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Effect of climate on the growth of dominant and suppressed Norway spruce (*Picea abies*)

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Abstract

Competition in forest stand is one of the key factors which governs both radial and height growth of a tree. Although this factor has been of a great concern for foresters but little is known about the interaction of competition and climate on radial growth of trees. In this research, the effect of competition on growth trend and the relationship between climate and tree-ring width of dominant and suppressed Norway spruce (Picea abies L. Karst) were studied in a plantation with fertile soil, located at 5° lower latitude than natural distribution of this species. Results showed that in the studied plantation, competition between two social classes is mainly for nutrient rather than light and the beginning of suppression was seven years after the onset of competition. Although suppressed trees showed a continuous decline in wood increment since after, but the effect of climatic factors especially minimum temperature was more pronounced in these trees rather than dominant ones. It was concluded that if the environment of a Norway spruce tree becomes harsher – even as a result of competition, it will react more sensitively to unfavorable exogenous factors. From the silvicultural point of view it was also confirmed that interplanting with the studied spacing and timing (three years delay) will practically be inappropriate. Further studies considering trees of middle height classes in natural forests are encouraged to consolidate or challenge the results of this study

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Introduction

Stand competitive dynamics is a key factor in forest stand evolution. This process is defined as sharing limited resources between neighboring trees, which leads to a reduction in performance, alteration in growth trend and/or survival of the trees. Therefore, competition has long been known as a capital process controlling stand size, structure and diversity (Weiner 1990, Oliver and Larson 1996). One of the key resources for competition between trees in forests is light. Competition for this resource alters the shape of tree growth and its social status, because taller trees shade on shorter ones, and so strongly affect their growth (Weiner 1990). Dependency of tree growth on competitive influence of neighboring trees, in most yield studies, has been regarded as a fundamental hypothesis (Smith and Bell 1983). To study the effect of competition on trees, not only the current status of the tree should be considered, but also the past competition history of the tree is of considerable importance (Cole and Lorimer 1994).

Norway spruce (*Picea abies* L. Karst) is one of the most important European tree species from the viewpoint of its growth rate, wood properties and its sensitivity to climate (Rybníček *et al.* 2010), and is among the top five most productive forest trees. This species belongs to the mountainous ranges of the Holarctic, European flora. The latitudinal range of natural occurrence of this species are from 69˚47′N in Norway to 41˚45′N in Macedonia and Greece (Boratyǹska 2007). With the characteristics mentioned above, competitive dynamics of this species in either mixed or pure stands is of considerable importance.

The contrasting climatic conditions in Asia offer plenty of opportunity to study relationships between trees and their adaptation to local climatic conditions by relating their ring-width to corresponding environmental factors (Bräuning 2013). However, social status of a tree has been mostly ignored in data analyzing of these researches and in a few studies taking into account this property, contradictory results has been obtained. Stand competition has been reported to have a minor effect on tree-ring growth compared to other variables in Norway spruce (Meyer and Brk̈er 2001) but suppressed Pines showed lower growth reductions than those of dominant trees (Dario *et al.* 2008).

Forestry models used by managers were developed using common static measures of site productivity without direct consideration of fluctuating climatic variables, and it is very important detection the relationship between climate and tree-ring width of dominant and suppressed Norway spruce.

The aim of this study is an effect and competition on growth trend and b) the relationship between climate and tree-ring width of dominant and suppressed Norway spruce in a plantation far away from its native range.

Materials and methods

Materials

The study was conducted on a 40 year old Norway spruce trial plantation located in the Mazandaran province forests, Iran (36˚ 04′ 09″ N 53˚ 09′ 53″ E; 1553 m. a.s.l.). Mean annual temperature and sum of annual precipitation are, 12ºC and 426 mm, respectively (Average from 1974-2008) (Fig. 1). Total area of plantation is about 2400 m² and the initial spacing between trees was 1×1 meter, which at the sampling time had risen up to 2m as a result of self-thinning (Oliver and Larson 1996). The only silvicultural practice applied to the stand was interplanting three years after the primary plantation in 1974.

Five diameter classes (5cm interval) were determined (10-30) in the stand and diameter at breast height (DBH) and height of seven trees in each class were measured. These data was used to obtain a height–diameter (H–D) model to simulate height growth trend during the period (1974-2011). Finally, a full inventory was conducted to obtain stand dominant height, and diameter and height distribution.

Methods

To measure ring-widths, four dominant and six suppressed trees, based on social status, were selected randomly from the highest and the lowest height classes (Meyer and Brker 2001), felled and 10 cm thick discs were cut off from DBH of each tree (Table. 1). The discs were visually investigated for probable eccentricity or compression wood which were absent in all samples. A stripe was prepared in a radius from pith to the bark of each disc (Fig. 2), sanded using fine-grain sandpapers (400, 1000 and 1500 grid) and scanned using a high resolution scanner (4800 dpi). The last 5 or 6 rings of suppressed trees had extreme narrow rings which were pictured under a stereo-microscope. Scanned and stereo-microscopic images were transferred to Corel draw X5 (Corel®) and ring-width measurements were done in 0.01 mm accuracy. After determining absence of missing and false rings, tree ring series were visually cross-dated within and between two groups.

