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Forest Ecology and Management 255 (2008) 3667–3671

Forest Ecology and Management

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Sustainability of wild pistachio (*Pistacia atlantica* Desf.) in Zagros forests, Iran

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Received 9 August 2007; received in revised form 25 January 2008; accepted 26 January 2008

Abstract

Wild pistachio (*Pistacia atlantica* Desf.) is the most economically important tree species in many rural areas in the west of Iran. The species produces resin used for a wide variety of traditional uses. Because the resin can be harvested non-destructively, the trees are maintained until mortality occurs from natural causes. The result is that natural, managed stands include a variety of age classes. In recent years, a lack of smaller size classes has been observed in the Qalajeh forest, which is located in the Zagros Mountain region of western Iran. We established a series of plots in an area typical of Qalajeh forest to characterize the diameter distribution of the wild pistachio component. We confirmed a deficit of stems <30 cm dbh, based in the expectation that the landscape-level diameter distribution should be characterized by a negative exponential curve. For trees ≥30 cm dbh, de Liocourt's equation closely fit the diameter distribution ($r^2 = 0.93$), translating to a q-factor of 1.34. We used this curve to estimate the deficit number of stems in diameter classes <30 cm. We estimate that this forest should have 19–24 wild pistachio trees/ha in the 5–25 cm classes, as compared to about 5 trees/ha found currently. Based on local conditions, we recommend that at least 30 seedlings/ha should be planted to allow 6–8 trees to reach to the 5 cm class.

Keywords: Diameter distribution; Uneven-aged; Stand structure; q-Factor; Resin production; Restoration; Zagros mountains

1. Introduction

Iran is the world's largest producer of pistachio (*Pistacia* spp.), with over 44% of world production (Esmail-pour, 2001; Razavi, 2006). Most of the production is from orchards that account for 53% of world planted area (Razavi, 2006), but there are a few places, such as in the Zagros Mountains, where wild pistachio (*Pistacia atlantica* Desf.) persists in natural and extensively managed (i.e., semi-natural) stands. Oak trees (*Quercus* spp.) commonly dominate forests of the Zagros Mountains (hereafter Zagros forests), but wild pistachio, known as Baneh in Iran, is the most economically important species for rural people in areas of natural forest. Cultivation of pistachio for multiple uses is believed to have been practiced in Iran for perhaps 3000–4000 years (Razavi, 2006). The resin of wild pistachio, called Saqez, is used for a variety of industrial and traditional uses, including food and medicine. The fruit of wild pistachio is an important source of food, although the fruit are smaller and not as commercially valuable as those produced in orchards (primarily from cultivars of *Pistacia vera* L.). It may require more than 200 years for trees to reach 1 m diameter and trees up to 2 m in diameter are known (Zangeneh, 2003; Arefi et al., 2006).

Most areas of Zagros forests have been overutilized and degraded, owing to a wide variety of factors (Ghazanfari et al., 2004; Pourhashemi et al., 2004). Management practices vary locally and have been found to be unsustainable (Ghazanfari et al., 2004) in many locations. Trees exceeding 50 cm are rare in most areas and in some areas trees are harvested by the time they reach 30 cm. Qalajeh forest is typical of Zagros forests that have a wild pistachio component; oak species are heavily utilized but wild pistachio trees are infrequently cut. Natural stands includes a variety of age classes and may include many large, old trees. However, in recent years a lack of wild pistachio regeneration has been observed there (Ebrahimi et al., 2003). Seedlings are rare, except in some sites that are inaccessible to domestic animals. Most of the wild pistachio trees are older than 50 years,

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doi:10.1016/j.foreco.2008.01.057

suggesting that long-term sustainability may be a problem (Zangeneh, 2003).

Certain aspects of *Pistacia* spp., such as genetics and fruit production, have been studied thoroughly because of commercial importance; the vast majority of literature addresses pistachio in a cultured orchard setting (see, e.g., Kaska et al., 1995; Javanshah et al., 2006). Studies of pistachio ecology in natural stands are relatively rare. Even in natural Zagros forests where wild pistachio is present, studies have focused on whole-stand structure or management practices associated with the oak component (Ghazanfari et al., 2004); information specific to the pistachio component is generally lacking.

In this study we investigate the size class distribution of the wild pistachio component in Qalajeh forest to assess the long-term sustainability of the species. Specifically, we aim to answer two questions: (1) is the current diameter distribution of wild pistachio consistent with sustainability, and (2) if the diameter distribution is unsustainable, what might be required to perpetuate wild pistachio in the long-term—i.e., what are the diameter-class deficits?

