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Review paper

A review of the influence of climate change on coniferous forests in the Balkan peninsula

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Abstract: Evidence of climate change and global warming is becoming more visible; it is an ongoing process that is likely to become increasingly influential in the near future, not only at the global level but also at the local and regional levels. The fact that climate change affects the development of all forest communities and forest tree species, accordingly, has resulted in the increasing awareness in society towards this phenomenon. Having this in mind, the main aim of this paper is to evaluate the relationship between climate change and coniferous forests in the Balkan Peninsula, as well as to review the management strategies that may contribute to forest adaptation to climate change, with a special emphasis on the conservation of forest genetic resources. Hence, we have analyzed 202 papers regarding climate change and its effects on coniferous forests in the Balkan region, as well as papers dealing with adaptive forest management and forest genetic resources conservation. We concluded that climate change will likely represent one of the major challenges for coniferous forests on the Balkan peninsula in the future, imposing a need for the application of different management strategies to address these challenges and to facilitate adaptation of forests to the altered environmental conditions.

Keywords: climate change, adaptive management, genetic resources, coniferous forest.

1. Introduction

The interaction between plants or forests as well as their development on one hand and climate on the other hand has always been the focus of scientific research. The effects of climate action near the plant directly affect the physiological processes (Morison and Morecroft, 2008). Starting from the fact that plants are related in every way to the climate, it can be said that climate change has an impact on the whole development of plants (trees) and on their distribution. Although there is more data explaining the manner and type of impact of climate change on plants, we have tried to make a concise analysis of the impact of climate change on the development of coniferous species in the Balkan Peninsula. Therefore, first, we need to broaden our understanding of plants` responses to climate change.

New climate change research is expected to make the impact of climate change more visible on the world's forest ecosystems. But forests are an important link in the system for dealing with climate change and even reducing their impact on society. A large number of well-documented cases are emerging of ecosystem change due to recent climate change (Walther et al. 2002). Therefore, forests have become widely studied in recent years because of their potential to mitigate climate change risks. Adaptation of forests to climate change is one of the biggest challenges for sustainable forest management. For this, it is necessary to understand the effects of climate change on forest development, as well as to be able to predict how these effects may change over time (Keenan, 2015). Climate change is more visible, therefore novel effects on forests can be anticipated, and innovative and untested response strategies may be required (Millar et al. 2007). For that reason, adaptive management approaches are required (Peterson et al. 2011).

The main aim of this paper is to evaluate the relationships between climate change as a factor that impacts and forests as an object that is affected by climate change. Also, the coniferous forests, especially the forests in the Balkan Peninsula will be elaborated and the adaptive management of the forests will be evaluated. If we like to reduce the impact of climate change on forest development, we have to focus on the adaptable management of forests. Therefore, this paper will contribute to understanding the bridge between climate change, forests and forest management. Finally, this paper will show that climate change has a significant impact on the development of trees and the development process of forests and forest ecosystems.

2. Material and methods

For the purpose of this review, we have analyzed more than 202 papers from different databases such as Web of Sciences, Scopus, Science Direct and web provider google scholar. First of all, we selected the papers with information for special coniferous species of trees (distribution, morphological characteristics, resistance to climate elements, etc.). Secondly, we summarized all research papers which investigate climate and climate change, especially climate change in the Balkan peninsula. Furthermore, we analyzed research papers that deal with dendrochronological, dendroecological, and dendroclimatological investigation, and also papers concerning the relationship between trees and the impact of climate. Finally, we included papers which study adaptive forest management methods and practices and we observed the maintenance of genetic resources. For all of this, we used keywords such as "climate", "climate change", "dendrochronology", "tree ring", "adaptive management", and "genetic resources". We decided to research the conifer forests with *Abies alba* Mill., *Picea abies* (L.) H. Karst, *Picea omorika* (Pancic) Purk, *Pinus sylvestris* L., *Pinus nigra* Arnold, *Pinus peuce* Gris., *Pinus heldreichii* H. Christ in relation with the climate of the Balkan Peninsula.

3. Climate change

In the recent decade, the problem of climate change caused by natural processes as well as anthropogenic factors is a major and important environmental issue (Alexandrov and Hoogenboom, 2000). Greenhouse gas emissions, the impact on green spaces, and the increasing number of industrial facilities are just some of the factors influencing climate (Zalasiewicz and Williams, 2009). An increase of 1-1.5°C is projected over the whole south-eastern Europe domain in the near future (2021-2050) relative to the reference period (1971-2000) (Georgoulias et al. 2022). Even projected Mediterranean warming during the summer season by the end of the century can span from 1.83 to 8.49°C in Coupled Model Intercomparison Project Phase 6 and 1.22 to 6.63°C in Coupled Model Intercomparison Project Phase 5 (Cos et al. 2022).

The linear increasing trend for the mean annual temperature for the Balkan peninsula, calculated since 1960, within 0.2 to 0.3°C per decade is statistically significant for the whole region (Djurdjevic et al. 2019). Additionally, over the past few decades, the occurrence of various extreme events, such as droughts, extreme temperatures, extreme rainfall, and heatwaves, has increased (Spinoni et al. 2015; Marx et al. 2016; Stadtherr et al. 2016; Stagge et al. 2017). The results of the Providing Regional Climates for Impact Studies projection and two periods in the top panels indicate that the regional warming in Balkan Peninsula will be gradual, with both maximum and minimum temperatures, ranging from 1°C to 3°C in the near future (2010–2039), to 3–5°C in the mid-century period (2040–2069) and 3.5–7°C by the end of the century (2070–2099) (Lelieveld et al. 2012). If the average increase in global temperature remains far below 2°C, we will face at least one more degree of warming (Djurdjevic et al. 2019).

