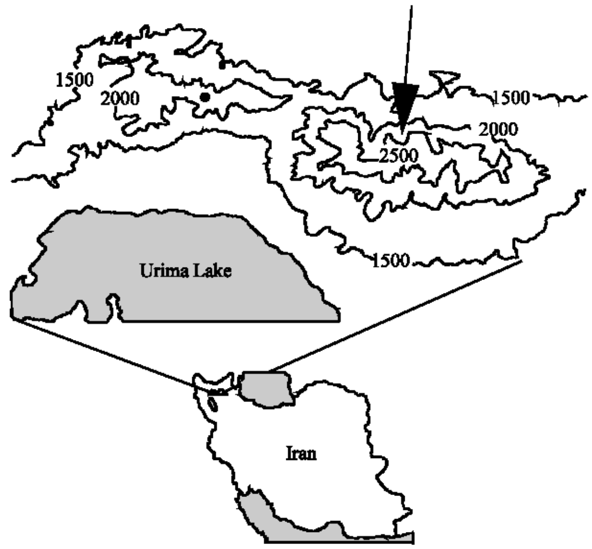

Fig. 1: Location of Mishu-dagh in northwestern Iran and location of the stand studied (arrow)

34.01-70.70% and the mean annual frost period in the region is quite variable but averages 110 days (Atmospheric Service of Tabriz Weather Station, located at 1990 m asl). The study site is characterized by low-shrub community composed mostly of several species of *Ephedra*, *Astragalus* (principally *Astragalus microcephalus* Willd. and *Astragalus compactus* Lam.), *Acantophyllum* and *Acantolimon*.

Field sampling for study of age structure: The field investigations were carried out from 15 May to 28 July 2004. Because the *J. communis* L. population in Mishu-dagh is located upward 2200 m asl, we prepared an altitudinal transect line with 250 m width from 2200 m asl up to 2450 m asl, as the upper boundary of growing of *J. communis* L. in the region. All juniper individuals inside the selected region were carefully marked and studied in terms of:

- The main stem diameter for estimating the age of each individual
- Canopy dimensions
- Sexuality of each shrub based on the presence of male or female cones
- The number of cones per cube decimeter
- The number of damaged individuals disregarding the amount of damages

J. communis L. is very variable in form according to habitat factors. It shows a stunted multistemmed morphology in mountainous areas, which are generally inaccessible due to the interlaced branching system. In view of that, age was estimated by measuring the largest diameter of the plant stem according to Garcia *et al.* (1999). For this purpose, ages of plants were determined by counting the growth rings and the age-diameter relation was established. Afterward, age was regressed against basal stem diameter and a reasonable average fit was obtained relating age to stem diameter. Age of individuals was estimated by the age-diameter relationships.

Seed characterization: Throughout our studies, 4000 ripe (bluish-black) seed cones from 50 *J. communis* shrubs were collected randomly by walking along the transect line (60-100 cones per shrub). Fifteen hundred cones were randomly opened and the developed seeds were counted. Based on the seed number per cone (1-5) the collected seeds were classified into five groups. In each group, the length, diameter and weight of seeds were measured. Furthermore, the seeds were cut transversely, noting how many contained an embryo (filled seeds).

Data analysis: The sex of approximately 75% of individuals could be determined by presence of reproductive structures. Those individuals without cones were juveniles of similar morphology (all of ≤25-year-old and a part of 25 to 55-year-old plants). Because the sex ratio for the mature individuals does not differ among age categories, we presume it would be the comparable for the juveniles. For tracing the history of population and in order to attain a prognosis for future population trends an age pyramid considering the sexuality of individuals was prepared.

Time-specific life table seems to be an obvious choice for the presentation of population state of perennial plants such as *J. communis*. In this kind of life table, current population is alienated into defined age classes. Consequently, the observed data in a distinct sampling time including all age classes are ordered as a life table. Based on the data obtained, a fertility life table was built for each cohort (Southwood and Henderson, 2000), where, x represents the average point of the age interval, l_x is survival rate of the age x disregarding mortality, m_x is the age-specific gross fecundity or number of females per female born in the age x and finally $l_x m_x$ represents the total number of females produced in the age x.

