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Growth parameters of *Pinus nigra* J.F. Arnold and *Picea abies* (L.) H. Karst. plantations and their impact on understory woody plants in above-timberline mountain areas in the north of Iran

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Abstract

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We investigated the growth parameters of 20-year-old plantations of *Pinus nigra* J.F. Arnold and *Picea abies* (Linnaeus) H. Karsten and their impact on understory woody plants and we compared them with a natural stand in above-timberline mountain areas. 30 sample plots (each of 400 m^2 in area) were systematically established on each site. Tree height, DBH, collar diameter, crown diameter and crown length of all trees were measured in each sample plot. The results of the diameter growth analysis of both species covered by this study showed higher numerical values in *P. nigra* than in *P. abies*. On the contrary, what was observed for data concerning height growth, showed higher numerical values in *P. abies* than in *P. nigra*. These conclusions showed that *P. nigra* has a lower slenderness ratio than the other species and is therefore more resistant to the adverse weather. Considering the effects on biodiversity, the planting of *P. nigra* showed a significant increase in density and species richness of woody plants while it decreased the diversity and evenness compared to the natural stands and plantations of *P. abies*.

Keywords: ecotone; slenderness ratio; tree species importance value; woody species diversity

Pinus sp. is a dominant genus of forest plantations. More than 40% of the world's forest plantations are planted with pines (Brown, Ball 2007). Pine plantations can provide significant economic, environmental and social benefits (Solberg 1996) useful to achieve multipurpose objectives. Pine plantations are playing an increasingly important role in facing the world's growing demand for wood and non-wood forest products (Jaakko 1999). Many pine plantations, mostly *Pinus nigra* J.F. Arnold, are carried out for environmental purposes as well as soil and water conservation, biodiversity preservation, and aesthetic aspects (Hartley 2002; Nagaike 2002). Biotic effects, including increases in understory cover and species richness (Lugo 1992; Chiarucci 1996), and abiotic effects, such as reduced soil moisture and fertility (Clough 1991), are documented in pine plantations in a variety of ecosystems (Khanhasani et al. 2009, Eshaghi Rad et al. 2014). The total Iranian forest area is estimated at 12.4 million ha, about 7.3% of the total land area (Marvi Mohadjer 2012). The forest plantation area is estimated at 944,000 ha (61% by broadleaved species and 39% by conifer species) (FAO 2005).

The development and success of forest plantation depend on the suitability of land, careful site and species selection, good management and silvicultural techniques. Black pine (*P. nigra*) is not a native coniferous species planted in different sites and climate conditions in Iran. Its impact on plant diversity is unknown in Iran. This pine is native to Europe and Asia and its range extends from Spain and Morocco to Eastern Turkey, and from Cyprus to north-east Austria and the Crimea region in Russia; its height reaches 50 m on native sites The main purpose of most conifer plantations changed from timber production to the hydrogeological protection and forest restoration (Hartley 2002; Nagaike 2002; Pourbabaei, Poorrahmati 2009; Tabari et al. 2011; Pourbabaei et al. 2012). Plantations established for site rehabilitation on degraded land can increase biodiversity, provide improved soil structure, increase soil organic matter and fertility, and improve the local microclimate (Jaakko 1999; Nagaike 2002; Brown, Ball 2007). They are also used in order to provide ecological corridors between protected areas, control water runoff, provide shelter from wind, heat and sand storms, and lower water tables in saline areas (Solberg 1996; Brown, Ball 2007).

The control of water runoff and soil erosion, protection of species diversity and wildlife habitats are other important goals of forest plantations with timber production. Conservation of forest biodiversity is one of the central targets in sustainable forest management (Burton et al. 1992; Brockerhoff et al. 2008). Research showed the importance of biodiversity in maintaining ecosystem productivity and stability in addition to retaining non-timber and alternative forest resources (Burton et al. 1992). Plant species diversity was widely studied in the plantation ecosystems (Hartley 2002; Nagaike et al. 2006; Newmaster et al. 2006; Koonkhunthod et al. 2007; Pourbabaei et al. 2012; Eshaghi Rad et al. 2014). The selection of suitable species for specific growing conditions is important in maximizing the productivity and quality of a plantation. When non-native plant species are introduced successfully into novel habitats, they can affect all organisms of the recipient ecosystem (Leege, Murphy 2000). A study reported that plantation of exotic pine species had a significant effect on a reduction of biodiversity and species richness, and changed vegetation structure in *Notofagus dombeyi* de Mirbel Ørsted forests in Chile (Paritsis, Aizen 2007). Single species plantations are often criticized for being associated with a low level of biodiversity in the ecosystems (Montagnini et al. 1995; Lindenmayer, Hobbs 2004). It was demonstrated that wider planting spacing (sparser plantations) caused higher richness, lower abundance of woody species and higher coverage of herbaceous species in pine plantations on abandoned agricultural land (Newmaster et al. 2006). Moreover, it was indicated that light absorption of pine needles and their litterfall had a negative impact on plant diversity (Newmaster et al. 2006). The effect of plantation with *Cupressus sempervirens* var. *horizontalis* (Miller) Loudon and *Pinus brutia* Tenore on plant species diversity was studied in the north of Iran (Pourbabaei et al. 2012). Results showed that the plant species diversity indices in the plantation were lower than in the adjacent natural broadleaved forest (Pourbabaei et al. 2012). In some studies, diameter and height growth of *P. nigra* plantation were investigated in the north and north-west of Iran (Gholizadeh et al. 2011; Eshaghi Rad et al. 2014). Adaptability of some non-native conifer tree species was studied in the Kurdistan province of Iran (Fattahi 1994).

