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Do changes in spatial distribution, structure and abundance of silver fir (*Abies alba* Mill.) indicate its decline?

Andrej Ficko, Ales Poljanec, Andrej Boncina*

University of Ljubljana, Biotechnical Faculty, Department of Forestry and Renewable Forest Resources, Vecna pot 83, 1000 Ljubljana, Slovenia

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ABSTRACT

Silver fir decline was investigated based on changes in spatial distribution of fir, fir abundance in forest stands, dbh (age) structure of fir, and abundance of fir regeneration. The authors used a large-scale approach to study the dynamics of silver fir over nearly 40 years. Based on Silva-SI, a spatial information system, the majority of total forest area in Slovenia was analysed for changes in the distribution of silver fir in the period 1970–2008 using artificial neural networks (ANNs), with respect to site, stand, and forest management variables. Additionally, changes in abundance of silver fir (hereafter fir) in the same period were analysed with a general linear model, while changes in the dbh structure of fir and fir regeneration were analysed with non-parametric tests. Most selected indicators confirmed the hypothesis of fir decline in the period 1970–2008, as evidenced by a reduction in the area of forests with a share of fir in the total growing stock >25% (from 18.9% to 9.5% of total area), a reduction in the share of fir in the growing stock of forest stands (from 17.5% to 7.5%), ageing of the fir population, and a disproportionate share of fir saplings in the total saplings relative to fir's share in the growing stock of forest stands. A 1.5% increase in fir distribution area in the observed period contradicts the decline hypothesis. ANNs showed that the spatiotemporal dynamics of fir was most affected by four variables: forest type, share of fir in the potential natural vegetation, mean annual precipitation, and mean annual temperature. The latter two, together with the growing stock at the start of study period, the degree of connectivity between fir stands, and bedrock type, were significant predictors of decline of fir abundance in forest stands. Significant differences in spatiotemporal dynamics and changes in fir abundance were found between forest types representing a complex of site conditions and past forest management. A further decline of abundance of fir on a large spatial scale in the next decades is expected. Conservation of fir in forest stands will depend mainly on the successful regeneration of fir and sufficient recruitment.

1. Introduction

Silver fir (*Abies alba* Mill.) is one of the most common tree species in Central Europe, along with European beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* Karst.). It is also found in other regions such as the Pyrenees and the Balkans (Ellenberg, 1996). Silver fir (hereafter fir) has frequently received particular attention from foresters and researchers. This is partly because there has been a long tradition of forest management in Central and Southeast Europe in areas where the natural share of fir is significant (e.g. Kramer, 1992; Horndasch, 1993; Brändli, 1996). But mainly it is because of fir's economic, environmental, and social significance combined with its intensive decline in the last decades (e.g. Elling et al., 2009) and problems concerning natural regeneration (e.g. Motta, 1996).

Fir is a typical shade-tolerant late-successional tree species. It appears most commonly in forests with European beech and Norway spruce, but it is also present in forests with hop hornbeam (*Ostrya carpinifolia* Scop.), European oak (*Quercus sessiliflora* Salisb.) and maple (*Acer sp.*) (Ellenberg, 1996). It occurs on a wide range of sites and is most commonly found in the montane vegetation zone. Although it can occur at lower elevations, it is more frequently found at higher elevations, up to approximately 2000 m in the Alps (Chauchard et al., 2010) or even higher, such as in the Pyrenees (Macías et al., 2006). In Europe, forest types where fir is the dominant tree species are divided into multiple groups (e.g. Kuoch, 1954; Mayer, 1974; Ellenberg, 1996; Dobrowolska, 1998), and division based on carbonate or non-carbonate bedrock is frequently emphasised (Barbati et al., 2010).

The composition, structure, and dynamics of forest stands in forest types in which fir does or could occur reflect growth conditions as well as past direct and indirect anthropogenic influences, such as forest management practices, domestic and wild ungulate grazing, and changing environmental conditions (climate changes,

* Corresponding author. Tel.: +386 13203500; fax: +386 12571169.
E-mail address: andrej.boncina@bf.uni-lj.si (A. Boncina).

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pollution, etc.). The first major industrial exploitation of forests – predominantly for glassworks and ironworks – profoundly altered the natural tree species composition and structure of forests in Europe (Johann, 2007). Fir conservation has been significantly affected by forest management systems. For example, in Central Europe fir was frequently the dominant species in selection forests, where it was often promoted for economic reasons while beech was consequently cut. Fir was also promoted due to its high shade-tolerance and its ability to survive long periods in the understory and respond when light conditions become more favourable (Schütz, 2002). Fir is less competitive in areas where management systems caused rapid and major changes in forest stands (e.g. clear cutting). Fir was rarely used in plantations or for planting and seeding in artificial regeneration (Schütz, 2001). Browsing by large ungulates, particularly red deer (*Cervus elaphus* L.), can be a key limitation for the natural regeneration and/or the recruitment of fir (Motta, 1996; Senn and Suter, 2003). Red deer density has fluctuated considerably over the past decades and centuries, and this has had a profound influence on fir regeneration (Klopcic et al., 2010). On the other hand, presumptions about the impact of grazing of domestic animals on fir regeneration and recruitment are slightly different; grazing together with litter raking could have improved the competitiveness of fir and contributed to abundant regeneration (Vrska et al., 2009). Since research on fir decline began in the 1950s, the role of ecological factors has been given increasing importance. The decline was first interpreted as a periphery effect of fir's natural range (Rubner, 1953; Dannecker, 1955). In the 1970s and 1980s widespread decline and even dieback of fir was observed in Central Europe, a phenomenon that was called "fir dieback" (Germ.: »Tannensterben«) (Larsen, 1986; Kandler and Innes, 1995). This raised concerns about the prospects for fir conservation in forest stands. There was a range of opinions regarding the reasons for fir mortality (e.g. Ulrich, 1981; Larsen, 1986; Bert, 1993), but the prevalent notion was that growth depression of fir between 1970 and 1990 was caused by SO_2 in a complex interaction with climatic and biotic factors (Eckstein et al., 1983; Elling et al., 2009). Climate change is believed to have had an adverse impact on the growth performance of autochthonous fir populations in Europe in the last decades. Macías et al. (2006) found an increasing water-stress effect on radial growth of fir during the last half of the 20th century in the Pyrenees. In the Mediterranean region, Battipaglia et al. (2009) showed that fir is more sensitive to drought and changes in the seasonal distribution of precipitation than non-native spruce.