Any deviation from expected trend of a population is related to sampling errors and/or biases, which was adjusted by smoothing (Southwood and Henderson, 2000). Accordingly, in this study, all individuals were categorized in 14 age classes with 10 year intervals. Numbers of individuals belonging to the different age classes were fitted to type III survivorship curves (r^2 = 0.81 for females and r^2 = 0.857 for both males and females). Observed numbers were log transformed and afterward, the expected quantities from a decreasing exponential relationship were used to calculate survival rates (l_x). The two initial age categories were excluded due to a significant deviation from the trend line. The rate of deviation was used to adjust expected numbers assuming that an external mortality factor may disturb population structure in the mentioned age classes. Age specific fecundities were used to construct a pair of fertility life tables in the presence and absence of external mortality factors and to estimate the population growth parameters. The population parameters computed were: Gross Reproductive Rate (GRR), which reveals how many females may expect to have on the average in one generation when no death occurs; Net Rate of Reproduction (NRR), which represents the total number of females produced in one generation; mean cohort generation time (T), which is the mean duration of one generation; Cohort Generation Time (T_c), which is mean time required for progeny production; Duplication Time (DT), which represents the time that a population needs to duplicate itself in number; intrinsic rate of population increase (r_m), which expresses the innate-capacity of increasing in number; capacity for increase (r_c), which describes the reproductive potential of population; and finite rate of increase (λ), which is the number of times that the population increases per unit of time (Southwood and Henderson, 2000).

For analyzing of seed characteristics we exploited one-way ANOVA using five above-mentioned treatments (seed groups) and all groups were then compared by Duncan's Multiple Range Test. All statistical analyses in this section were carried out by SAS with Proc GLM.

RESULTS

Inside the selected transect line a number of 296 *J. communis* shrubs were examined. Disregarding completely destroyed plants (about 20% of shrubs), 13% of individuals were obviously damaged. These data indicate that the shrubs suffer from relatively intense damages caused by wild and domestic herbivores as well as anthropogenic pressure. Consequently, the conservation of juniper population in the long term is strongly dependent on the reduction of the herbivore and anthropogenic pressure in the distribution region.

The height of canopy in the population was positively correlated with the age of individuals ($r = 0.387$, $n = 296$, $p<0.01$). Nevertheless, canopy

Table 1: The observed number of shrubs, the expected number of shrubs using a type III survivorship curve and the number of female cones produced by females of distinct age classes. N_x represents the number of individuals in each age classes

Age class	Pivotal age	Nx (observed)	Nx Smoothed	Nx Expected*	Males (observed)	Females (observed)	Females Smoothed	Females Expected*	Female cones
0-10	5	27	95.98	341.16	14.00	13.00	50.95	199.67	0
11-20	15	21	74.08	261.30	11.00	10.00	38.20	145.91	0
21-30	25	49	57.17		29.40	19.60	28.64		89
31-40	35	37	44.13		14.80	22.20	21.47		2'559
41-50	45	49	34.06		23.70	25.40	16.10		54'045
51-60	55	34	26.29		22.00	12.00	12.07		23'646
61-70	65	16	20.29		7.00	9.00	9.05		56'106
71-80	75	24	15.66		10.20	13.80	6.79		235'048
81-90	85	10	12.09		5.00	5.00	5.09		153'856
91-100	95	9	9.33		6.00	3.00	3.81		28'320
101-110	105	7	7.20		5.83	1.17	2.86		66'880
111-120	115	3	5.56		1.00	2.00	2.14		52'934
121-130	125	3	4.29		2.00	1.00	1.61		21'780
131-140	135	7	3.31		4.00	3.00	1.21		710'080
Total		296	409.42		155.10	141.00	199.99		1'405'343

*After excluding external mortality

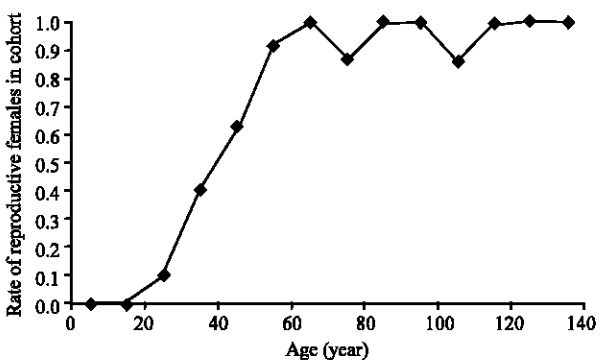

Fig. 2: Rate of reproductive females in age cohorts

dimensions of studied plants did not exhibited any significant correlation with their age (r = 0.077, n = 296, p>0.05). As a result, a study of age structure instead of size structure was carried out by classifying each individual to distinct age classes.

