Research Article
Araştırma Makalesi
DOI: 10.24011/barofd.744832

Bartın Orman Fakültesi Dergisi,
22 (3): 929-938,
15 December/Aralık, 2020

Journal of Bartin Faculty of Forestry
p-ISSN :1302-0943
e-ISSN :1308-5875

Investigation of the 18-Year Status and Changes of Mixed Stands in Europe

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Abstract

Forests play essential roles for the protection of the earth when we are struggling with global climate change. It is necessary to examine the current status of the forests and their changes over time in order to determine the precautions to be taken in the future to overcome the environmental issues associated with the climate change. For this reason, the current status and the 18-year change of European Continent mixed forest stands in acreage were examined in this article. The Coordination of Information on the Environment (CORINE) land cover datasets belonging to 2000, 2006, 2012 and 2018 were used for the analyses in the study. Approximately 2.8 million hectares of mixed forestland have been lost in the last eighteen years in Europe, which has approximately 31 million hectares of mixed forest stands as of 2018. It was determined that this decrease was mostly caused by the change during the period of 2006-2012. In addition, it was revealed that mixed forests of Finland, Germany and Turkey dramatically suffered a high rate of destruction in the last eighteen years as a result of this study.

Keyword: Forest cover change, mixed forests, CORINE, land cover, GIS.

Avrupa Kıtasında Karışık Meşcerelerin Durumu ve 18 Yıllık Değişiminin İncelenmesi

Öz

Küresel iklim değişikliği ile mücadele etmede ve dünyamızın korunmasında ormanlar önemli bir rol oynamaktadır. Ormanların durumunun ve değişim trendlerinin ortaya çıkarılması, çevresel sorunların çözümü ve önüne geçilebilmesi adına oldukça önemlidir. Bu sebeple, bu çalışmada Avrupa kıtasının karışık ormanlarının durum ve 18 yıl içerisindeki değişimleri incelenmiştir. Değişim analizleri için 2000, 2006, 2012 ve 2018 yıllarına ait CORINE arazi örtüsü veri setleri kullanılmıştır. 2018 yılı itibari ile Avrupa kıtasında yaklaşık 31 milyon hektarlık karışık orman varlığı tespit edilmiş ve yaklaşık 2.8 milyon hektarlık karışık ormanın son 18 yıl içerisinde kaybedildiği görülmüştür. 2006-2012 yılları arasındaki değişimin bu azalımda temel etken olduğu gözlemlenmiştir. Ayrıca, Finlandiya, Almanya ve Türkiye'nin, bahsi geçen 18 yıllık süreç içerisinde, olumsuz yönde en çok etkilenen ülkeler olduğu görülmüştür.

Anahtar Kelimeler: Arazi örtüsü değişimi, karışık ormanlar, CORINE, arazi örtüsü, CBS.

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Received (Geliş) : 29.05.2020
Accepted (Kabul) : 26.11.2020
Published (Basım) : 15.12.2020

1. Introduction

Forests have become the lifeline of human existence since the very beginning. The more we learn about the ecosystem functions (Nadrowski et al., 2010) that forests contribute, the better we understand that life would not have much success without in the near future. Human ambitions are the leading causes behind the forest decline, however they are not necessarily poverty related (Wickham et al., 2007; Margono et al., 2014; Watson et al., 2018). Insensitive policies imposed on the forests in the name of development are doing more damage. Here, forest composition, which is the definition of how diverse the species are in any given forest area, plays a rather crucial role in the environmental responses to the anthropogenic adversities (Govedar et al., 2018). In majority of the industrialized countries, forests are managed because technology has not been able to compensate the wide range of tangible and intangible products and services, obtained from them. This incentive in time has transformed the diverse old-growth forests to monotonous industrial plantations, which have solely been shaped by the market demands (Mcdermott et al., 2015).