2. Study area and methods

Qalajeh forest is part of the Zagros forest and is located in Kermanshah province in the west of Iran (Fig. 1). The area has a Mediterranean climate, with average of rainfall of 516.7 mm. Soils are generally silty-clays to clays. Forest types with an important *P. atlantica* component occupy approximately 16% of the Zagros region (Ghazanfari et al., 2004). In Qalajeh forest there are three important forest types that are closely correlated with elevation: *Quercus persica* (<1500 m asl), *Q. persica–P. atlantica* (1500–2170 m), and *Amygdalus orientalis* (>2170 m). Although they are an important component of these forests, wild pistachio trees are widely scattered. The forests are sparsely stocked; nearly 90% of Zagros forests have canopy cover less than 30% (Ghazanfari et al., 2004). Wild pistachio is slow growing in Qalajeh; diameter increment ranges between 2 and 6 mm per year (Zangeneh, 2003). Because of the open stand structure and the slow, but relatively constant growth pattern of individual trees, we believe that diameter is a reasonable approximation of age for wild pistachio. As a result, diameter distribution should reflect age class distribution.

Fig. 1. Location of study area.

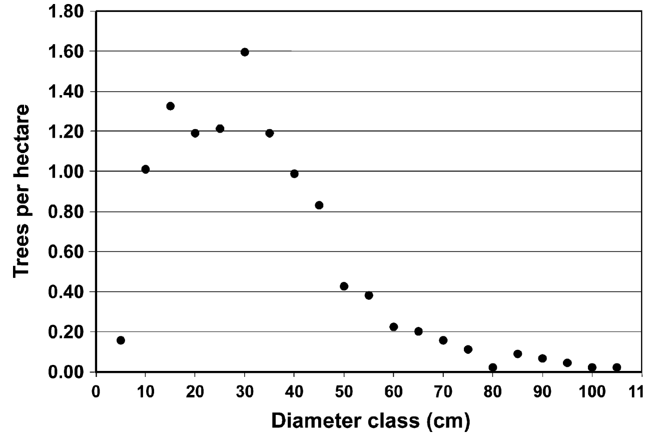

Fig. 2. Diameter distribution of wild pistachio on Qalajeh forest. Data points are the number of trees per hectare, based on 44.5 sampled hectares (178 plots, 2500 m^2 each).

In order to characterize the diameter distribution of wild pistachio, we established 178 sample plots, each with an area of a 2500 m^2, on a systematic grid in a typical area of Qalajeh forest. The large surface area of each plot was necessary to reduce the number of empty plots, because of the wide spacing of pistachio trees. Diameters of wild pistachio trees were measured at breast high and recorded in 5 cm classes. Other trees occurring on the plots, mostly *Quercus* spp., were not tallied. We measured 502 trees ranging from 5 to 105 cm, or nearly 11.3 trees/ha of plot area.

Upon inspection, our data confirmed that pistachio trees were rare in the smaller size classes (Fig. 2). The modal diameter class was 30 cm, with 71 tally trees or 1.6 trees/ha in that size class. The number of trees in diameter classes ≥30 cm appeared to diminish according to a negative exponential curve, so we fitted de Liocourt's (1898) equation, in nonlinear form (Eq. (1)), to the data starting with the 30 cm class. We considered that the 30 and 35 cm diameter classes might represent an unusual establishment event, so we also fitted Eq. (1) using data from diameter classes ≥40 cm.

$$N = a(\exp(-bD)) \tag{1}$$

where N = number of trees per diameter class, D is diameter class in cm at breast height, and a and b are estimated parameters.

3. Results

Diameter distributions for trees ≥30 and ≥40 cm closely followed the negative exponential distribution, with R^2 values of 0.93 and 0.90, respectively. The curves produced by the subsets of data (Eqs. (2) and (3)) are nearly identical (Fig. 3), suggesting that the number of trees observed in the 30 and 35 cm classes are consistent with the distribution of trees in the larger diameter classes.

$$N = 9.084(\exp(-0.0587D)) \tag{2}$$

$$N = 8.853(\exp(-0.0584D)) \tag{3}$$

where N and D are defined as above.