Foresters and forest researchers need to evaluate any case in order to find the best solutions of forestry intervention and forest harvesting in pine plantations preserving their timber production and non-timber (ecological) benefits (Marchi et al. 2014; Cambi et al. 2016). For example, a key factor to estimate these methods is the work system, full tree or tree length system, in relation to soil fertility and prevention of wildfires (Picchio et al. 2012; Cambi et al. 2017). Considering correct forest road network planning during the realization of a new pine plantation, it is important to pay attention to both forestry and environmental purposes (Corona et al. 2015; Picchio et al. 2018).

In order to guarantee sustainable management of these stands, it is necessary to construct a strategy for conserving biodiversity in plantation ecosystems. To achieve ecologically sustainable forest management, it is widely recognized that plantations must not only provide wood, but also serve various other functions, including biodiversity conservation (Hansen et al. 1991; Nagaike 2002; Tavankar, Bonyad 2015).

There is a lack of information about the potential effects of different types of management regime on diversity patterns for many forest communities (Roberts, Gilliam 1995). The maintenance of biological diversity is an important component of sustainable forest management.

Our research hypotheses were: (*i*) growth parameters of two planted species (*P. nigra* and *Picea abies* /Linnaeus/ H. Karsten) are different, (*ii*) they have different effects on density and species diversity of understory woody plants in above timberline areas. The aims of this research were: (*i*) estimation of growth parameters of plantations with *P. nigra* and *P. abies*, (*ii*) analysis of plantation effects on species diversity of understory woody plants, and (*iii*) comparison of understory woody plant species diversity in plantations with adjacent natural stand as the control.

MATERIAL AND METHODS

Study area. This study was carried out in the area above timberline ecotones of Hyrcanian forests, with an altitude from 1,550 to 1,650 m a.s.l. in Ardebil province, north of Iran (latitude 38°26'51''N to 38°27'11''N, longitude 47°36'10''E to 47°36'57''E). The climate is cold mid-arid (aridity index, $I = 16.1$), according to De Martonne climate classification (De Martonne 1926), with mean annual temperature of 9.1°C and average rainfall of 309 mm per year. The average temperatures during the hottest and coldest months are 15.5 and 3.6°C, respectively (Anonymous 2005; Ghasemi Aghbash et al. 2006). The average annual humidity value is 67.3%, 51.4% in summer and 83.1% in winter. Most days of the year have a lot of wind, and most of the precipitation is in the form of snow. There are about 130 frost days throughout the year. The soil texture is clay-loam and the bedrock is typically limestone (Anonymous 2005; Ghasemi Aghbash et al. 2006). The original vegetation of this area is an uneven-aged mixed forest dominated by *Quercus macranthera* von Fischer & C.A. von Meyer (ex Hohenacker) and *Carpinus orientalis* Miller, black pine (*Pinus nigra* var. *caramanica* (Loudon) Rehder) and Norway spruce (*P. abies*) were planted on each area of 20 ha in 1997. Planting spacing was 3 m × 4 m (833 stems per hectare). In the first planting year, late and severe ground frost destroyed about 60% of the planted seedlings. In the following years, severe ground frost during spring also destroyed a large number (10 to 20%) of young seedlings (Anonymous 2005). These plantation areas were protected by barbed wire against animal grazing and human disturbance. During this period, neither timber nor firewood was extracted from the plantations.

Data collection and analysis. Systematic sampling by 30 sample plots in each site, each of 400 m^2 (20 m × 20 m) in area (Pourbabaei et al. 2012), was established in all three sites: (*i*) *P. nigra* plantation, (*ii*) *P. abies* plantation, (*iii*) natural stand (control plot). Grid dimensions were 75 m × 75 m. Tree height – h (m), DBH (cm), collar diameter (CD), crown diameter (CrD) and crown length (CrL) of all trees were measured in each sample plot. The h and CrL were measured with a clinometer (Suunto, Finland) in dm, DBH and CD were measured using a calliper (Waldmeister, Germany) in mm, and CrD was measured with a tape on the ground in cm.