Mixed forests mainly denote forests with two or more dominant tree species. These forests are known to have more advantages than pure forests. Tree mixture in a stand may enhance ecosystem stability and biodiversity, and increase stand productivity (Noss 1990; Richards et al. 2010; Pádua and Chiaravalotti 2012). Moreover, tree mixture in stands can mostly cause higher durability and resilience of stands against wind, drought, insects, diseases and frost (Odabaşı et al. 2004). For recreational and aesthetics purposes, mixed forests are usually considered more preferable. They also usually create better wildlife habitats than pure forests. Moreover, tree growth in some mixed stands is less affected from the global warming in comparison to pure forests (Pretzsch et al. 2013; Pretzsch et al. 2017), When the heterogeneity in forests is broken, their resilience to biotic, abiotic and human generated, anthropogenic factors decreases dramatically (Kelty et al., 2013; Fanta & Petrik, 2018; Liu et al., 2018). Given the negative effects of global climate change as well as the importance of mixed forests, concern over the establishment and maintenance of mixed forests has increased (Cavard et al., 2011; Hulvey et al., 2013; Pretzsch & Schütze, 2016). However, as opposed to taking numerous derivatives into consideration while managing hetero-culture forests, industry driven forest management tends to limit uncertainties by going mono-culture most of the time in many countries (Scheidel & Work, 2018). This approach, against the natural mechanism of the nature (Hua et al., 2018), and under the growing threat of global warming, has started raising the damage scale to unprecedented levels (Lindskog & Sjodin, 2016). Despite the fact that almost all of the nations across the Europe and North America are aware of the importance of mixing heterogeneity into forest management, the rate of hetero-culture forests in overall forest covers is still not ideal.

It seems to be vital to examine the current status of the mixed forests and their changes over time in order to determine the precautions regarding the mixed forests across the Europe. Remote sensing, at this point, has long provided the means for land cover change detection. There are a number of large scale data sources including Global Forest Cover Chance (GFCC) of NASA (Kim et al., 2014), Global PALSAR-2/PALSAR/JERS-1 Mosaic and Forest/None-Forest Map of JAXA (Japan Aerospace Exploration Agency) (Shimada et al., 2014), Global Forest Change Map of the University of MARYLAND (Hansen et al., 2013) and the Global forest/non-forest map from Tandem-X interferometric SAR data (Martone et al., 2018). European Environment Agency (EEA) has started monitoring the land cover changes under "CORINE (The Coordination of Information on the Environment) Land Cover (CLC) inventory program since the late 1980s, using the period current and accepted satellite imagery (Martinez-Fernandez et al., 2019). It is believed that the use of CORINE to determine the current status of the mixed forests and their changes over time in Europe is logical.

Identifying and examining the status and change trend of mixed stands is of great importance in terms of interventions to be conducted in the coming years. To our knowledge, there has not been a recent research that presents the current status of the mixed forests across the Europe. Moreover, our knowledge on the changes of mixed forests in acreage in the Europe is limited. Thus, the main objective of this study is to find out the current status of mixed forests and to reveal the change trend of mixed forests in Europe in order to take precautions and to mitigate the effects of environmental problems such as global climate change.

2. Material and Method

2.1. Study Area and Data Preparation

The study area covers a large part of the European Continent. Statistical data of mixed forest stands were collected and classified by thirty-eight countries from the data of CLC 2000, 2006, 2012 and 2018. However, five countries (Cyprus, Iceland, Liechtenstein, Malta, and Luxembourg) with less than 20,000 hectares of mixed forests were excluded from the analysis in order to make sense of the relationship between datasets (Figure 1).

CORINE inventory program using CLC data of 2000, 2006, 2012 and 2018 was used to examine the current status, change trend in acreage and descriptive statistics of mixed forest stands of European Continent and European Countries. In another words, CLC data from four different periods covering a total of eighteen years were used in this study. It should be noted a "mixed forest" refers to a forest consisting of conifer and deciduous trees in CORINE inventory. Thus, the term "mixed forest" used in the analysis and results denotes a forest with both conifer and deciduous trees. The advantage of this data over the others (i.e., GFCC, Global PALSAR-2/PALSAR/JERS-1 Mosaic and Forest/None-Forest Map of JAXA, Global Forest Change Map the Global forest/non-forest map) is the extreme amount of land cover detail provided in each different time periods. The data issued in five different time periods (i.e., 1990, 2000, 2006, 2012 and 2018) has differentiated forests as deciduous, coniferous and mixed forests in distinct classes.