Climate analysis for Serbia showed that the average annual minimum temperature has a significantly increasing trend from 1981 to 2010 throughout the country, with a regional average rate of 0,48°C per decade. While the average annual maximum temperature showed a significant increase in the trend for the period 1981-2010, with a regional average rate of 0.56°C per decade (Ruml et al. 2017). Future climate change analysis shows an accelerated increase in temperature by the end of the 21st century. Thus, the temperature increase averaged over the territory of Serbia is 1.2°C for the period 1996 to 2015 with the highest increase of maximum daily temperature during the summer season, 2.2°C. In compliance with Intergovernmental Panel on Climate Change (IPCC) fifth assessment report (AR5), it is estimated that temperature may increase by 1.9°C according to the Representative Concentration Pathway 4.5 (RCP4.5) scenario and by 4.4°C according to the RCP8.5 by the end of the century (Vuković et al. 2018). Also, in the last 30 years (1990-2019) the average temperature in Serbia increased by 1°C (Stojanović et al. 2021). In the first decade of the 21st century, global warming has become increasingly evident in Croatia (Pilaš, 2009), on the other hand, there has been observed a decrease in rainfall in many parts of Croatia (Vrbek et al. 2011). Climate models for the wider area of Split forecast very small changes in annual and seasonal precipitation in the near future (until 2040). For the period 2040–2100, these models forecast an increase of 0.6–4.0°C, on average, in the annual temperature and a reduction of 2–7% in annual precipitation (Margeta, 2022). Montenegro is a country with more types of climates as a result of relief, terrain forms, geographical position, and vicinity of the sea (Burić et al. 2013). But the climate changes also are present here with the fact that from 1950 to 2010 the temperature has risen by 1.3°C, and also from 1980 to 2019 already by 2.0°C (Kostianoy et al. 2020). Climate change is recognized in Macedonia with changes in many climate elements. In the period 1906–2005, there is a linear trend of growth of the average air temperature by 0.74°C. But on a time, scale of 50 years, the trend is even more worrying as there is an increase of 0.13°C per decade in the period from 1956 to 2005 (Karanfilovski et al. 2013). The Asian Pacific Integrated Model constructed four families of scenarios, designated as A1, A2, B1, B2, and predicted that the warming will continue to increase, while precipitation will decrease in the period 2025–2100 (Čarni and Matevski, 2015). In Greece, warming has been particularly noticeable in the last three decades (Founda et al. 2013). The average annual air temperature in Greece could increase from 1.5°C and 3.2°C, for the periods 2021-2050 and 2071-2100 respectively (Kapsomenakis et al. 2013), while precipitation will decrease in winter by 15% (Giannakopoulos et al. 2011) Bulgaria has had many episodes of drought during the twentieth century, especially between 1940 and 1980 (Alexandrov et al. 2004), as a result of decreasing in the mean annual precipitation (Alexandrov and Hoogenboom, 2000). The increasing trend in average air temperature is obvious with the increase of temperatures from 0.7ºC to 0.8ºC per ten years in Bulgaria (Chenkova and Nikolova, 2015). Results for Bosnia and Herzegovina show climate variability. that reflects in rising temperatures, fluctuations in the pluviometry regime, longer and more frequent droughts and floods, and increasing days characterized by tropical air temperatures above 30°C (Trbić and Bajic, 2011; Trbić et al. 2013; Trbic et al. 2018). Thus, for the period from 1961 to 2010, the average temperature has increased from 0.4 to 0.8°C (Mandić et al. 2019). In Albania, the effects of climate change are presented with higher seawater temperatures, changes in frequency and intensity of precipitation, and temperature oscillations (Pojani et al. 2013). The projections indicate variations for the period between 2030 and 2100 for temperature increases from +1.0 to +3.2°C, otherwise annual precipitation reductions are predicted from 8.5% to 18.1% from 2050 to 2100, respectively (Bruci et al. 2016).

In the Balkans region, climate change is proven to manifest its negative impact with more pronounced changes. Temperature data correlates with the IPCC 2021 report Allan et al. (2021) which states that each of the last four decades has been successively warmer than any decade that preceded it since 1850. Global surface temperature in the first two decades of the 21st century (2001–2020) was 0.99°C higher than 1850–1900. The global surface temperature was 1.09°C higher in 2011–2020 than in 1850–1900. The estimated increase in global surface temperature is principally due to further warming from 2003 to 2012 (+0.19°C). In the future, it can be predicted that this region will become dryer and warmer. To have a real insight into climate change and global warming, we need precise regional models for climate change.

4. The impact of climate change on trees and forests

The impact of climate and climate change on forests, is visible; it has different effects on angiosperms and gymnosperms species (Li et al. 2021). Additionally, the worrying fact is that all knowledge and strategies predict that if significant efforts are not made to reduce climate change, their impact will continue increasingly. Thus, in a certain part of Europe, it is predicted that the increased concentration of atmospheric carbon dioxide and the higher temperatures will result in positive effects on forest growth. While the increasing periods of drought will negatively affect forest development (Lindner et al. 2010). On the other hand, soils that retain more water have a positive effect on radial growth during drought events, while forests growing on chernozem (with sand) and solonetz (highly saline soils) are more drought-sensitive and have smaller radial increments (Kostić et al. 2021). It can be concluded that the forest is affected by climate changes, with various implications such as global warming, less precipitation, the appearance of drought, increasing concentration of CO_2, and fires (Lindner et al. 2014).