The slenderness coefficient (SC) was calculated using the ratio of h to DBH, as Eq. 1 (Bonyad, Tavankar 2014):

$$SC = \frac{h}{DBH} \quad (1)$$

Species importance value (SIV) for each species was calculated by summing the relative values of density (RD), frequency (RF) and dominance (RDo), as Eq. 2 (Ganesh et al. 1996; Krebs 1999):

$$SIV = RD + RF + RDo \quad (2)$$

Basal area considered for dominance and relative dominance was calculated by Eq. 3 (Amoroso et al. 2011; Pourbabaei et al. 2013):

$$RD = \frac{\text{basal area of each species} \times 100}{\text{total basal area of all species}} \quad (3)$$

The species diversity index was computed using the Shannon-Wiener information function – H' (Krebs 1999; Sharma et al. 2009; Pourbabaei et al. 2012; Tavankar, Bonyad 2015), as Eq. 4:

$$H' = -\sum \frac{n_i}{n} \log_2 \frac{n_i}{n} \quad (4)$$

where:

n_i – SIV of a species,

n – the sum of total SIVs of all species.

The species evenness index was computed using Pielou's evenness index (J), as Eq. 5:

$$J = \frac{H'}{\ln S} \quad (5)$$

where:

S – total number of species in each plot (species richness).

Eq. 6 calculated the stem volume (SV) of each planted tree:

$$SV = \left(\frac{\pi}{4}\right)\left(DBH^2\right) \times h \times f \qquad (6)$$

where:

f – form factor, its calculated values were 0.3925 and 0.4163 for *P. nigra* and *P. abies* respectively.

Normality of data and equality of variances were checked by Kolmogorov-Smirnov and Levene's tests, respectively. ANOVA and Duncan's tests were used for the analysis of species indices (H', J and S) and tree density in three sites. Independent t-test was used for comparing means of h, DBH, CD, CrD, CrL, SC, and SV between *P. nigra* and *P. abies* plantations. The relationship between the following parameters in *P. nigra* and *P. abies* was analysed by a regression method: DBH-h, DBH-CrD, DBH-CrL, h-CrD, DBH-SV, and DBH-SC.

RESULTS

The growth of *P. nigra* in relation to *P. abies*

Average DBH of *P. nigra* (22.6 cm) was significantly ($P < 0.01$) higher than in *P. abies* (17.3 cm) (Table 1). The *P. nigra* DBH growth average (11.05 mm·yr^{-1}) was significantly ($P < 0.01$) higher than that of *P. abies* (8.45 mm·yr^{-1}), while *P. abies* tree height average (9.12 m) and its height growth (0.43 m·yr^{-1}) were significantly ($P < 0.01$) higher compared to the same parameter of *P. nigra* (8.04 m) as well as its average of tree height growth (0.38 m·yr^{-1}). Even the *P. nigra* stem volume average (0.1775 m^3) and the growth of stem volume (0.0089 m^3·yr^{-1}) were significantly ($P < 0.01$) higher than the criteria of judgment used for *P. abies*: stem volume (0.1184 m^3) and growth (0.0039 m^3·yr^{-1}).

Structure curves in both plantations describe an almost normal shape (Fig. 1a). The maximum density of stem sizes in *P. abies* plantation (67 stems per hectare) was for DBH of 16 cm, and for *P. nigra* plantation (58 stems per hectare), it was for DBH of 21 cm.

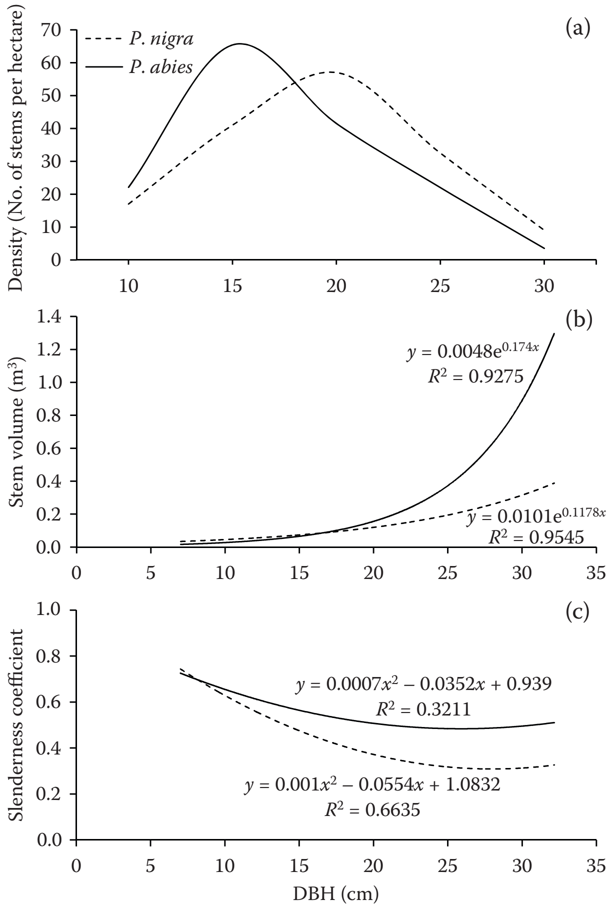

Fig. 1. Density (a), stem volume (b), h/DBH (c) in relation to DBH of trees in 20-year-old plantations of *Pinus nigra* J.F. Arnold and *Picea abies* (Linnaeus) H. Karsten