CLC data is available free of charge from the Copernicus Land Monitoring Service website (URL-1, 2019). The spatial resolution of these data is 100 meters and the minimum mapping unit is 25 hectares. There is no change in the spatial resolution of the CLC that was produced five times in total from 1990 to 2018. However, the technological improvements in the sensor quality reflected themselves well in the classification accuracies which can be seen through URL-1 (2019). CLC uses three level hierarchical classification system. Level 3, which gives us the most detailed land cover scheme, consists of forty-four different land cover classes. Mixed forests placed in the third level and they were grouped under 'Forests and Semi-Natural Areas' category with the number 3.1.3. In this class, stands were chosen where tree vegetation was dominant but neither deciduous nor coniferous trees were dominant (URL-2, 2019). In the context of this study, only the 'Mixed Forest' class of the CLC was used and divided into individual countries. ArcGIS 10.6 software and ETRS89-LAEA coordinate system were used for these analyses.

The changes of mixed forests in acreage among four periods (i.e., 2000-2006, 2006-2012 and 2012-2018) were compared using a one-way analysis of variance (ANOVA) statistical model to see whether these changes are statistically significant at $\alpha=0.05$. Multiple comparisons of means of the periods were performed using Tukey's method. The "aov" and "multcomp" functions were utilized for the statistical analysis in R-Statistical software (R Development Core Team, 2010).

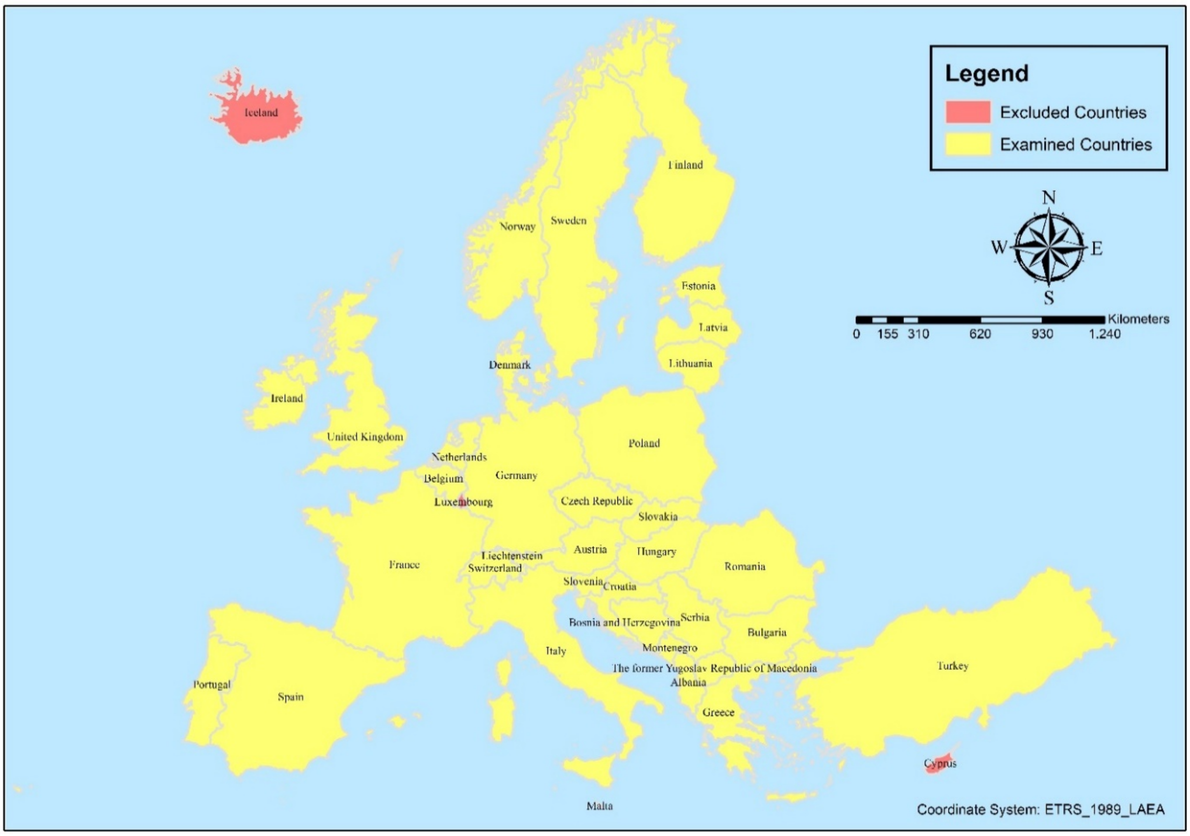

Figure 1. Study area and covered countries.