Climate change has specific impact on cambial activity and tree growth (Begum et al. 2013). The temperature has a significant impact on the relationship between the diameter at breast height and the height of the trees, in that way, tree height increased with increasing mean annual temperature whereas decreased with increasing summer mean maximum temperature (Lu et al. 2021). One more fact is that, with a lot of precipitation, the tree ring widths vary only slightly, while at minimal precipitation the sequence is extremely variable. The availability of light influences the growth of the tree, thus trees that receive poor illumination will produce drastic narrower rings (Schweingruber, 2012). Trees affected by fire (Seifert et al. 2017), storms (Charles and James, 2002), or some silvicultural activities (Manetti and Cutini, 2006) will produce notably different tree rings dimensions in the following year**.** A significant number of studies have shown that certain climatic elements are associated with particular plant communities (Holdrige, 1947; Thornthwaite, 1948; Whittaker, 1975; Walter, 1985; Ravindranath et al. 2006) as well as the distribution area of some species are largely defined by climate at a global scale (Hamann and Wang, 2006; Benito Garzón et al. 2008). It is logical to assume that climate change is going to affect the structure (Solomon, 1986) and ecology of forest ecosystems on a global scale (Kirschbaum and Fischlin, 1996).

4.1. The impact of climate change on evergreen species in the Balkan Peninsula

4.1.1. European silver fir – *Abies alba* Mill.

Silver fir of previous decades is influenced by climate warming and climate change in Central Europe (Büntgen et al. 2014). The future distribution of Silver fir is the subject of debate. Some studies suggest a reduction in response to future warming (Maiorano et al. 2013; Cailleret et al. 2014), while others suggest stable conditions or even expansions (Bugmann et al. 2015). In that way, according to Stojanović et al. (2021) and climate scenarios A1B and A2, the projected reduction of the silver fir distribution range by 2100 could be from one-fifth to one-third of today's habitat in Serbia. Also, according to the climate change scenarios it can be expected that there will be a significant reduction in the Silver fir habitat within the territory of Montenegro (Matovic, 2013). Silver fir is very sensitive to several abiotic and biotic factors (Mauri et al. 2016), particularly SO_2 pollution (Elling et al. 2009). Precipitation and solar radiation can influence Silver fir tree performance and radial growth (Stanhill and Cohen, 2001; Dorado-Liñán et al. 2016). Regarding this, minimum wood density negatively responds to spring precipitation, particularly in dry sites forming the southernmost distribution limit of the species (Camarero and Gutiérrez, 2017). But during the late 20th century the intensification of water stress might affect the future development of the fragmented Silver fir populations in the southwestern distribution limit of the species (Macias et al. 2006). Although the Silver fir is sensitive to drought, it has been observed that the Silver fir has adaptive population divergence in drought tolerance (Csilléry et al. 2019), which means that it may acquire drought adaptability over time. For instance, compared to other species such as the Norway spruce, European beech and Larch, some dendroecological studies demonstrate that the Silver fir is more resistant to drought (Vitasse et al. 2019), especially old trees (Suarez et al. 2004). Also, a longer drying period affect tree growth and development primarily, because after that come some biotic factors such as insects and pathogens. Some insect pests such as mistletoe and bark beetles already have an impact on a reduction of Silver fir in the Mediterranean, especially in those areas where drought stress is more frequent (Durand-Gillmann et al. 2014).

4.1.2. Norway spruce – *Picea abies* (L). Karst.

In the mountainous areas of Central Europe starting in the 1980s, die-back of branches accompanied by yellowing of needles, loss of needles, and reduced growth, even a falling of stems appeared in spruce forests, which can be caused by air pollution (Jansson et al. 2013). On the other hand, in the European Alps until today climate change has had no negative effect on Norway spruce (Hartl-Meier et al. 2014). The natural distribution of this species regarding climate is favourable in the continental type of climate, but thanks to its climatic tolerance it grows even in extreme climates (Savill, 2019). Although, the distribution range is expected to be drastically reduced by the end of the 21st century in Serbia, i.e., 70% and 77% according to A1B and A2 climate scenarios, respectively (Stojanović et al. 2021). Also, according to the climate change scenarios it can be expected that there will be a significant reduction of Norway spruce habitat in the territory of Montenegro (Matovic, 2013). This species is described as a particularly sensitive species to summer drought (Oberdorfer and Schwabe, 2001; Zang et al. 2011; Hartl-Meier et al. 2014), and mean temperature is a more important indicator than precipitation in a way that with the increasing temperature in the previous and current year, the tree-ring width decreases (Matović et al. 2018). Also, the increment of trees to some extent depends on climatic elements (Kesić et al. 2016). At high elevation, the Norway spruce with the rising temperatures will cause increased growth but will have negative effects in places that are at lower altitudes, as a result of increased drought stress (Savva et al. 2006). The resilience of the Norway spruce at the trailing edge of its distribution is under influence of climate change, and we need considerable efforts to sustain these ecosystems with some specific silvicultural activities and special management treatments (Honkaniemi et al. 2020). The distribution of Norway spruce would be conditioned by climate change because pheno-phases and reproductive processes depend on climatic conditions, in particular by temperature, which becomes more important in higher latitude regions (Caudullo et al. 2016).