The relationship between stem volume and DBH was significant ($P < 0.01$) and of J shape in both plantations (Fig. 1b). *P. abies* stem volume was growing more dynamically from DBH of 15 cm in comparison with *P. nigra*.

The mean ± standard deviation of *P. abies* SC (0.55 ± 0.10) was significantly ($t = 8.16$; $P < 0.01$) higher than the mean of *P. nigra* SC (0.38 ± 0.11). The relationship between SC and DBH was significant ($P < 0.01$) and SC decreased with increasing DBH in both species (Fig. 1c).

Table 1. Growth parameters (mean ± standard deviation) of 20-year-old plantations of *Pinus nigra* J.F. Arnold and *Picea abies* (Linnaeus) H. Karsten, and results of t-test

Parameter	*P. nigra*	*P. abies*	*df*	t-value	P-value
DBH (cm)	22.6 ± 7.1	17.3 ± 5.6	58	4.68	0.000
DBH (mm·yr^{-1})	11.05 ± 3.2	8.45 ± 2.2	58	5.34	0.000
Height (m)	8.04 ± 1.5	9.12 ± 2.2	58	2.69	0.008
Height (m·yr^{-1})	0.38 ± 0.08	0.43 ± 0.11	58	2.72	0.007
Volume (m^3)	0.1775 ± 0.1186	0.1184 ± 0.0778	58	6.37	0.000
Volume (m^3·yr^{-1})	0.0089 ± 0.0059	0.0059 ± 0.0039	58	3.42	0.001

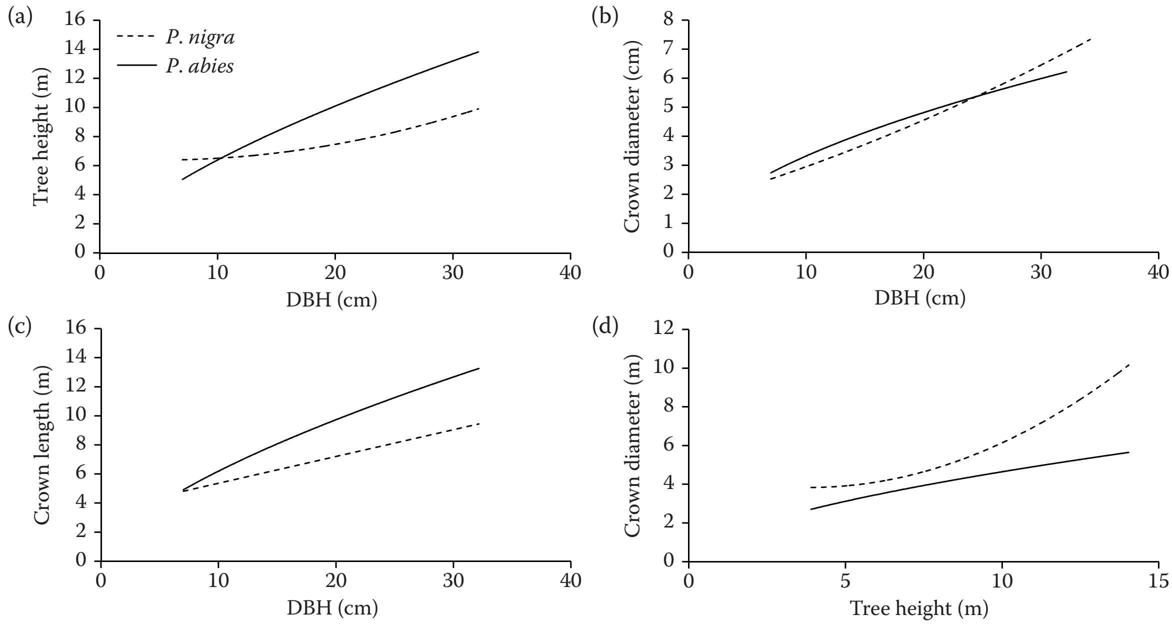

Fig. 2. Relationships between DBH and tree height (a), crown diameter (b), and crown length (c), and tree height and crown diameter (d) in plantations of *Pinus nigra* J.F. Arnold and *Picea abies* (Linnaeus) H. Karsten

The relationships between DBH and *h*, DBH and CrD, DBH and CrL, and *h* and CrD were direct and significant ($P < 0.01$) in both species (*P. nigra* and *P. abies*) (Fig. 2 and Table 2). The *h* value of *P. abies* was higher than *h* of *P. nigra* at DBH of more than 10 cm (Fig. 2a). CrD of *P. abies* was higher than CrD of *P. nigra* at DBH of more than 25 cm (Fig. 2b). CrL of *P. abies* was higher than CrL of *P. nigra* at all DBH values (Fig. 2c). CrD of *P. nigra* was higher than CrD of *P. abies* at all *h* values (Fig. 2d).