3. Results

According to the results of the study, approximately thirty-one million hectares of the European continent is composed of mixed forests as of 2018. This is equivalent to 4.24 % of the continent. In addition, it is noteworthy that nearly 2.8 million hectares of mixed forest loss occurred from 2000 to 2018 throughout the whole European Continent (Table 1). In another words, the area of mixed forests of the European Continent decreased by 8.3% in the last eighteen years. The changes in the area of mixed forests was not statistically significant across the time periods (p=0.98). It was determined that a decrease mainly occurred in six years between 2006 and 2012 (Table 1). However, based on the Tukey's test, there was no statistically significant differences between any pair of time periods (p<0.05), that is, the decrease in acreages of mixed forests from 2006 to 2012 was not statistically significant (p=0.99). Although not significant, the area of mixed forests from 2012 to 2018 increased (Table 1).

Table 1. The current condition and changes of mixed forests of European Continent in different time periods. (AMF: Area of Mixed Forests, PMFCAF: Percentage of mixed forests compared to all forest types)

	CLC 2000	CLC 2006	CLC 2012	CLC 2018	Total Change
Mixed Forest Area (ha.)	33.878.903	33.928.342	30.126.842	31.065.342	**-2.813.561**
PMFCAF (%)	20.30	20.18	17.59	18.12	

Finland was found to be the country with having the largest part of mixed forests in Europe, with around 6.5 million hectares as of 2018 Finland, which has about 21% of European mixed forest stands, was followed by Poland, Turkey, Sweden and France In addition, the countries with the least mixed forests were found to be Macedonia, Albania and Ireland, respectively (Figure 2).