4.1.3. Serbian spruce – *Picea omorika* (Pancic) Purk.

It is assumed that this species originated from Asia (Dizdarevic et al. 1984; Gajić et al. 1994; Lockwood et al. 2013; Aleksić and Geburek, 2014). The effect of climate change on Serbian spruce is different among some individuals and at certain sites, in that way younger trees and those growing at lower altitudes suffer more from drought (Dell'Oro et al. 2020). During 2012 and 2013, the extinction of individual trees and even populations in the forests of Serbia was observed, where Serbian spruce forests were not excluded. This phenomenon is due to the three-year dry period and the dynamics of extinction going in the following order: drought, physiological weakening, disease, pests and mortality (Ivetić and Aleksić, 2016). The unfavourable climate conditions lead to the physiological weakening of trees and as a result, they become more susceptible to diseases and pests, leading ultimately to the lethal outcome – unfortunately, this is the most likely response of Serbian spruce to the ongoing rapid climate change (Ivetić and Aleksić, 2019). That is why the Serbian spruce is susceptible to *Hylobius abietis* L. (Barredo et al. 2015), is susceptible to the bark beetles *Ips typographus*, *Dendroctonus micans* also to

Gremmeniella abietina (Vujičić and Budimir, 1995), especially because the precipitation and temperature are the crucial factors for this canker (Thomsen, 2009). Besides this, Serbian spruce becomes physiologically weak and more susceptible to *Armillaria ostoyae* as result of unfavourable climatic conditions (Ivetić and Aleksić, 2016). Today, the natural forest succession combined with global warming, constant human pressure, and environmental change especially climate change are the major problems encountered in the conservation of natural populations of Serbian spruce (Ballian et al. 2006).

4.1.4. Scots pine – *Pinus sylvestris* L.

The impact of climate change is also presented in *Pinus sylvestris* L. forests. Thus, by the end of the 21st century, according to the A1B and A2 climate scenarios, the range of Scots pine (*Pinus sylvestris* L.) in Serbia is likely to be reduced by up to 22% and 31% respectively (Stojanović et al. 2021). Consequently, it can be expected that there will be a reduction in the area of Scots pine habitat in the territory of Montenegro (Matovic, 2013). The authors Rebetez and Dobbertin, (2004) stated that climate change has an indirect impact on the mortality of trees and also indicate that nematodes or other diseases may weaken the organism of the trees (Reich and Oleksyn, 2008). Other authors Mencuccini and Grace, (1995) expressed that as a result of the impact of climate change changes in the structure and shape of the needles are observed and consequently changes occur in the processes of transpiration. On the other hand, it has been investigated that climate change with increasing temperature and the appearance of drought harms radial growth and that the formation of tree rings (Martinez-Vilalta et al. 2008; Bogino et al. 2009; Martínez-Vilalta et al. 2012; Panayotov et al. 2013). Furthermore Inward et al. (2012) stated that increased temperature will create better conditions for pine weevil *Hylobius abietis* which will cause a bigger attack on the Scots pine. Latitudinal range limits of Scots pine distribution are susceptible to alteration by the changes in climate which are predicted for the coming decades (Matías and Jump, 2013). But these populations are tolerant and often remarkably vigorous and may be of value for future breeding (Mátyás et al. 2004).

4.1.5. Austrian pine – *Pinus nigra* Arnold

Black pine can grow in both extremely dry and humid habitats with considerable tolerance to temperature fluctuations (Nikolić and Tucić, 1983; Stojanović et al. 2014). This is a light-demanding species but shows shade tolerance more than Scots pine (*Pinus sylvestris* L.) (Trasobares et al. 2004). It is assumed that in the future distribution of Austrian pine will change considerably as a result of climate warming, but the response is likely to be different depending on the geographic region and magnitude of climate change (Martín-Benito, del Río, and Cañellas, 2010). According to the climate change scenarios it can be expected that there will be a significant increase in Austrian pine habitat in the territory of Montenegro (Matovic, 2013). In the Mediterranean regions, climate warming increases water stress and thus has a negative influence on the growth of this species (Tíscar and Linares, 2011), whereas in central Europe climate amelioration is thought to lead to an expansion of this species (Thiel et al. 2012). Some studies characterize Austrian pine trees as sensitive to summer drought (Martin-Benito et al. 2011; Móricz et al. 2018; Sangüesa-Barreda et al. 2019) and summer temperatures (Martín-Benito et al. 2008; Camarero et al. 2013; Shishkova and Panayotov, 2013; Janssen et al. 2018). Garrett et al. (2006) demonstrated a causal relationship between climate change and the emergence of plant diseases. Thus, climate change, especially global warming, became more favourable to *D. pinea* presence within the last 15 years compared to the previous 30-year period (Fabre et al. 2011).

4.1.6. Macedonian pine – Pinus peuce Gris.

Macedonian pine well withstands exposure and pollution of the atmosphere, while the cold mountain climate and high humidity provide good quality conditions according to (Alexandrov and Andonovski, 2011), therefore, it can be said that this species has great ecological adaptability. Some studies stated that the increase in the temperature (Panayotov et al. 2010; Tsvetanov et al. 2020), low precipitation or both of these climatic elements (Panayotov and Yurukov, 2007; Panayotov et al. 2009; Tanovski, 2017; Zafirov et al. 2020) affect the development of Macedonian pine. The expansion of Macedonian pine to higher altitudes was observed by (Meshinev et al. 2000) and was correlated with the increase in winter temperatures.