Sex determination in the total population was not possible due to lack of reproductive organs in relatively young classes (plants of ≤20 years old). The first reproductive activity was observed in a small part of population (about 10%) in plants of 25±5 years old. The frequency of reproductive individuals in the classes increased up to 55±5 years old and thereafter, remained nearly constant (Fig. 2). Because sex determination was not feasible in immature individuals, the female fraction of total population was estimated (Table 1). The results were then used for calculation of m_x (age-specific gross fecundity: the expected number of daughters produced by mothers of age x) in fertility life tables. Population age pyramid exhibits a narrow base and top with a broad middle, showing a declining population with a low recruitment rate (Fig. 3). Although the vast majority of plants are over-mature, it is important to note that the number of young, seedling plants and dying (senile) plants is not inconsequential. The expected number of females obtained from a type III survivorship curve (Fig. 4) was used to calculate survival rate in life tables. Total counts were also employed in a similar way to estimate the total number of individuals in each class (Table 1). The first two points in the chart are outlying from the expected line. Most probably, it is because of an external mortality factor, which affects young stocks.

The rates of observed and expected data were used to adjust the frequencies of the first and second classes and to reconstruct their survival rates (l_x). These rates for the first and second classes (0.255 and 0.262) show no significant difference. Ignoring the sexuality, the rates were still similar for both classes (0.281 and 0.283). Adjusted survivorship curve of females. The elimination of mortality will tend to a 4-fold increase in the number of females (199.7 and 145.9 females in the first and second age classes, respectively).

Population growth parameters have been estimated under two conditions, regarding and ignoring (control) of the external mortality. Noticeably, GRR and T_c are the only parameters that show no change in comparison to control population (disregarding the mortality) and they were estimated to be ~ 410'000 females/female/generation and 102 years, respectively. When the mortality was included, NRR, r_m, r_c and λ decreased, while T and DT increased. The highest changes occurred in NRR, which was 18966.85 females/female/generation in absence of mortality and 4839.65 in its presence (approximately 4-fold decrement). Considering external mortality, the Duplication Time (DT) and the mean cohort generation time (T) increased 1 and 4 years, respectively. On the

Fig. 3: Age pyramid of studied population of *J. communis* concerning the sexuality

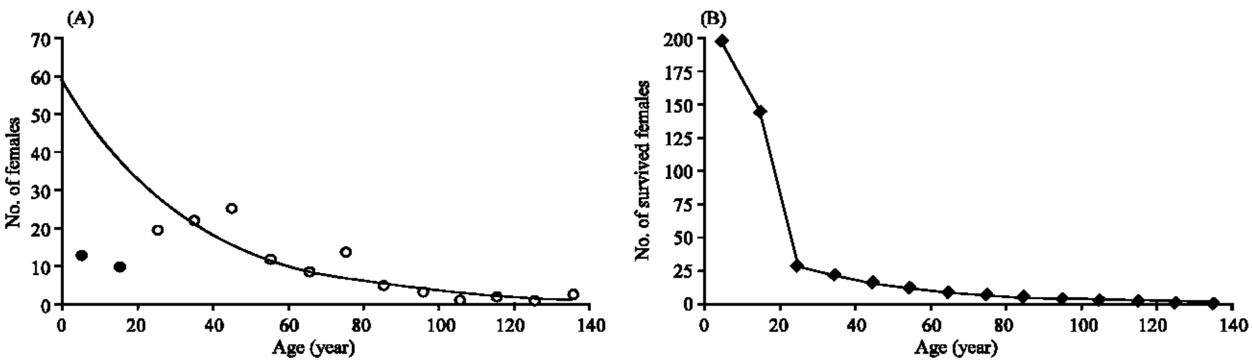

Fig. 4: Survivorship curves of female cohorts of *J. communis*. A: The fitted curve to a type III survivorship; B: The adjusted curve by rate of deviation of the two initial observed data from the expected line. Black point were excluded because of high deviation