Effects of plantation on stand and biodiversity indices

Totally 24 woody species from seven families were recorded in the sample plots (Fig. 3). The family Rosaceae with 14 species had the highest number of woody species in the study area; those were: *Rosa canina* Linnaeus, *Crataegus microhylla* K. Koch, *Rosa iberica* Steven, *Pyrus syriaca* Boissier, *Rubus caesius* Linnaeus, *Prunus spinosa* Linnaeus, *Rubus hirtus* von Waldstein & Kitaibel, *Prunus divaricata* von Ledebour, *Malus orientalis* Uglitzk., *Sorbus orientalis* Schönbeck-Temesy, *Rubus hyrcanus* Juzepczuk, *Sorbus torminalis* (Linnaeus) Crantz, *Mespilus germanica* Linnaeus and *Crataegus melanocarpa* Marschall von Bieberstein. The family Fagaceae had two woody species that include *Q. macranthera* and *Quercus castaneifolia* C.A. von Meyer. The families Corylaceae, Caprifoliaceae, and Aceraceae, each had also two woody species; *C. orientalis* and *Corylus avellana* Linnaeus from Corylaceae, *Lonicera caucasica* Pallas and *Viburnum lantana*

Table 2. Regression models of tree growth in 20-year-old plantations of *Pinus nigra* J.F. Arnold and *Picea abies* (Linnaeus) H. Karsten

Parameters	Tree species	Equation	R^2 adjusted	*df*	SE	*F*-value	*P*-value
DBH-*h*	*P. nigra*	$h = 0.0047(\mathrm{DBH})^2 - 0.0461(\mathrm{DBH}) + 6.50$	0.450	155	1.13	14.1	0.000
	P. abies	$h = 1.3966(\mathrm{DBH})^{0.6605}$	0.586	155	0.17	170.1	0.000
DBH-CrD	*P. nigra*	$\mathrm{CrD} = 0.0015(\mathrm{DBH})^2 + 0.1161(\mathrm{DBH}) + 1.64$	0.754	155	0.66	50.1	0.000
	P. abies	$\mathrm{CrD} = 0.9636(\mathrm{DBH})^{0.5373}$	0.515	155	0.15	129.6	0.000
DBH-CrL	*P. nigra*	$\mathrm{CrL} = 0.1841(\mathrm{DBH}) + 3.5277$	0.553	155	1.06	40.5	0.000
	P. abies	$\mathrm{CrL} = 1.3823(\mathrm{DBH})^{0.6515}$	0.571	155	0.17	162.0	0.000
h-CrD	*P. nigra*	$\mathrm{CrD} = 0.0608(h)^2 - 0.4662(h) + 4.73$	0.298	155	1.12	8.00	0.002
	P. abies	$\mathrm{CrD} = 1.2396(h)^{0.5741}$	0.423	155	0.17	91.1	0.000

h – height, CrD – crown diameter, CrL – crown length, *df* – degree of freedom, SE – standard error