4.1.7. Bosnian pine – *Pinus heldreichii* H. Christ

The Bosnian pine shows great adaptability to extreme environmental conditions and great colonizing potential, making it suitable for reforestation (Vendramin et al. 2008). However, climate change impacts the development of this species. Thus, research indicates that the formation of tree rings does not depend on one single dominant factor but different combinations of climatic phenomena such as reduced summer rainfall increased temperature, and sensitivity of drought (Seim et al. 2012). According to that, presented results from (Panayotov et al. 2009) demonstrate mixed climate signals which are influenced by low summer temperatures and low precipitation. Thus, a negative impact on tree growth is noted from the increasing of temperature (Levanič et al. 2020; Tsvetanov et al. 2020), and the appearance of drought (Panayotov et al. 2010). Bosnian pine becomes more vulnerable when it is under physiological stress due to high temperatures or droughts (Lazarević and Menkis, 2020). Otherwise, Ivanova et al. (2013) confirmed that warmer winters contribute to the formation of wider annual rings. Moreover, research on climate change effects is considered a priority in the case of populations located at the limit of the species’ geographical range and away from the main range, because these populations may be more sensitive to climatic change and global warming than those at the centre of the natural range (Brubaker, 1986).

As we can see from the previously stated, the lower capacity of precipitation or frequent occurrence of droughts in most cases has a negative influence on the radial growth and development of the trees. On the other hand, global warming is expected to increase evaporation, thereby causing a decrease in soil moisture (Valladares, 2017). Also, the increase in temperature makes conditions favourable for many diseases and pathogens. Finally, even slight climate warming may have negative consequences for the Eurasian tree species across their range (Persson and Beuker, 1997; Davis and Shaw, 2001; Rehfeldt et al. 2002; Stromgren and Linder, 2002).

5. Adaptive forest management

The impact of climate change on forest development is still a field that needs to be seriously explored. In this connection, there are no significant measures for adaptive forest management to climate change, only recommendations for greater dilution, reduction of the rotation time, and change in species composition (Hörl et al. 2020). Adaptive forest management and reforestation are the two main ways of adapting forests that improve the functionality of forests and forest systems that are under increasing pressure from climate change (Trumbore et al. 2015; Mansourian et al. 2017). As forest resilience is affected by climate change, the composition and structure of forests should receive more attention in forest management (Honkaniemi et al. 2020), as well as finding new methods for their adaptation to climate change. The methods of forest management for adaptation to climate change depend on the species composition, age of trees and their biological position (Bouriaud et al. 2015). But, some of the responses to climate change will be at the level of species, so that the tree species will migrate more to the northern areas (McKenney et al. 2007) as well as at higher altitudes (Attorre et al. 2011) and all this will result in the emergence of new assemblies of species (Hebda, 1997; Kirschbaum, 2000; Hansen et al. 2001; Serra-Diaz et al. 2015). An introduction is needed for some activities for adaptation of forests such as i). identification of more suitable genotypes through examinations of origin, ii). inclusion of climate elements as variables in growth and yield models, iii). developing "smart" stands including climate change considerations when planning (Spittlehouse and Stewart, 2003).

Silver fir will be endangered by the end of the 21st century in Serbia (Stojanović et al. 2014), therefore there are adaptive strategies for Silver fir forest as well as some populations (Csilléry et al. 2020) and from different zones (Roschanski et al. 2016) can provide suitable seed sources for creating populations that will be more resistant to future climate change. The mixed composition can help to some point to compensate for the impact from climate changes, especially, older forests show greater stress tolerance (Norris et al. 2011), therefore a balanced mix of the following three tree species is recommended (*Abies, Picea, Fagus*) (Hilmers et al. 2019) in certain habitats. Also, the mixture may allow a higher level of *A. alba* Mill. growth during extreme climatic events and reduce the impact of summer drought (Lebourgeois et al. 2013).

Adaptation measures at Norway spruce forests are focused largely on the stand level, therefore modifying forestry composition and structure can be used to foster resilience (Honkaniemi et al. 2020). Norway spruce has low resistance to drought in pure stands and mixed stands with beech (Pretzsch et al. 2013), but if favourable conditions were created for another type of mixed forest with other species, Norway spruce would be more resistant to dry periods. Also, the thinning has a positive response to the drought periods (Kohler et al. 2010), because the density will become lower and, in that place, will have more free water capacity. Nevertheless, the different ways of thinning have different effects on the resistance of stems to drought (Laurent et al. 2003). Therefore, thinning should be considered an effective strategy that would contribute to increasing the drought tolerance of Norway spruce (Sohn et al. 2013).

To improve the development of Serbian spruce have to use appropriate management measures, the introduction of other species of trees that are suitable for the development of Serbian spruce, create a mixed and uneven age structure, and preservation of special, economic and genetic diversity of the population (Matovic et al. 2020). These are important postulates in the adaptive management of ecologically unstable and endangered forests.