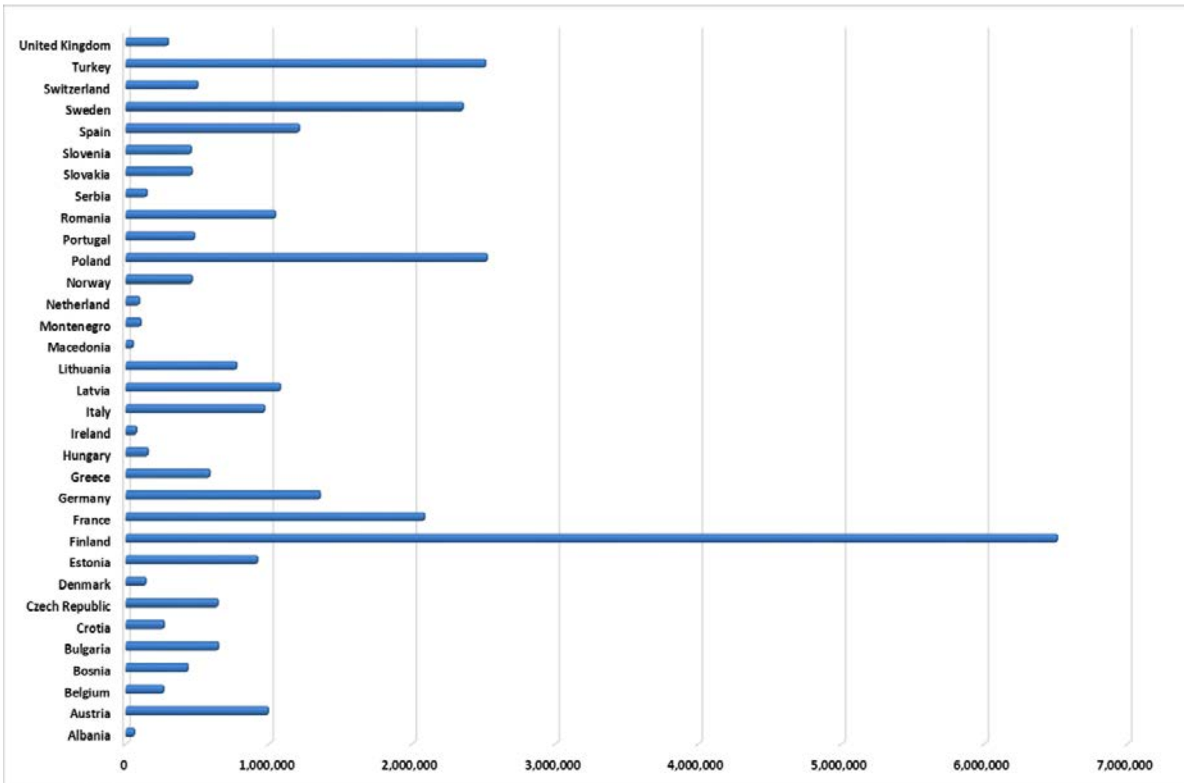

Figure 2. Current mixed forest area (ha.) of European countries.

The ratio of mixed forest stands to all forest cover was calculated and given in Figure 3 for each country. Accordingly, Lithuania, Estonia and Belgium are the countries with the highest mixed forest percentages. On the other hand, Norway, Serbia and Macedonia had the least mixed forest percentage. In addition, six countries out of the all European countries with mixed forests below 10% among all forest compositions were identified with this analysis. Similarly, in seven European countries, the percentage of mixed forests to all forests types was found to be over 35 percent. In other words, it is seen that mixed forests are one of the dominant forest formations

in the mentioned countries (i.e, Switzerland, Slovenia, Lithuania, Latvia, Estonia, Denmark, and Austria.).
Examining the 18-year change is a very important subject in terms of determining the change trends of mixed forests. If we look at the results of country-based changes in time, it is observed that mixed stands in ten countries have decreased while the remaining twenty-three countries have increased their mixed stands. The overall decrease across the whole of the European continent was likely caused by the loss of mixed stands in the ten countries. Among the all countries, it was seen that the biggest decline in the acreage of mixed stands was experienced in Finland, which has the most mixed stand assets (Figure 4). Germany and Turkey have been identified as countries that have experienced the most decline after Finland. However, when analyzing each time period of Finland and Germany, there can be seen increases in the last period (i.e., 2012-2018) (Table 2). Within the period of 2006-2012, the decrease was experienced likewise the whole European Continent (Table 2). As for Turkey, its mixed stands had steadily decreased across all time periods (Table 2). Our analysis found out that, in Finland, the decline in the acreage of mixed forests was mainly due to the conversion of mixed forests to coniferous forests. In Germany and Turkey, conversion of mixed forests to coniferous forests and broad-leaved forests are main reasons for the decline in the areas of mixed forests in these countries.

Table 2. Areas of mixed forests for Finland, Germany and Turkey in different time periods.

Countries	CLC 2000 (ha)	CLC 2006 (ha)	CLC 2012 (ha)	CLC 2018 (ha)	Total Change (from 2000 to 2018) (ha)	Changes to
Finland	8.737.029	9.140.687	5.931.881	6.510.355	-2.226.674	mixed to coniferous
Germany	2.361.398	2.392.147	1.344.649	1.357.951	-1.003.447	mixed to coniferous and broad-leaved
Turkey	3.392.391	2.532.675	2.524.386	2.513.325	-879.066	mixed to coniferous and broad-leaved