Annual radial growths of trees were averaged within each group to calculate and compare the competition effect on radial growth trend.

In order to investigate climate–ring width relationship, monthly climatic data (average, minimum and maximum temperature, and sum of precipitation) were obtained from the nearest meteorological station for the period of 1974 to 2008. To asses growth-diameter dependence in both groups, an autocorrelation test using ARIMA procedure has been conducted, and to investigate climate response of both groups, standardization was carried out in two steps (Cook and Peters 1981, Mäkinen *et al.* 2002). Finally, correlation between both standardized and raw ring width with climatic variables (from the previous year October to the current year September) were tested separately using Pearson correlation coefficients. All statistical analysis was done using SAS 9.3 (SAS®).

Results

Tree ring width

Tree ring width variations of supressed and dominat trees between the years 1974 to 2011 are shown in figure 3. As can be seen, the competition began in 1985 when common slope of the curves turned negative. At this year, dominant and suppressed trees were at the age of 11 and 8, respectively (according to DBH ring count). However, ring width variations of both groups followed a homogenous trend with almost the similar intensity until 1992; since when tree ring width in suppressed trees dramatically and continuously declined. Hence, the beginning of suppression was seven years after the onset of competition, when a sharp decline was observed in radial growth trend of trees. All suppressed trees were those of interplanted, and growth trend in these trees was highly affected by competition pressure, but dominant trees have shown little pressure of competition.

Table 1. Characteristics of studies trees.

Tree No.	Diameter	Height	Group	Rings count
1	8.5	11.8	Suppressed*	25
2	9.2	10.9	Suppressed*	26
3	10	13.6	Suppressed*	22
4	12	14.1	Suppressed*	22
5	10.3	11.2	Suppressed	27
6	10	12	Suppressed*	28
7	25.7	22.1	Dominant	38
8	29	22.7	Dominant	37
9	27.1	21.8	Dominant	38
10	21.7	20.8	Dominant	31

* Interplanted trees.

Interplanted seedlings had the opportunity to justify their growth in the first 10 years, but they couldn't compensate delayed growth (Fig. 4) and suppressed after the onset of competition. Just one of the suppressed trees (No. 5) does not belong to interplantings.

However, suppressed trees were still alive at the time of sampling, radial growth ceased in all of them between 1999 to 2005(on avereage at the age of 28). Meanwhile, crown of these trees has been deteriorated from the lower parts upward. At this time estimated mean heights of dominant and suppressed trees were 136 and 808 centimeters, respectively (Fig.4). Growth halt of suppressed trees led to a promoting shift in ring width of dominant trees during 1995 to 2006. One of the dominant trees (No.4) stopped growing because of intense light competition with neighbours at final stages.

ARIMA procedure

The results of ARIMA procedure showed high autocorrelation in the first and second lags in ring width of suppressed trees (Fig. 5).

To simulate height growth trend, a power model was fitted to diameter data (R^2=0.996):

$$H = -0.0315 * d^2 + 1.6711 * d \qquad \text{(Eq. 1)}$$

where H is tree estimated height in meters and d is tree diameter in centimeters.

Height growth curves

Height growth curves of both suppressed and dominant trees, as depicted in figure 4, shows a declining slope, but it is sharper in suppressed trees compared to dominant ones. Slope of the suppressed trees curve equals to zero at the end of the curve when the radial growth stopped.

Correlation analysis has shown interesting results. Standardized ring width of dominant trees had no significant correlatin with climate and suppressed trees were only significantly correlated with June precipitation (P=0.0002). However, raw ring width of dominant trees were correlated with minimum temperature of march (r=-0.35), precipitation of may (r=0.35), and precipitation of july (r=-0.36) at <0.05 significance level. Surprisingly, raw ring width of suppressed trees showed a very high correlation with minimum and average temperature of almost all months during and before growing season. Correlation coefficients of dominant and suppressed trees with monthly minimum temperature are shown in figure 6.