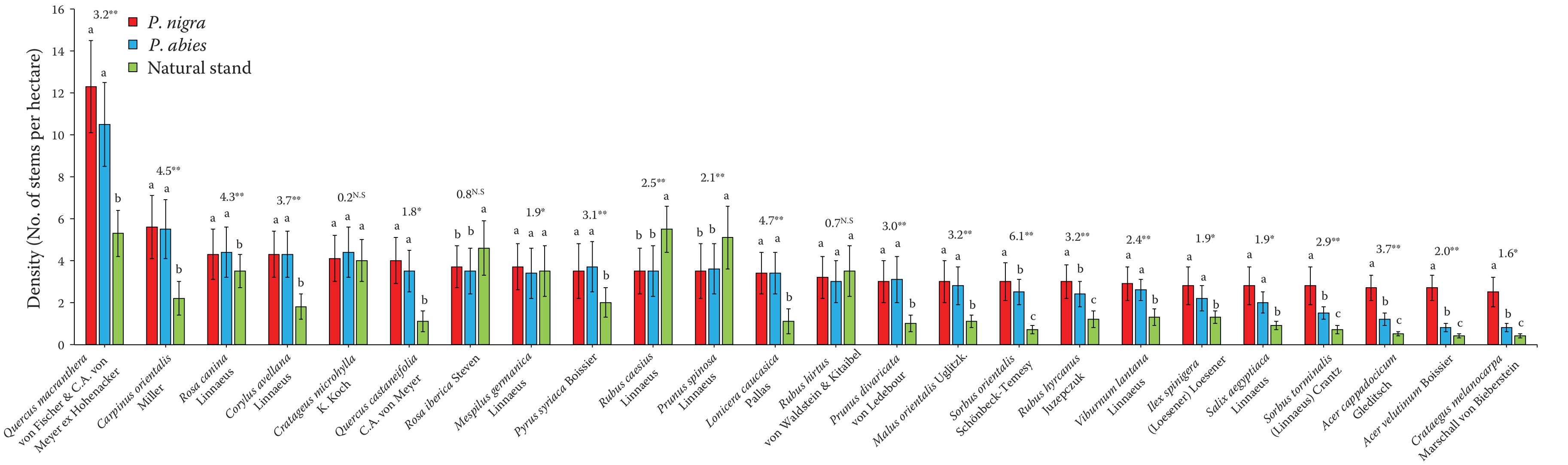

Fig. 3. Density (mean ± standard deviation) of native woody plants in 20-year-old plantations of *Pinus nigra* J.F. Arnold, *Picea abies* (Linnaeus) H. Karsten and in natural stand, and results of ANOVA and Duncan's tests; *F*-values: *significant at α = 0.05, **significant at α = 0.01, N.S – not significant; different letter in columns indicates significant difference at α = 0.05

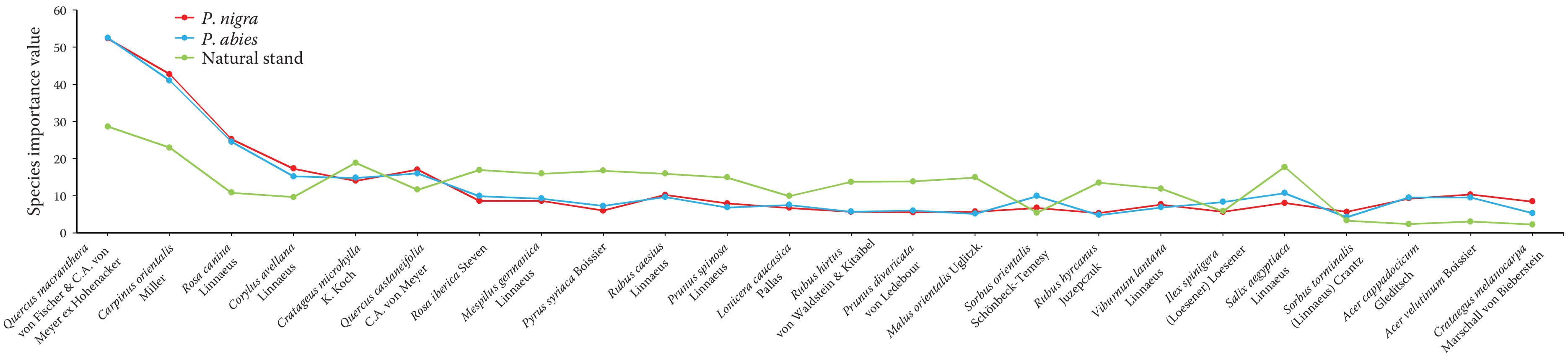

Fig. 4. Species importance value of tree species in the plantations of *Pinus nigra* J.F. Arnold, *Picea abies* (Linnaeus) H. Karsten and in natural stand

Table 3. Biodiversity indices in the plantations of *Pinus nigra* J.F. Arnold, *Picea abies* (Linnaeus) H. Karsten, and in natural stand, and results of ANOVA and Duncan's tests

Index	*P. nigra*	*P. abies*	Natural stand	*F*-value	*P*-value
Diversity	4.02 ± 0.22^{b}	4.18 ± 0.26^{b}	4.68 ± 0.46^{a}	32.39	0.000
Evenness	0.68 ± 0.11^{a}	0.63 ± 0.10^{a}	0.46 ± 0.09^{b}	75.05	0.000
Richness	7.57 ± 1.69^{b}	8.23 ± 1.72^{b}	10.46 ± 2.24^{a}	19.16	0.000

Linnaeus from Caprifoliaceae, *Acer cappadocicum* Gleditsch and *Acer velutinum* Boissier from Aceraceae. Each of the two families Aquifoliaceae and Salicaceae had one woody species (*Ilex spinigera* (Loesener) Loesener and *Salix aegyptiaca* Linnaeus, respectively).