other hand, the instantaneous population growth rate and finite rate of population were declined, when external mortality included. Their values were 0.1563 and 0.1266 for r_m and 1.169 and 1.135 female/female/year for finite rate of increase (λ) in two stated situations, respectively. These results clearly imply that in spite of mentioned problem in seedling establishment, population growth rate is still high enough to avoid extinction risk (r_m>0, λ>1, NRR>1). This is undoubtedly due to both high *per capita* rate of seed GRR and NRR. It should be highlighted that age specific reproduction ($l_x m_x$) increases linearly with plant age (Fig. 5).

To substantiate the ability of matured individuals in seed production, the number of seeds per cone was counted. Ripe cones contained 1 to 5 seeds (more than 95% of cones contained up to 3 seeds and 5% of them produced 4 or 5 seeds). The average number of seeds per cone was 1.99.

All of 5 seed groups were significantly different in studied traits (i.e., percent of filled seeds, length of seed, maximum diameter of seed and seed weight) (Table 2).

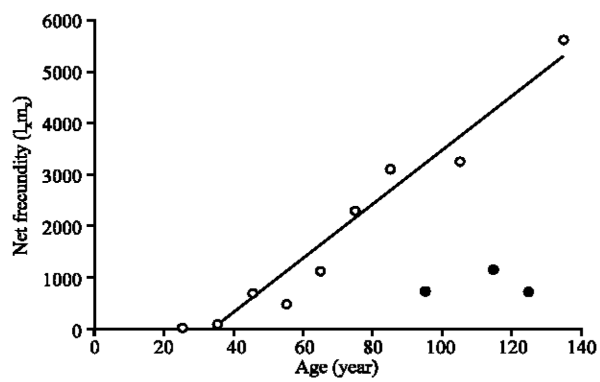

Fig. 5: Reproductive trend of population regarding distinct age classes. Black points were excluded because of high deviation

Taken together, the fewer seeds produce by juniper in each cone, the better physical quality of the seeds was observed. On the other hand, the number of seeds per cone was correlated negatively with the number of produced seeds by individuals (r = -0.896, n = 5, p<0.05).

Table 2: Mean comparison of traits by Duncan's Multiple Range Test

Group	Length (mm)	Diameter (mm)	Weight (g)	Percent of filled seed
1	5.108±0.091a	3.378±0.025a	0.0236±0.0003a	43.19±4.957a
2	4.764±0.091ab	3.080±0.025b	0.0159±0.0003b	31.36±4.957b
3	4.470±0.091bc	2.545±0.025c	0.0113±0.0003c	25.00±4.957b
4	4.568±0.091bc	2.578±0.025c	0.0098±0.0003d	28.64±4.957b
5	4.292±0.214c	2.395±0.059d	0.0074±0.00085e	30.28±8.936ab

The experimental values that have no common alphabet are significantly different ($p<0.05$)

In other words, it seems that junipers in the studied region prefer to produce small number of seeds with high quality instead to larger quantity of low-featured seeds.

DISCUSSION

Species diversity in the mountainous areas of Iran is high due to ecological and geographical reasons (Parsa *et al*., 1978; Zehzad *et al*., 2002). In this diverse scenario some species such as *J. communis* have a wide but extremely scattered distribution consisting of many small mountain populations (Korori and Khoshnevis, 2000). These fragmented distributions are in several cases related to the function of mountain habitats as refuges during harsh environmental conditions (Bennett *et al*., 1991). Species with wide geographical distribution but relatively small population dimensions have been considered to constitute a specific category of rarity requiring a meticulous approach for conservation (Rabinowitz *et al*., 1986; Kier *et al*., 2005). To assure the persistence of these species at a regional scale is particularly challenging, because threatens acting at a local stage might destroy whole populations, thereby reducing the plant's geographic distribution. The present study was carried out to investigate age structure and regeneration ability as two important indicators for population viability of *J. communis* in one of its mountain habitats in the north-west of Iran, Mishu-dagh.