Discussion

Tree ring width

Suppression of interplanted trees may be a result of prosperity of dominant trees in competition for light as they were planted three years earlier and therefore established better. Competition for light has a major control on growth curve (Weiner 1990), so main part of difference between dominant and suppressed growth trend could be caused by light competition. Pacala *et al.* (1996) assumed that light is the major defining factor of forest structure, however, with regard to a sudden increase in ring width of dominant trees after the growth halt in suppressed trees it can be assumed that suppressed trees do not compete for light; instead they suffer light extinction after their crown are covered by dominant and co-dominant ones. Here, it is possible that the competition between two groups is for nutrient, and this is a logical reason for such growth shift. In accordance with our findings, Coomes and Allen (2007) in a study on *Nothofagus solandri* showed that light competition is just between taller trees, and competition on nutrient occurs between all the neighbors. Although as the stand ages, the pressure of competition intensifies (Corona and Ferrara 1989), but it seems that the pressure is severe on suppressed trees, so that the last rings didn't produce (Fig.3).

Generally, ring width decreases outward from the pith (Saranpää 2003), and larger growth reductions were observed in smaller crown classes in some conifers and deciduous trees (Mäkinen *et al.* 2002, Kunstler *et al.* 2011). As presented here, our results are in agreement with these general ideas. Moreover, they show that the timing and intensity of these trends highly depends on social status of a tree. This is in contrast with the findings of Meyer and Brk̈er (2001) in which they found that growth variation of a tree does not depend on social status of the tree. Comparing our results with the results of Zubizarreta-Gerendiain *et al.* (2012), it is intresting to see that the growth trend of suppressed trees are almost the same as the clones of south finland, at least for the first 22 years. However, there is more intense competition pressure here, because the spacing between trees in establishment time is half of the stands studied by Zubizarreta-Gerendiain. This may be partly due to a higher temperature of studied site (as a result of a lower latitude), and higher irradiance (as a result of higher altitude) which leads to a greater growth rate in our site.

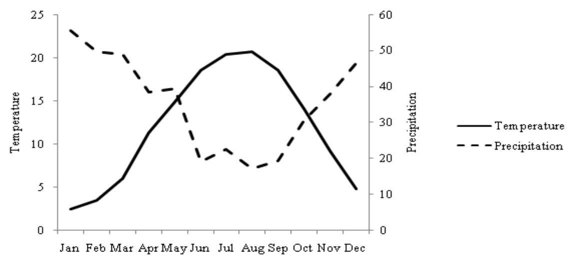

Fig. 1. Mean monthly temperature and precipitation of the study area during 1974-2011.

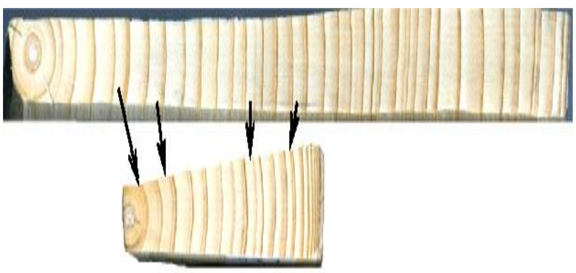

Fig. 2. Strip cuts of dominant and suppressed trees with cross-dated rings.

ARIMA procedure

The growth of dominant trees didn't show such a sharp declining trend, although there is a decreasing trend in growth after the onset of competition. It can be concluded that if the spacing was more distant, and interplanting wasn't done, the trend might have been more closer to that of dominants for whole stand, and the sharpness of curve reduced. Kunstler *et al.* (2011) showed that by increasing the temperature and water budget, the competition importance of this species changes significantly. This may be the cause of much of the difference between the growth curve of dominant and suppressed trees.

High autocorrelation in suppressed trees (Fig. 5) implies that the more the competition pressure, the more the growth-diameter dependency. Our results confirms that the first and even the second order autocorrelation increases as the relative size of the tree decreases (Mäkinen *et al.* 2002).

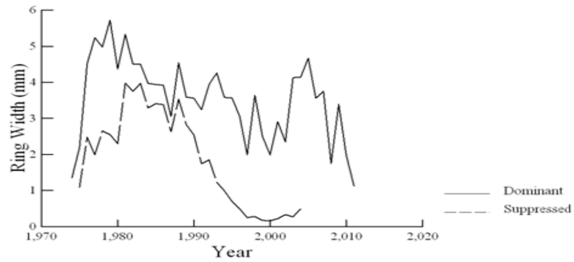

Fig. 3. Mean ring widths of dominant and suppressed trees.

With a precise look at height trend (Fig. 4), we may conclude that the difference in height and establishment time of seelding has a determinant effect on social status of the tree in the future. This results demonstrate that tree height represents a good descriptor of competition dynamics (Castagneri *et al.* 2008), and is a determinant factor of social status of the tree (Meyer and Brk̈er 2001). Besides, we showed that the past competitive status has a determinant effect on current social status of the tree (Cole and Lorimer 1994).

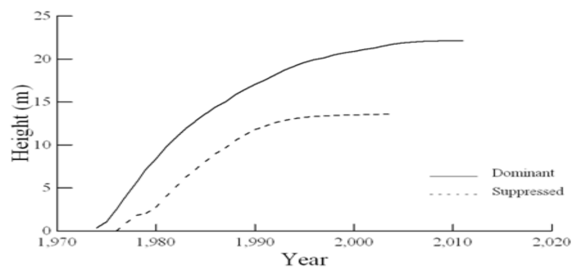

Fig. 4. Height-growth curve of dominant and suppressed trees of the target stand.