Reduction of stand density by thinning is one of the silvicultural treatments which give positive results for adapting to climate change of Scots pine (Ameztegui et al. 2017). Thus, the named authors suggest thinning more than 30% and doubled basal area increment for the following. Thinning will decrease the transpiration on the stand level despite increasing the use of water on the tree level (del Campo et al. 2014; Gebhardt et al. 2014). Thus, this will increase soil water availability for other trees (Bréda et al. 1995; Limousin et al. 2008), will reduce tree drought stress (Aussenac and Granier, 1988; Rodríguez-Calcerrada et al. 2011) and will increase the amount of water exported via deep drainage (del Campo et al. 2014). Therefore, managers should modify the stand structure and use specific silvicultural systems by reducing competition for water in the most vulnerable populations (Huber et al. 2013; Sánchez-Salguero et al. 2015). Also, by changing the structure from monocultures to a mixed forest the impact of climate change can be mitigated. The conversion in Europe from common monocultures of Scots pine and European beech into the mixture of both tree species could be a significant contribution to forestry which will mitigate the global warming effect, also will contribute to increased sequestration of carbon storage, and will decrease the effect from climate change (Pretzsch et al. 2016).

The results of Martin-Benito et al. (2011) for *P. nigra* Arn. have significant implications for forest management practices and measures aimed at adapting forests to climate change and global warming. Thinning of the Austrian pine forest can be a useful measure to adapt to climate change, reducing their drought vulnerability (Martín-Benito, Del Río, Heinrich, et al. 2010). Also, the introduction of *P. nigra* Arn. into regions outside its range of natural distribution as well as establishing populations with high genetic diversity will contribute to easier adaptation to climate change (Thiel et al. 2012). Moreover, it is considered that the establishment of the forestry system close to nature offers the best operational way of adaptive management and can improve the adaptive capacity of Austrian pine forests according to the expected climate change scenarios. It would be best, to establish an appropriate relationship between the coverage of the crowns and the space for the development of the trees to enable the best acceptance of precipitation (Tíscar and Linares, 2011). Austrian pine seedlings' adaptation to the new environment (climatic or edaphic) is minimal or excluded (Tíscar et al. 2018). Therefore, forest managers can use seedlings that have a high level of genetic variance, which can be a real form of pre-adaptation to new climate change (Rubio-Moraga et al. 2012).

Adaptive forest management represents an integrative part of the overall strategy of "avoiding the unmanageable and managing the unavoidable" (Bierbaum et al. 2007). Spathelf et al. (2018) suggested forest adaptation and restoration as well as helping to reforestation to improve the ability of ecosystems to self-organize in the future and to adapt to the environment. Therefore Bolte et al. (2009) proposes three different strategies for future forest management at the stand level. The proposal "conservation of forest structures" should maintain the structure of the forest in one permanence or should provide durability even though there is a danger of pressure on the same forest as a result of environmental change. The method "active adaptation" proposes the use of specific ways of silvicultural activities, such as a thinning to create forest structures that will be able to adapt to the impact of climate change. This method is actively involved in the transformation of forests in such a way that existing tree species that are less resistant to climate change are replaced or mixed with species that are significantly more tolerant and more adaptable to climate change. From here, forest resilience and adaptation to climate change will increase through the introduction of a mixed structure at different levels (Yousefpour et al. 2017). The last or third method is "passive adaptation". This method does not allow any activities to adapt the forest to climate change. Moreover, does not allow for the entry of new species and eliminates many opportunities to control the structure of stands that are of exceptional importance for the composition and functioning of forests. Depending on the context, Millar et al. (2007) offers a few approaches:

To deal with climate change, forest managers need scenarios and information on the current and future state of climate and climate change to plan certain activities as well as to form capacities to adapt tree species to new habitats. Also, climate change information could be used to prepare a plan for protection against an increased number of harmful insects and diseases and extinction of a certain number of trees, as well as preparing special plans for protection and rescue from fires (Thomas Ledig and Kitzmiller, 1992; Parker et al. 2000).

It is proposed to be used more species of trees to create diversity in stands through practices that spread risks rather than concentrate them (Millar et al. 2007). All of this could be achieved by introducing new species from the surrounding areas of the forest rather than importing the same species of native origin. Regarding this, the seed collection process or germplasm will be moved in a suitable direction by using seeds from populations that grew in warmer growing conditions (Millar et al. 2007).

Moreover, to establish managing for asynchrony and using the establishment phase to reset succession. This method can be achieved by promoting and adapting a diverse structure, introducing different age classes, creating a mixed structure, and forming genetic diversity (Millar et al. 2007). To achieve the adaptation of the tree species to the new habitats, the forest system managers should create forest structures that contain continuous habitat with few physical and biotic obstacles, to enable the migration of the trees themselves (Halpin, 1997; Noss, 2001).

In summary, adaptive management is one of the most important challenges for modern forestry in the coming years. Uncertainty about the manner and intensity of global and in some cases local climate change, is a complicated factor for adaptive management in the future. For this reason, there is a sense of uncertainty about what forest ecosystems will look like in the future in terms of the use of specific and adaptive management methods (Peterson et al. 2011). It may be necessary to provide measures called "decision-making approaches" (Radke et al. 2020) that will provide access to change of silvicultural measures and methods in the course of climate change. Regarding this, serious emphasis should be placed on the choice of adaptive management as a whole and the selection of the appropriate silvicultural method of forest cultivation.