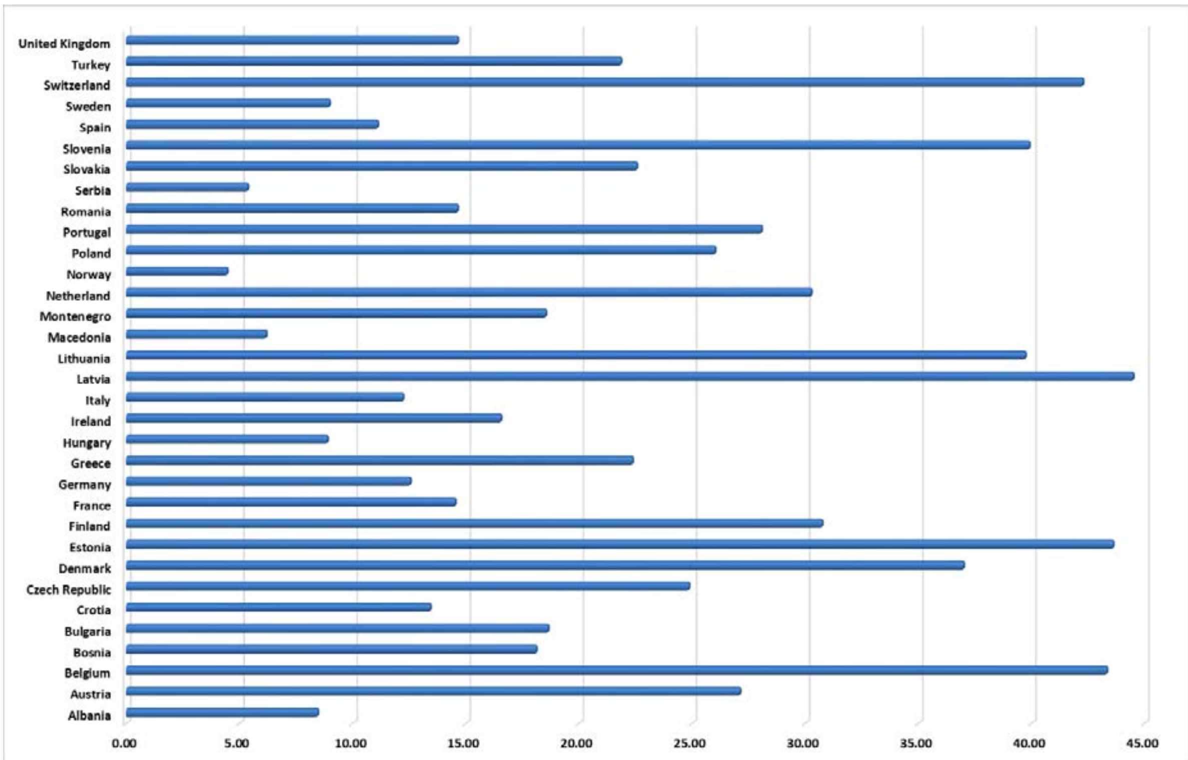

Figure 3. Percentage of current mixed forest area within all forest compositions of European countries.