Woody species density in the plantation with *P. nigra* (90 stems per hectare) was significantly ($P < 0.01$) higher than in the plantation with *P. abies* (79 stems per hectare) and in natural stand (53 stems per hectare). Density of *R. iberica*, *R. caesius*, and *P. spinosa* in natural stand was significantly ($P < 0.01$) higher than their density in both plantations with *P. nigra* and *P. abies*, while density of *Q. macranthera*, *C. orientalis*, *R. canina*, *C. avellana*, *Q. castaneifolia*, *P. syriaca*, *L. caucasica*, *P. divaricata*, *M. orientalis*, *S. orientalis*, *R. hyrcanus*, *V. lantana*, *I. spinigera*, *S. aegyptiaca*, *S. torminalis*, *A. cappadocicum*, *A. velutinum* and *C. melanocarpa* in both plantations with *P. nigra* and *P. abies* was significantly higher than their density in natural stand (Fig. 3).

This index comprising all woody species is almost equal in the plantations of *P. nigra* and *P. abies* (Fig. 4). SIV of *Q. macranthera*, *C. orientalis*, *R. canina*, *Q. castaneifolia*, *S. orientalis*, *S. torminalis*, *A. cappadocicum*, *A. velutinum* and *C. melanocarpa* in the plantation stands was higher than their SIV in the natural stand, while SIV of other woody species in the natural stand was higher than the plantation stands.

The species diversity index value in the natural stand (4.68) was significantly ($P < 0.01$) higher than in the plantations (Table 3). The species evenness index value in the plantations was significantly ($P < 0.01$) higher than in the natural stand, while the species richness value in the natural stand (10.5 species) was significantly ($P < 0.01$) higher than the same values in the plantations.

DISCUSSION

The concept of sustainable forestry emphasizes the maintenance of both ecological and economic values of managed forests (Hansen et al. 1995; Moore, Allen 1999). However, for some forests practices, such as afforestation, there is a lack of information about the potential effects of different types of management on diversity patterns. This study developed a discussion about differences in growth parameters of two planted species (*P. nigra* and *P. abies*), and effects on density and species diversity of understory woody plants in above-timberline areas.

Tree growth

Results proved that the *P. nigra* DBH growth (11.05 $mm \cdot yr^{-1}$) was higher than in *P. abies* (8.45 $mm \cdot yr^{-1}$), while the height growth value of *P. nigra* (0.38 $m \cdot yr^{-1}$) was lower than in *P. abies* (0.43 $m \cdot yr^{-1}$). These results showed that *P. nigra* has a lower slenderness ratio than the other species and therefore it is more resistant to windthrow. This is very important in terms of stand resistance against windthrow because the lower slenderness ratio leads to higher mechanical resistance of trees (Picchio et al. 2011).

In a research, DBH and height growth of a 40-year-old plantation with *P. nigra* were reported 4.6 $mm \cdot yr^{-1}$ and 0.29 $m \cdot yr^{-1}$, respectively, in the north-west of Iran at an altitude of 1,327 m a.s.l. (Eshaghi Rad et al. 2014). The reported values of DBH and height growth for *P. nigra* were lower than the results obtained from our research. The reason for the growth difference could be due to different tree age. DBH and height growth usually decrease increasing age of trees in plantations (Mosadegh 2005; Bonyad 2006).

DBH and height growth of a 19-year-old plantation with *P. nigra* in two altitudinal classes in northern Iran were reported 5.2 $mm \cdot yr^{-1}$ and 0.41 $m \cdot yr^{-1}$, respectively, at lower altitude (450 m a.s.l.), and 3.8 $mm \cdot yr^{-1}$ and 0.69 $m \cdot yr^{-1}$, respectively, at higher altitude – 1,000 m a.s.l. (Gholizadeh et al. 2011). Lower growth of DBH and higher growth of height in *Pinus nigra* showed how the altitude of the plantation can be influential. Usually, the growth of DBH increases with increasing altitude, while the growth of height decreases as the same parameter increases.

The growth and the adaptability of some non-native conifer tree species are studied in the northwest of Iran (Kurdistan province). The results of this research showed that *P. nigra* (30-year-old plantation) with DBH growth of 3.2 $mm \cdot yr^{-1}$ and height growth of 0.11 $m \cdot yr^{-1}$ had good growth, classifying this species as a wide adaptation species (Fattahi 1994). The values of DBH and height growth of *P. nigra* reported in Kurdistan province are much lower than the values obtained from the present research. This might be due to lower precipitation and temperature in the Kurdistan plantation compared to the study site.

DBH and height growth of 35-year-old plantation with *P. nigra* were reported 5.9 $mm \cdot yr^{-1}$ and 0.44 $m \cdot yr^{-1}$, respectively (Leege, Murphy 2000). Average stem volume of *P. nigra* was 0.1775 m^3 while average stem volume increment was 0.0089 $m^3 \cdot yr^{-1}$. A study on stem volume and stem volume increment of 30-year-old *P. nigra* plantation in Turkey reported much lower values: 0.076 m^3 and 0.0031 $m^3 \cdot yr^{-1}$, respectively (Özel, Ertekin 2010). The reported cover of understory vegetation was lower in *P. nigra* stands than in the adjacent non-pine stands, while the number of woody stems in *P. nigra* stands was significantly higher than in the adjacent non-pine stands (Leege, Murphy 2000).