6. Conservation of genetic resources

The ability of organisms to adapt to ever-changing environmental conditions, within their ecological potential and distribution, is essential to the survival of individuals and species (Atkins and Travis, 2010). Some trees, but also entire populations (forests) that are not sufficiently adapted to certain changes in environmental conditions, die and form weak or no vital offspring (Kätzel, 2009). In contrast, those stands or individuals that have adapted well and formed vital individuals survive and pass on their genetic material to their offspring (Valladares et al. 2014). Preserving genetic diversity is an essential element. Therefore, the goals set for the conservation of genetic diversity must include elements of sustainability that affect the adaptability of individuals (Boshier and Amaral, 2004). Also, a prediction system that will provide information on adaptability and future changes that can occur in the environment has to be established (Namkoong, 1997). To ensure the sustainability of forest ecosystems, it is essential to maintain the diversity of stands and forests, provide the selective choice of different tree species that will adapt to conditions of habitat, as well as using reliable genotypes. All activities for the conservation of forest genetic resources are grouped in the following set of goals (Behm et al. 1997; de Vries et al. 2015):

- The first set of goals consists of maintaining and favoring great genetic variability which will be able to adapt to forest stands in the environment and external influences. This group of activities aims to ensure the complete stability of the stand as well as the forest.
- The next set of goals envisages the conservation of individuals and populations that are formed from indigenous tree species in the long run. This group aims to favor the major indigenous species that will be used as the basis for genetic material.
- The third group of activities is aimed at preventing the introduction of new genetic material in indigenous populations with minimally adapted origins and varieties. This group aims to provide complete protection of the natural origin of the genetic material.
- And the last group of activities, which has a more observational character, envisages cross-generational monitoring of the functionality and adaptability of genetic systems. Mainly this group of activities aims to perform genetic monitoring of genetic materials.

The genetic system consists of the generation, modification, preservation, and transfer of genetic information for future generations and builds the foundation for long-term natural development and the use of forests (Kätzel, 2009). Consequently, the long-term adaptability and survival of a species can only be secured on the population level and by including species-specific genetic systems. Preservation of long-term adaptability and survival of the species is a central principle of forest genetic conservation (Kätzel, 2009; Kelleher et al. 2015). To implement this goal, the following principal tasks were devised for the conservation of forest genetic resources: i) evaluation and inventory of endangered (conservation-needy) and conservation worthy genetic resources; ii) identification of the degree of exposure experienced by the population and tree species; iii) genetic characterization of chosen genetic conservation units; iv) determination and implementation of measures for the conservation of gene resources; v) long-term documentation of the chosen measures.

The implementation of conservation activities depends on the level of endangerment of the population that is selected for conservation. In essence, in-situ and ex-situ measures differ from each other, as static and dynamic practices. In-situ activities include all activities for the conservation of genetic material or resources that take place at the same location as the genetic resource. These activities are carried out in a natural location (in-situ), and represent dynamic genetic conservation because the gene pool is not fixed, but is constantly adapted to environmental factors that affect genetic processes. This dynamic approach to conservation is preferable to the more static ex-situ conservation because it maintains ecological functions and processes to allow for continued evolution (Millar et al. 1990; Finkeldey and Gregorius, 1994). Ex-situ conservation (conservation of components of biological diversity outside their natural habitats), is applied when conservation in-situ is not possible (Skrøppa, 2005). Ex-situ conservation will safeguard populations that are in danger of physical destruction or genetic deterioration, and will allow commercial improvement and supply of the genetically improved reproductive material. Ex-situ conservation can be dynamic or static (Alizoti et al. 2019). Dynamic ex-situ conservation can occur in stands, which are established artificially by planting species, ensuring in this way that the genetic structure of the next generations is shaped by natural selection (Amaral et al. 2004). To avoid losses of genetic material and succeed in most effective conservation, multiple stands/populations should be established in environmentally different areas, despite their high establishment cost (Eriksson et al. 1993; Geburek and Turok, 2005). Static ex-situ conservation of genetic resources includes mainly populations established for tree breeding purposes, like clonal archives, seed orchards, provenance and progeny tests, as well as stored seed and pollen (Skrøppa, 2005).

To preserve the specific structures of the silver fir genetic population in local habitats as well as to enable distribution in specific habitats, different populations from different areas of distribution should be systematically selected to preserve genes. The best and most effective way of conservation is with the in-situ method which contributes to the preservation of larger occurrences of the silver fir and its genetic resources in the stands or forests that it builds (Wolf, 2003). In addition to this, specific silvicultural activities can be implemented such as thinning and tending at the same time establishing strict control over the way of forest management. To overcome the process of isolation of certain individuals, preservation of genes and genetic material should be established through the method of ex-situ for obtaining quality seeds. Therefore, sampling should be performed exclusively by domestic individuals that are representative of the environment and in which the ecological variation is preserved (Wolf, 2003).

The use of certain afforestation units for genetic conservation of Norway spruce can be performed with ex-situ and in-situ activities (Skrøppa, 2003). In the afforestation process, one of the basic requirements is to know the origin of the reproductive material as well as all its inherited information, while its adaptive properties should be appropriate to the environmental conditions offered by the site for regeneration. Also, in terms of usage and ranking for which genotypes are to be used in the breeding process, the occurrence and frequency of dry periods should be taken as a major factor. Therefore, drought-resistant genotypes that show good growth predispositions should be selected and tested at different locations (Hayatgheibi et al. 2021). Preserving the genetic material of *P. abies* through the in-situ process often yields positive results in protected areas. The purpose of the ex-situ method will be the conservation of genetic material through the formation of new populations that will maintain the original genetic formula and will enable their adaptation over a longer period under the influence of local living conditions. One more fact is that the establishment of additional dynamic gene conservation units must be done to protect the adaptive and neutral genetic diversity of the species (Stojnić et al. 2019).