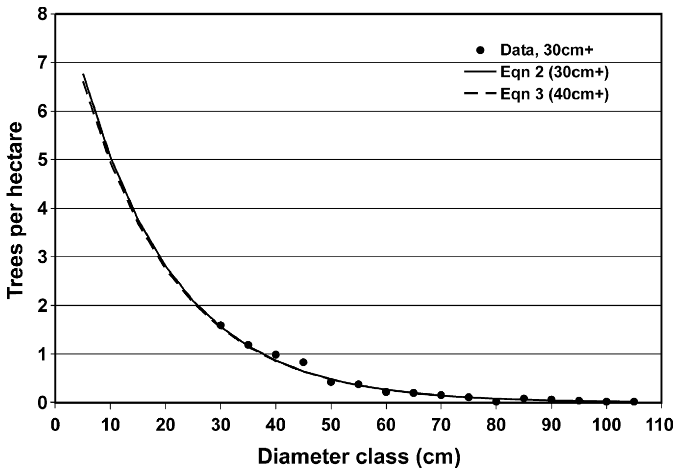

Fig. 3. Curves fitted to wild pistachio diameter distribution data. Number of trees represented by the curve is total expected per hectare.

Being satisfied that all diameter classes $\geq$30 cm belonged to an ‘‘intact’’ or ‘‘relict’’ part of the natural diameter distribution, we used Eq. (2) to determine the number of trees expected to occur in the smaller diameter classes. Eq. (2) yielded a q-factor (de Liocourt, 1898) of 1.34. This value is within the range of q-factors that have been used in uneven-aged silviculture using 5-cm diameter classes—e.g., Guldin (1991) considered $q = 1.1$ to be ‘‘low’’ and $q = 1.7$ to be ‘‘high’’ for 2-inch (5.08 cm) diameter classes. Our calculation of the expected number of trees showed that an ‘‘intact’’ diameter distribution should have 26.6 trees/ha in the 5–105 cm diameter classes, indicating a deficit of 15.3 trees/ha (Table 1). As expected, the entire deficit was accounted for in the 5–25 cm diameter classes.

We considered the possibility that the entire distribution curve might be depressed – i.e., that all diameter classes might be proportionally reduced by management practices – so we computed diameter class totals for curves representing 20, 25, 30, and 40 total trees/ha as a measure of sensitivity. In these alternative distributions, the majority of change in total number of trees per hectare occurred in the 5–25 cm classes, suggesting that the observed q-factor has little impact on the number of large trees. Eq. (2) was also used to compute the number of trees needed in the zero (i.e., seedling) diameter class. According to the modeled curve, there should be 9.1 seedlings/ha in the present stand, or approximately 7–14 ha^{-1} in the alternative density scenarios.

Table 1
Number of trees calculated based on the negative exponential model and possible stocking scenarios

					Trees 5 to 105 cm dbh				
DBH class (cm)	**N/ 44.5ha**	**N /ha**	**Model N / 44.5 ha**	**Model N/ha**	**20/ha**	**25/ha**	**30/ha**	**35/ha**	**40/ha**
5	7	0.16	301.41	6.77	5.10	6.37	7.65	8.92	10.20
10	45	1.01	224.75	5.05	3.80	4.75	5.70	6.65	7.60
15	59	1.33	167.58	3.77	2.83	3.54	4.25	4.96	5.67
20	53	1.19	124.96	2.81	2.11	2.64	3.17	3.70	4.23
25	54	1.21	93.18	2.09	1.58	1.97	2.36	2.76	3.15
30	71	1.60	69.48	1.56	1.18	1.47	1.76	2.06	2.35
35	53	1.19	51.80	1.16	0.88	1.10	1.31	1.53	1.75
40	44	0.99	38.63	0.87	0.65	0.82	0.98	1.14	1.31
45	37	0.83	28.80	0.65	0.49	0.61	0.73	0.85	0.97
50	19	0.43	21.48	0.48	0.36	0.45	0.54	0.64	0.73
55	17	0.38	16.01	0.36	0.27	0.34	0.41	0.47	0.54
60	10	0.22	11.94	0.27	0.20	0.25	0.30	0.35	0.40
65	9	0.20	8.90	0.20	0.15	0.19	0.23	0.26	0.30
70	7	0.16	6.64	0.15	0.11	0.14	0.17	0.20	0.22
75	5	0.11	4.95	0.11	0.08	0.10	0.13	0.15	0.17
80	1	0.02	3.69	0.08	0.06	0.08	0.09	0.11	0.12
85	4	0.09	2.75	0.06	0.05	0.06	0.07	0.08	0.09
90	3	0.07	2.05	0.05	0.03	0.04	0.05	0.06	0.07
95	2	0.04	1.53	0.03	0.03	0.03	0.04	0.05	0.05
100	1	0.02	1.14	0.03	0.02	0.02	0.03	0.03	0.04
105	1	0.02	0.85	0.02	0.01	0.02	0.02	0.03	0.03
Sum	**502**	**11.3**	**1182.5**	**26.6**	**20.0**	**25.0**	**30.0**	**35.0**	**40.0**
Trees per ha in seedling class				**9.1**	**6.8**	**8.5**	**10.3**	**12.0**	**13.7**
Total trees per ha				**35.7**	**26.8**	**33.5**	**40.3**	**47.0**	**53.7**