The results showed that *h* had a positive relation with the tree stem DBH in both species. The height of *P. abies* was taller than that of *P. nigra* in the same DBH classes. This result can be indicative of higher resistance of *P. nigra* to wind compared to *P. abies*. CrD had a positive relation with tree DBH. Therefore, the values of CrD are predictable from values of DBH. In addition, CrL had a positive relation with tree DBH. CrD had also a positive relation with *h* in both species. The CrD of *P. nigra* was larger than that of *P. abies* in all *h* classes. These growth models can be used for management and regulation of stand structure in plantations of these tree species.

Plantation effects on woody species diversity

Management of conifer plantations has strong and variable effects on plant species occurrence and diversity (Moore, Allen 1999; Pourbabaei et al. 2012). Conifer plantations can change in stand structure, landscape structure and physical environments (Brosofske et al. 2001; Tavankar, Bonyad 2015).

According to the results, in *P. nigra* plantation density and species richness of woody species significantly increased, while diversity and evenness of woody species decreased compared with natural stand and *P. abies* plantation.

High density and richness of woody species in pine plantations indicate the high potential of this stand for biodiversity restoration in the studied site. Different plant and animal species that guarantee the environmental health have adapted to native trees thus native tree species should accompany non-native tree species in plantations (Hartley 2002). Plantations contribute to biodiversity conservation variously. Another study (Pourbabaei, Poorrahmati 2009) found a high similarity in species composition between plantation and adjacent natural forest, in this case the natural forest was an important seed source. Neighbourhood of plantation and natural forest resulted in the dispersion of hardwood tree seeds within the plantation. Leege and Murphy (2000) indicated that *P. nigra* plantation has alerted understory species composition and diversity.

Various studies found that plantations of native or non-native timber species can increase biodiversity by promoting woody understory regeneration (Carnevale, Montagnini 2002).

Numerous studies have shown that establishment of plantations or restoration plantings on degraded lands can ameliorate unfavourable microclimatic and soil conditions, and provide habitats for seed-dispersing wildlife, thereby greatly accelerating natural forest regeneration (Parrotta et al. 1997; Carnus et al. 2006). Plantations are most likely to contribute positively to biodiversity conservation when they are used to reforest degraded or deforested areas (Tavankar, Bonyad 2015). Establishment and growth are difficult for woody species in above-timberline (high altitudes) sites. Plantations of *P. nigra* and *P. abies* caused an increased woody species density in comparison with the natural site. An increase of woody species density occurred along with an increase of woody species evenness in both plantations. Increasing density and evenness of woody species are very important from an ecological viewpoint. This result indicates that plantations provide a suitable site for establishment and growth of seeds of natural woody species. Increasing density of different woody species can lead to structural diversity. Increasing structural complexity could attract seed-dispersing wildlife and thus increase seed inputs from neighbouring native forest (Koonkhunthod et al. 2007). The two main woody species whose density was increased by plantations are *Q. macranthera* and *C. orientalis*. Species richness and diversity were shown both to decrease (Richardson et al. 1989) and to increase (Chiarucci 1996) in pine stands, depending on the initial conditions. Exotic plantations can help to restore native biota in degraded sites by stabilizing soil and creating suitable site conditions for native animals and plants to recolonize (Lugo 1992).

CONCLUSIONS

Conservation of biological diversity is one of the important goals of managing forests in an ecologically sustainable way, particularly with respect to the potential cumulative effects of forest management practices. In this research, we investigated the growth parameters of *P. nigra* and *P. abies* 20-year-old plantations and their impact on natural woody species density and diversity in the above-timberline mountain areas in the north of Iran. The loss of a large number of seedlings in the early years of plantation, due to the severe ground frost during spring, indicates the harshness of conditions in the study area. Therefore, correct management practices through the selection of suitable seedling age and planting time, and their support in the first few years after planting, play a key role in the success rate of the plantation with *P. nigra* and *P. abies* in the study area. Height growth of *P. abies* was higher than height growth of *P. nigra*, while diameter growth of *P. nigra* was higher than diameter growth of *P. abies*. Density and diversity of understory woody species in *P. nigra* plantation were higher than in *P. abies* plantation and in natural stand. Due to the increased density and species richness of woody species plants in the plantation sites, *P. nigra* is suitable for biodiversity maintenance, natural stand structure, soil conservation, and it prevents erosion in the above-timberline forests. This species can be considered much more effective than Norway spruce in relation to forest restoration.

According to these results, correct management of pine plantations is very important in terms of sustainable forest management. Intensity, type and time of thinning are important management issues in conifer species plantations.

According to the results the species *P. nigra* and *P. abies* are suitable for plantings in the above-timberline areas in the north of Iran, for non-timber, ecological and environmental aims.

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