For the Serbian spruce so far, little attention has been paid to ex-situ conservation both nationally and internationally. Proof of this is that there is only one nursery with seeds of this species in Godovik (Serbia) (Ballian et al. 2006). Therefore, the establishment of orchards and seed plantations should be established by offspring from different populations in appropriate locations, and perhaps the storage of seeds in gene banks should be reasonable and it is necessary to supplement the measures taken by conservation agencies (Ballian et al. 2006). Such as Serbian spruce seed samples stored in banks in Italy and France at -80°C (Koskela et al. 2007).

Furthermore, Scots pine is a tree species with widely proven genetic diversity, so it is needed as an example in addressing the genetic resources and effects of long-term breeding in relation to the expected environmental changes in the range of its distribution (Mátyás et al. 2004). Therefore, the local material should be used for regeneration, while ex-situ conservation stands should be placed in places that represent endangered environments.

Breeding activities of Austrian pine provide valuable information by defining potential plantation, seed collection, and transfer zones. In situ conservation activities should be encouraged separately as seed stands and gene conservation forests. As intraspecific hybridization is easy among Austrian pines, exotic or improved Austrian pines should not be planted in the vicinity of autochthonous and naturalized stands (Isajev et al. 2004). Conservation and management practices for Austrian pine should strive to maintain genetic differentiation, specifically by emphasizing reforestation efforts with stocks from local provenances to avoid non-local introductions (Naydenov et al. 2015). Clonal seed orchards by Austrian pine may serve as static ex-situ conservation plantations, harbouring elite phenotypes/genotypes originating from different natural populations, some of which are marginal/peripheral ones and potentially bearing specific adaptation alleles. As soon as the breeding programs advance to the next generation of seed orchards, natural regeneration can be allowed in the first-generation ones, so that new generations subjected to natural selection can develop. In that case, the seed orchards could gradually form a dynamic ex-situ site harbouring high genetic variability (Alizoti et al. 2019).

Macedonian pine forests require most regeneration processes to be directed by forest managers by implementing special silvicultural methods to preserve, care for and reproduce this species. The process of conservation of this species involves the use of in-situ and ex-situ measures. The in-situ method involves conservation through the formation of reserves, use and nurturing of plus trees, and formation of national and natural parks and seed plantations. While with the ex-situ method, the genetic materials of the Macedonian pine are generally conserved through stands where the origin is tested, test stands of regulated offspring are formed, and gene banks for seeds are created. Concerning these two methods, the use of the in-situ method seems to be more reliable in the implementation as well as the use of the advantages of both methods for the preservation of genetic material (Alexandrov and Andonovski, 2011).

Ecological and genetic considerations must be included in the conservation of the genetic diversity of the Bosnian pine. Where appropriate forest management strategies are used, it is an effective hub that can designate gene conservation units and conserve the genetic resources of Bosnian pine. On the other hand, of course, natural regeneration should be carefully monitored and if necessary to help sow locally harvested seeds. If forests are under pressure or if their genetic resources are of particular interest, measures should be taken to preserve the ex-situ system and it must be carefully implemented to represent the original genetic diversity of the population (Climent et al. 2021).

From all of the above, we can define that genetic conservation that will enable the protection, adaptation, and formation of genotypes will contribute to the adaptation of genetic resources to climate change, and thus the conservation of tree species and entire populations of forest ecosystems.

7. Conclusions

Finally, we can conclude that coniferous forests are fairly common forests in the Balkan Peninsula. The species *A. alba* Mill., *P. abies* (L.) H. Karst, *P. sylvestris* L., *P. nigra* Arn., *P. peuce* Gris. are the most common species in the Balkan Peninsula with ecological, social and economic importance. These species create pure or mixed forests by mixing amongst each other or with broadleaf species, mostly with beech. Climate change, in the whole world and so in Europe and with that in the Balkan Peninsula, exists and will continue to be present. With time the temperature started to increase and the occurrence of drought has become more common. These climate changes affect forests in many ways. First in the development and growth of trees, and second in the whole development of the forest. We could see this through dendrochronology, dendroecology, and dendroclimatology studies observed in this paper. Climate change affects these species in the Balkan Peninsula. The Macedonian pine and Serbian pine may be most endangered because their distribution is significantly smaller than the others, although they presented adaptability to climate change. Otherwise, the *P. nigra* Arn. *and P. sylvestris* L. are widespread but also show adaptability to climate change. Generally, the climate changes have an impact on forests, but they presented more or less adaptability for now. Although, if climate change continues it will have a significantly bigger impact on forest development. Therefore, we as foresters should strive for sustainable forest management and adaptive forest management. With adaptive management, we will be able to reduce the negative impact of climate change, and maybe we will contribute to the smooth development of forests. This selected genetic material probably will be contributed to decreasing the climate change effect on tree growth and forest development. We have to use in-situ and ex-situ conservation methods and proposals for protecting endangered species and forests. Finally, we have to research climate change, adapt to it, and use the adaptable methods and practices in forest management to create sustainable forests and protect the forest.

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