4. Discussion and conclusion

Because of the long history of human intervention in Zagros forests, as elsewhere in Iran, reference conditions representing natural stand structure are lacking. As a result, it is necessary to assess the status of Qalajeh forest on the basis of theory and in the context of other Zagros forests. In other studies of Zagros forests, traditional management practices have produced negative exponential and normal (Gaussian) diameter distributions (Ebrahimi et al., 2003; Ghazanfari et al., 2004). These diameter distributions tend to be right-truncated, with few or no trees exceeding 55 cm diameter (Ghazanfari et al., 2004). Stands exhibiting somewhat normal distributions are typically not intended to be managed as even-aged stands; rather, the diameter distributions are an unintended consequence of utilization. Therefore, the number of trees in the smallest size classes is low enough to warrant concern over long-term sustainability.

de Liocourt (1898) and Meyer and Stevenson (1943) reported that the diameter distributions of uneven aged forests are characterized by a negative exponential distribution. The change in number of trees between successive size classes is a constant ratio (q-factor). In theory, stand structures described by such distributions are possible to maintain indefinitely. As a result, residual diameter distributions defined by constant q-factors are widely used in formulating uneven-aged management prescriptions (Frank and Blum, 1978; Marquis, 1978; Leak et al., 1987; Guldin, 1991; Lamson and Smith, 1991; Murphy et al., 1991). Determination of appropriate q-factors, as well as optimal stocking rates, may be determined through analysis of natural, uneven-aged stands. In contrast, normal diameter distributions are characteristic of even-aged stands. Trees in these stands become established and grow as a single cohort, with little regeneration expected to occur during most of the life of the stand. Although structural diversification may occur by stand re-initiation if the stand becomes old enough (Oliver and Larson, 1990), even-aged stands are commonly succeeded by another single cohort following a stand-replacing event.

Based on diameter growth rates observed in Qalajeh forest (Zangeneh, 2003), we estimate that the decline in regeneration of wild pistachio began at least 50 years ago. Factors likely to be responsible for decreasing regeneration in this forest include overgrazing, absence of desirable seedbed, lack of seeds because of use as food, and decreasing the forest canopy. Of these, overgrazing is the probably most important factor. Not only are seedlings killed directly, but trampling appears to reduce suitability of the seedbed. Sparse forest canopy is also important, because the ameliorating effects of shade on seedling survival are more important than the negative effects of competition. In fact, once established wild pistachio may be a superior competitor. Drought may be considered a factor; El-Moslimany (1986) suggested that expansion of Zagros forests is limited by the ability of seedlings to survive the 4-month summer drought. Although the reduction in establishment over the past 40 years may be partly attributable to increasing heat and drought related to climate change, more research is required to separate the relative impacts of each factor.

Although it may be possible that some Zagros forests exhibited even-aged behavior in their natural state, possibly in response to extreme drought or stand-replacing fire, the even-aged model is not applicable in light of traditional management practice. There is no history of, or plan for, even-aged management under traditional use systems. As a result, in Zagros forests we must conclude that stand structures approximating normal diameter distributions represent potentially unsustainable conditions. In the wild pistachio component of Qalajeh forest, such is the case. The diameter distribution curve of wild pistachio trees in Qalajeh forest indicates that this forest is unsustainable because of decreasing regeneration during the last century.

In Qalajeh forest, the diameter distribution of wild pistachio may be cause for both hope and concern. On one hand, the presence of very large trees and their distribution along a predictable curve suggest that local management practices may be compatible with long term retention—i.e., the right tail of the curve represents an apparently natural rate of attrition and lack of artificial right-truncation. In this respect, Qalajeh forest appears to be less severely degraded than other Zagros forests. On the other hand, the progressive reduction in number of trees in diameter smaller than 30 cm indicates that problems with regeneration have worsened over the past 40 or 50 years. However, given the expected diameter distribution revealed in this study, it may be possible to restore the wild pistachio component of Qalajeh forest to a sustainable structure. Reliable field methods of wild pistachio seedling production are known (Arefi et al., 2006). Given the sensitivity of seedlings to drought and other potential causes of mortality, planting densities may need to be much higher than the 7–14 trees/ha suggested by our diameter distribution curve. Based on conditions at Qalajeh forest, we recommend that planting densities should not be lower than 30 seedlings/ha. Assuming successful seedling establishment, the remaining, potentially limiting factors to recovery are the ability of young trees to survive under current climatic conditions, and the ability of those who manage the forest to protect young trees from grazing. Assuming that solutions to early survival are found, restoration and sustainability should be possible.