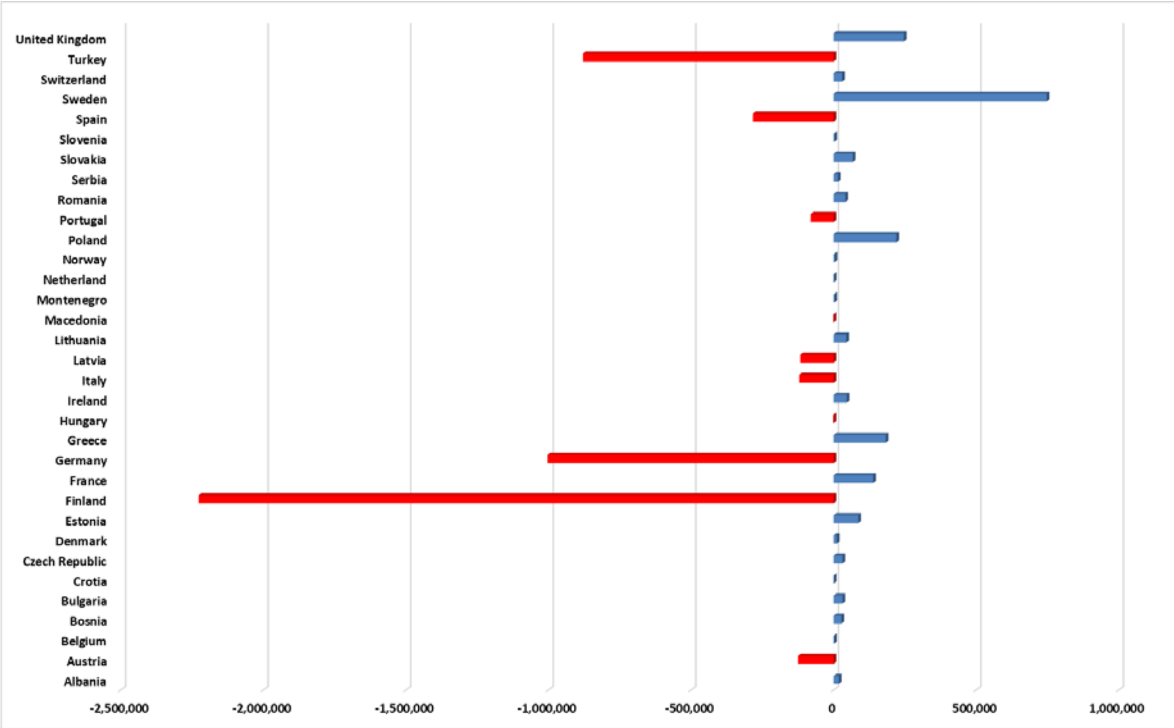

Figure 4. 18-year mixed forest area change (ha.) of European countries.

4. Discussion and Conclusion

Given the importance of mixed forests, more attention should be given the countries where the decline in the acreage of mixed forests is higher. As stated above, higher declines in mixed forests occurred in Finland, Germany and Turkey. Previous studies have revealed that global warming, natural forest dynamics, forestry policies and silvicultural practices may affect the species composition and tree mixture in stands (Elliott & Swank 1994; Kellomäki et al., 2001; Muller-Kroehling et al., 2014; Petrian et al., 2017; Pretzsch et al., 2017; Fadrique et al., 2018). The tolerance of different tree species to climate extremes such as drought varies (Elliott & Swank, 1994; Dittmar et al. 2003; González de Andrés et al., 2018). Global warming may result in replacement of a tree species by a more drought tolerant species (Pederson et al., 2014). For example, Rubio-Cuadrado et al. (2018) found that beech is more vulnerable to drought than oak in mixed (*Quercus* spp.)-beech (*Fagus* spp. L.) forests, thus, it is likely that these forests may convert into pure oak stands if a prolonged drought period happens. In another study, Pretzsch et al. (2013) found that spruce (*Picea* spp.) is more sensitive to drought than beech and oak in their mixed forests. Moreover, previous research discovered that global warming may favor certain tree species in mixed forests (González de Andres et al., 2018), and result in conversion of mixed forests to pure forests. It has been stated that the silvicultural practices that favor more drought-tolerant species should be conducted if the aim is to enhance the resilience of an ecosystem against climate change in mixed forests (Rubio-Cuadrado et al., 2018). It is also essential to quantify the foundational climate-growth relationships for mixed forests so that better management strategies can be developed to mitigate the effects of global warming in mixed stands (Kara & Lhotka, 2020).

Silvicultural implications in mixed forests can influence the tree mixture, and result in the replacement of a tree species by others (Pretzsch et al., 2017). Finland, Germany and Turkey have vast forested areas that consist of shade-tolerant and intolerant tree species (Mosandl & Küssner, 1999; Vettenranta, 1999; Odabaşı et al., 2004). In these forests, silvicultural treatments that create smaller scale of disturbances are commonly utilized. Thus, these disturbances may favor relatively more tolerant species than intolerant species. For example, forest managers have recently concerned for the exclusion or decreasing proportion of Scots pine (*Pinus sylvestris* L.) trees in mixed fir (*Abies*)-pine forests in Turkey. Kara and Lhotka (2020) stated that the current silvicultural practices conducted in these mixed fir-pine forests have favored fir, and may cause conversion of these mixed stands into pure fir stands in the long term. Same concerns may apply for other countries as well. Intensity and timing of silvicultural disturbances play vital role to ensure tree mixture in mixed forests (Raymond et al., 2003). As stated above, most areas of mixed forests were mainly changed to coniferous forests in Finland, Germany and Turkey.

This may be due to forestry policy of the countries if mixed forests are aimed to be replaced by industrial plantations to increase timber production.