We found significant correlation between June precipitation and suppressed trees ring indices, which is contrary to findings of Mäkinen *et al.* (2002) and Rybníček *et al.* (2010), which found such relationships for dominant trees. Highly significant correlation between raw ring widths of suppressed trees and climate is partly because the climate generally had a positive trend during the period. Our results are in contrary to the assumption that dominant trees are more sensitive to climate, as they are less affected by competition, and the suppressed ones are less capable of reacting with climate because of larger autoccorrelation (Phipps 1982, Mäkinen *et al.* 2002); Instead, our results demonstrated that, because of lower avalibility of resources, smaller trees react faster and more severely to unfavorable climate (Abrams and Mosteller 1995).

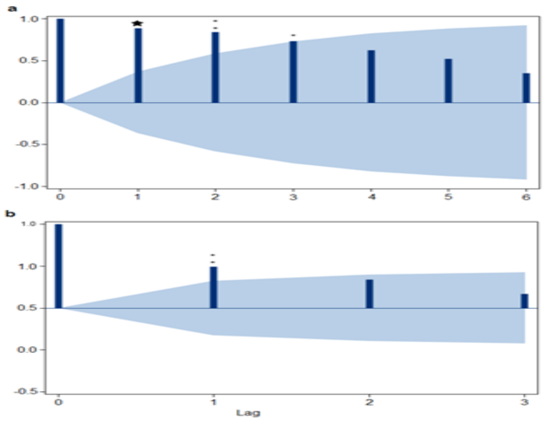

Fig. 5. Autocorrelation of growth curves in (a) suppressed and (b) dominant trees. Significance levels: ✱ :<0.0001, **: 0.01, *: 0.05. Blue area shows two standard errors.

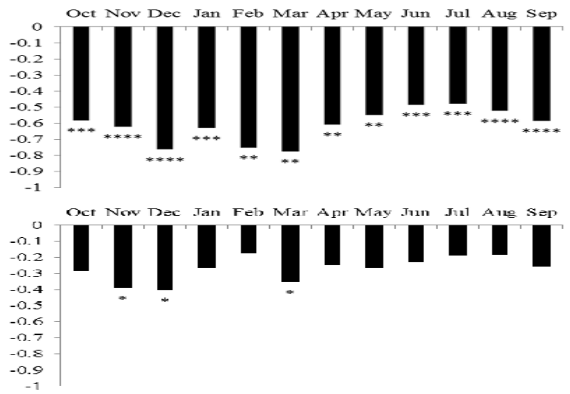

Fig. 6. Climate ring correlation of monthly minimum temperature during past October to current September in (a) suppressed and (b) dominant trees. Significance levels: ****: 0.0001, ***: 0.001, **: 0.01, *: 0.05.

Zubizarreta-Gerendiain *et al.* (2012) showed that trees that grown on fertile sites react less than others to climatic factors. This may be the reason that in our study the dominant trees didn't react with climate significantly. Besides, after finding such high correlation for suppressed trees, it may imply that suppressed trees have suffered nutrient inavalibility, so acted like trees on low fertility sites.

Conclusion

In this article the effect of competition on growth trend and ring width-climate relationships were studied on four dominant and six suppressed trees on a trial plantation. In brief, the results showed that: 1) competition has a determinant effect on growth trend of Norway Spruce trees, 2) height is the main determinant factor of social status of trees and even a little height difference at establishment time can determine social status of tree in the future, 3) interplanting with the density of our study site has negative effect on stand, and therefore is unprofitable, 5) climate response of trees has inverse relationship with nutrient avalibility, even if this inavalibility is a result of competition, and 6) tree ring-width standardization can dramatically alter the results of climate-ring relationships (Tessier *et al.* 1997) and 7) Considering unstandardized tree ring width, the influence of unfavorable climatic factors such as minumum temprature is greater on the supressed trees than on dominant ones.

Although in this study, the difference of growth trend among individual trees in each group was not considerable, it is recommend to increase the sample size in future studies in order to consolidate the results proposed here. It is also a possibility that the contrasting relations between climate and tree growth ,considering standardazed and raw tree ring widhs, is partly affected by the low number of samples. Besides, we simply studied the growth trend between just two extreme height classes (suppressed and dominant), so that can not confidently be extrapolated to middle height classes, even in a homogenous plantation. The studied plantation was on a fertile forest soil, at 5° lower latitude than natural distribution of Norway spruce and as discussed by Mäkinen *et al.* (2002) these differnces may explain some inconsistency between our results and others.

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