Acknowledgements

We thank J. Long for comments on an early version of this manuscript. This manuscript was prepared in part by an employee of the U.S. Forest Service as part of official duties and is therefore in the public domain.

References

Arefi, H.M., Abdi, A., Saydian, S.E., Nasirzadeh, A., Nadushan, H.M., Rad, M.H., Azdoo, Z., Ziedabadi, D.D., 2006. Genetics and breeding of *Pistacia atlantica* in Iran. Acta Hortic. 726, 77–81.

de Liocourt, F., 1898. De l' amenagement des sapinieres. Soc. For. Franche-Comte Belfort Bull. 6, 369–405.

Ebrahimi, R.M., Latifi, G., Bodaghy, E., 2003. The role of *Pistacia atlantica* in forest management of outside Caspian area of Iran. Iranian Journal of Forest and Poplar Research, a Special Issue: The Second National Symposium on Wild Pistachio. No. 333, 518–542 (in Persian).

El-Moslimany, A.P., 1986. Ecology and late-quaternary history of the Kurdo-Zagrosian oak forest near Lake Zeribar, Western Iran. Vegetatio 68, 55–63.

Esmail-pour, A., 2001. Distribution, use and conservation of pistachio in Iran, in: Padulosi, S., Hadj-Hassan, A. (Eds.), Toward a Comprehensive Documentation and Use of Pistacia Genetic Diversity in Central and West Asia, North Africa and Europe. Report of the IPGRI Workshop, December 14–17, 1998, Irbid, Jordan, pp. 16–26.

Frank, R.M., Blum, B.M., 1978. The selection system of silviculture in spruce-fir stands: procedures, early results, and comparisons with unmanaged stands. U.S. Department of Agriculture Forest Service Northeastern Forest Experiment Station Research Paper NE-425, p. 15.

Ghazanfari, H., Namiranian, M., Sobhani, H., Mohajer, R.M., 2004. Traditional forest management and its application to encourage public participation for sustainable forest management in the northern Zagros Mountains of Kurdistan Province, Iran. Scand. J. For. Res. 19 (Suppl. 4), 65–71.

Guldin, J.M., 1991. Uneven-aged BDq regulation of Sierra Nevada mixed conifers. West. J. Appl. For. 6, 27–32.

Javanshah, A., Facelli, E., Wirthensohn, M. (Eds.), 2006. Proceedings of the IVth International Symposium on Pistachios and Almonds, Tehran, Iran, May 22–25, 2005, Acta Horticulturae, vol. 726, p. 724.

Kaska, N., Kuden, A.B., Ferguson, L., Michailides, T. (Eds.), 1995. First International Symposium on Pistachio Nut, Adana, Turkey, October 20–24, 1994, Acta Horticulturae, vol. 419, p. 425.

Lamson, N.I., Smith, H.C., 1991. Stand development and yields of Appalachian hardwood stands managed with single-tree selection for at least 30 years. U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station Research Paper NE-655.

Leak, W.B., Solomon, D.S., DeBald, P.S., 1987. Silvicultural guide for northern hardwood types in the Northeast (revised). U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station Research Paper NE-603. p. 36.

Marquis, D.A., 1978. Application of uneven-aged silviculture and management on public and private lands, in: Unevenaged Silviculture and Management in the United States, Washington, DC, U.S. Department of Agriculture Forest Service, Timber Management Research, pp. 165–182

Meyer, H.A., Stevenson, D.D., 1943. The structure and growth of virgin beech-birch-maple-hemlock forests in northern Pennsylvania. J. Agric. Res. 67, 465–484.

Murphy, P.A., Baker, J.B., Lawson, E.R., 1991. Selection management of shortleaf pine in the Ouachita Mountains. South. J. Appl. Forest. 15, 61–67.

Oliver, C.D., Larson, B., 1990. Forest Stand Dynamics. McGraw-Hill, New York, p. 467.

Pourhashemi, M., Mohajer, M.R.M., Zobeiri, M., Amiri, G.Z., Panahi, P., 2004. Identification of forest vegetation units in support of government management objectives in Zagros Forests, Iran. Scand. J. For. Res. 19 (Suppl. 4), 72–77.

Razavi, S., 2006. Pistachio production, Iran vs. the World. Acta Hortic. 726, 689–694.

Zangeneh. H., 2003. Ecological requirements of *Pistacia atlantica* in Kermanshah Province, Iran. J. For. Poplar Res. Special issue: The Second National Symposium on Wild Pistachio. No. 333, pp. 122–130 (in Persian).