Stand dynamics may also result in dominance of relatively more tolerant species over less tolerant one (Odabaşı et al., 2004). Recently, the movement of forest management towards the emulation of natural dynamics, which may lead to formation of pure forests, has increased across the Europe (Rubio-Cuadrado et al., 2018). Rohner et al. (2012) stated that natural succession in oak-beech mixture in Switzerland leads to dominance of beech over oak due to its higher tolerance to shade. Recent studies found that higher density of shade-tolerant species in understory can be associated with the small-gap disturbance regimes, which emulate the natural stand dynamics, typical of temperate forests (McCarthy, 2001; Odabaşı et al., 2004; Petrian et al., 2017). On the other hand, these small-scale disturbances would hinder the establishment of the shade intolerant species in mixed forests resulting in pure stands (Brockway & Outcalt, 1998; Rozenbergar et al., 2007). Our findings substantiate literature studies. We previously stated that areas of mixed forests were also changed to broad-leaved forests, which are usually more shade-tolerant tree species, in Germany and Turkey. Thus, it is likely that natural stand dynamics and small-scale silvicultural practices have influenced the decline of mixed forests in these countries. In Finland, the shade-tolerant tree species in mixture is usually coniferous such as spruce (Vettenranta, 1999), thus, mixed forests have mainly converted to coniferous forests, rather than broad-leaved forests.

The notion of integrating heterogeneity into mostly industrial-driven monoculture forest management being executed since the turn of the 20th century, has for many years been a major ambition after biotic, abiotic and anthropogenic factors started derailing the strategic management targets (Dalin et al., 2009, Morimoto et al., 2013, Felton et al., 2016). However, after straining the natural forests this long, it is not an easy feat to accomplish within the operational terms. As can be seen from the results of the study, decreases experienced between 2006-2012 have greatly affected overall changes within eighteen years for whole continent. Slight increases in other time periods did not prevent the decreases in the mentioned six years and caused a loss of approximately three million hectares.

The principles and understanding of the natural forest structures and dynamics are somewhat limited, so the natural diversity initiatives are not easily attainable (Kuuluvainen, 2002). Ecosystem services supplied through biodiversity in natural forests lacks many important factors in industrialized forest management (Turner & Daily, 2008). Forestry policy of the countries may be another reason for the decreasing area of mixed forests, that is, mixed forests might have been replaced by industrial plantations. Despite all these positive remarks, market demand for the raw timber in the shortest possible terms has forced the decision makers to alter the natural cycle and species compositions in many countries, worldwide. Although the Europe was not exempt from this inevitable outcome, the study's conclusion showed that the majority of the Baltic states, such as Denmark, Latvia, Lithuania, Estonia, and Belgium, Slovenia, and Switzerland have currently at least one third of their national forest area composed of heteroculture forest covers. Is this the matter of knowing something in the names of the decision makers in these countries that the others don't? It may be true for Switzerland's long-established heritage (Scaramellini, 1996) or for Slovenia's great appreciation for a sustainable nature (Ruzzier & Chernatony, 2013). However, the rest probably grasped the idea though different reasoning. Turkey, while still maintaining more than one fifth percentage with mixed forests, has a long tradition of state ownership, applying sustainable as well as functional forest management principles within its 85 % natural forest cover (Atalay & Efe, 2010). Unfortunately, the demand coming from big forest products enterprises invested in the country, has pushed the forest service to single out the coniferous species over the deciduous ones, to produce volume sooner. This, along with Germany, Finland and Spain, caused heteroculture forest area losses varying in percentage.

CLC with its high spatial resolution and dependable data covegare (Maucha & Büttner, 2005), was reliable in monitoring such trends within the Europe. Compared to other global forest/non-forest maps, which lack the precision requiring classifications, i.e. coniferous, deciduous, mix stands etc. CLC provided high precision only attainable through case studies utilizing spatialized data. Furthermore, these openly accessible data are worth utilizing while additionally verifying with other supplemental data sources.

Although common reasons for the conversion of mixed forests into pure forests are given above, they cannot be considered as the main reasons for the decreasing areas of mixed forests in the studied countries. It should be noted that the main objective of this study was to examine the use of CORINE for determining mixed forest areas of the countries.

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