Some (e.g. Gagov et al., 2003) see the future in intensifying fir provenance trials and culturing southern and south-eastern and drought-resistant provenances. Reduced fir vitality may increase its susceptibility to biotic impacts such as xylophagous insects, mistletoe, and fungi, which could in turn play an important role in the further decline of fir (Oliva and Colinas, 2010; Solla et al., 2006).

Tree species decline is most commonly described as a persistent, long-standing decline of tree species abundance and/or as a decline of species distribution area (Manion and Lachance, 1992). The decline of species abundance and its distribution area can result either from increased mortality or decreased fertility (i.e. regeneration, recruitment), or from both processes. Due to increased mortality rate and poor regeneration, several population characteristics, such as age or dbh structure, change. Fir decline was most commonly recognised by the decreasing vitality of firs, which resulted in higher mortality rates. Research on the influence of poor regeneration and insufficient recruitment on fir's decline is less frequent (Motta, 1996; Prietzel and Ammer, 2008). The decline of a tree species may be described with indicators such as habitat loss, decrease of tree species abundance, population ageing, and inadequate regeneration (or even no regeneration). To date no large-scale study of changes in distribution or abundance of fir populations in the last few decades has been published. Although fir decline has been indicated by the results of some national forest inventories (e.g. ÖWI, 2002; BWI 2, 2004), most studies have been limited to smaller study areas (e.g. Manetti and Cuttini, 2006) or individual impact factors (e.g. Heuze et al., 2005; Oliva and Colinas, 2010). It is thus unclear whether changes in fir distribution and abundance are similar in different forest types or whether there are significant differences among forest types.

Using Slovenia as a study area (22,230 forest compartments, 7446 km^2, classified into four forest types), the first objective of our study was to examine changes in distribution and abundance of fir in the main forest types in which fir is present, in the period for which relatively reliable data on stand parameters are available (1970–2008). The goal was to identify areas of habitat loss and/or fir expansion and to explain the processes giving rise to these changes using variables associated with site and stand conditions, and forest management practices. The second objective was to determine changes in fir abundance and dhb structure in stands in which fir was already present in 1970, and relate any changes to the above-mentioned variables. We tested two hypotheses. The first hypothesis is that fir declined in the period 1970–2008. This can be shown by a reduction in fir distribution area, a reduction in fir abundance in the total growing stock of forest stands, ageing of the fir population, or insufficient regeneration. The second hypothesis is that the rate of fir decline varies depending on the forest type.

2. Data and methods

2.1. Study area

Forests in Slovenia are a suitable test area for studying changes in fir abundance and distribution in forest stands due to (1) the relatively high proportion of fir (7.9%) in Slovenian forests, as compared to other European countries; (2) the variety of natural conditions in a small area (the Alps, the Dinaric mountains, the Sub-Mediterranean and the Pannonian basin); (3) the variety of management techniques practiced in different areas over the past decades and centuries; and (4) the abundance of available data on forest stands in the past. Forests cover 11,400 km^2, which represents 58% of the total land area of Slovenia. Elevation ranges from 40 m to 1900 m above sea level, with most of the area consisting of mountain ranges of medium height. Climate conditions vary from Sub-Mediterranean in the Southwest to temperate humid in the central part of the area and continental in the Northeast. Mean annual temperature is 8 °C and varies from 2 °C in the mountains to 11 °C in the lowlands (ARSO, 2004a). Mean annual precipitation ranges from 3000 mm in the western mountainous region to 800 mm in the eastern part of the study area (ARSO, 2004b). Karstic terrain and clastic sedimentary rock cover most of the territory, while the presence of felsic, igneous and various metamorphic rocks is rarer. The predominant soils are cambisols and leptosols.

The forests are characterised by small-scale management using mainly irregular shelterwood systems. Mean growing stock is 272 $m^3\ ha^{-1}$, and mean annual increment is 6.6 $m^3\ ha^{-1}$. Norway spruce (32%) and European beech (32%) account for the highest proportion of the growing stock, followed by fir (8%) (SFS, 2009a). The zonation of forest vegetation is quite clearly defined due to distinctive orographic factors, different bedrock, and well-preserved forest structure. According to the terminology of the Ministerial Conference on the Protection of Forests in Europe (EEA, 2006), the forests in the study area are classified into eight European forest categories (EFCs) and 14 forest types (EFTs) (Matijasic and Boncina, 2006). EFCs reflect distinctive and unique patterns of human impacts sensu modification of species composition,