According to previous studies individual size correlates significantly with age in common juniper (Marion and Houle, 1996; Garcia *et al*., 1999). However, the correspondence between different plant sizes and age classes could be affected by environmental factors (Hutchings, 1986). Therefore, for age-structure survey we judged the age of individuals with awareness by measuring the basal diameter of the main trunk. Subsequently, the current age-structure of the individuals in the region was demonstrated in a time-specific life table. The data presented in Table 1 support the notion that in comparison to trend of a stable cohort some deviations are evident most likely due to disturbance on the development of population age structure. Accordingly, narrow based age pyramid (Fig. 3) characterizing a senescent population (Price, 1997) confirmed the presence of external factors responsible for mortality of saplings. Consequently, recruitment rate was found smaller than a typical secure population. The similar patterns of mortality caused by low recruitment have been shown in south Spain (Garcia *et al*., 1999), England (Ward, 1981; Clifton *et al*., 1997) and Belgium (Verheyen *et al*., 2005). Overgrazing and changes in land use strategies in England, summer drought in south Spain and habitat quality (acidification, eutrophication and drought) in Belgium have been claimed to be responsible for high seedling death. Nevertheless, extinction risk reported to be not very high in Atlantic populations of Spain and north Europe due to less water limitation (Rosen, 1988; Austad and Hauge, 1990). In contrast, in warm and drought climates the extreme temperatures, radiation and summer draught are major factors limiting recruitment (Garcia *et al*., 2001; Castro *et al*., 2004). Climatologically, mountainous areas in northwest of Iran is predominantly semi-arid (Zehzad *et al*., 2002) and on the basis of meteorological data in the region (Shahi, unpublished data), parallel with global climatic warming in recent 50 years (Dale *et al*., 2001; Lewis, 2006; Menendez *et al*., 2006; Walker, 2007) atmospheric temperature, especially in summer, has arisen. Based on these data high temperature and summer draught are most probably main factors limiting sapling growth in Mishu-dagh. The comparable effects of regional draught on distribution and development of conifers were previously reported (Allen and Breshears, 1998). In addition, our surveys showed that a big part of damages (33%) was caused mainly by herbivores and anthropogenic pressure. It means that ungulates and anthropogenic perturbations are the other restrictive factors on saplings establishment and growth throughout the distribution area, a situation that in turn could significantly affect population demographic structure. These findings are in agreement with previous reports on herbivorous and anthropogenic influences on juniper population dynamics (Knapp and Soulé, 1998; Danell *et al*., 2006).

In this study seedling mortality was thoroughly estimated to be 75% leading to 4-fold decrease in replacement rate per generation. The amounts of this parameter were determined ≈4840 and ≈18970 females/female/generation in damaged and undamaged model populations, respectively. This revealed that a seedling mortality of 99.995% (survival rate 32 times lower than Roskams's experiments in a greenhouse in Heiderbos) (Verheyen *et al*., 2005) or more is required to lead to extinction. In other words, the calculation of population growth rate of common juniper in Mishu-dagh exposed that from the present perspective, there is no extinction risk for the species in the studied area despite the seedling establishment problem. The main reason is most likely a high *per capita* rate of seed production (GRR) and as a result a high net rate of reproduction (NRR). Our data suggest that although Mishu-dagh juniper population has lower seed number in each ripe cone in comparison with populations of Iberian Peninsula and Alps mountain chain (Garcia, 2000), females produce higher proportion of filled seeds. The production of relatively good quality seeds by individuals, in comparison with some other populations (Garcia *et al*., 2000; Ortiz *et al*., 2002; Verheyen *et al*., 2005), is the most important basis for maintenance of natural regeneration.

According to the demographic characteristics obtained in the current investigation, it seems that the juniper population in Mishu-dagh survives due to individual longevity and good seed features (Table 1 and 2), inertias which partially counteract losses to unfavorable environmental conditions and delays the possible extinction process. These inertias would maintain populations through the unfavorable regression period imposed by the current climate with persistent drought period. However, global warming trend may change current position via increasing drought intensity, which consequently will result in recruitment rate and survivorship (Winnet, 1998; Menendez *et al*., 2006). Therefore, further detailed demographic studies and monitoring population changes are recommended.

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