CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Forestry and Wood Sciences

Department of Forest Ecology

Effect of disturbance regimes on the characteristics of coarse woody debris in primary Norway spruce stands in Slovakia

Diploma Thesis

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Sujan Timsina

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Objectives of thesis

The aim of the master thesis is to evaluate the effect of disturbance regimes on quantitative and qualitative characteristics of coarse woody debris cumulated during the recent period in primary Norway spruce forests in Slovakia. Specifically, two main objectives will be studied: 1) to assess the effect of disturbance regimes on the amount of coarse woody debris, 2) to assess the effect of disturbance regimes on the qualitative characteristics of coarse woody debris.

Methodology

The study will be based on previously collected data about the Norway spruce in Slovakian nature reserves. During the field work stand characteristics as amount and quality of CWD, tree density, DBH, crown area and radial increment cores were collected. Disturbance regime will be reconstructed based on radial increment analysis. Two radial growth patterns for disturbance events reconstruction will be used: 1) release from suppression, 2) gap recruitment. These events will be used for construction of disturbance regimes. Further, the influence of disturbance regimes on the CWD will be assessed by correlation or linear regressions. The final results will be discussed and it will be compared with other studies from the similar ecosystems within the region of Central Europe.

The proposed extent of the thesis

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Keywords

forest dynamics, temperate zone, primary forest, dead wood

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DECLARATION

I hereby declare that the work entitled **"Effect of disturbance regimes on the characteristics of coarse woody debris in primary Norway spruce stands in Slovakia"** presented in the dissertation is the genuine work done originally by me and has not been submitted elsewhere for the award of any degree. All sources of information have been specially acknowledged by reference to the author(s) or institution(s).

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Abstract

Deadwood has great ecological importance in the forest ecosystem. It is a source of nutrients and habitat for thousands of dead woods depending organisms. Deadwood contributes as a fundamental element for carbon storage, regeneration of the forest and biodiversity protection, etc. Moreover, it is very well for soil development, water retention and protection against soil-erosion. The main objective of this study is to find out the effect of disturbance regimes on the qualitative and quantitative characteristics of CWD. We studied the role of disturbance history (Percentage of canopy area removal) on the total volume of CWD and volume of lying dead wood (amount of dead wood) in different decay classes and the stand characteristics from the 2 different forest stands dominated by Norway spruce. Unmanaged forest from central Slovakia from two different localities, Koprová dolina (KOP, High Tatras) and Jánošíkova Kolkáreň (JAK, Large Fatras) was chosen for the study.

Altogether 33 plots were established using a stratified random sampling approach. Line transit method was used to measure the amount of lying dead wood. CWD was classified by 5 decay classes degrees. In average lying dead wood volume from the locality KOP is 191 m^3/ha whereas an average volume of lying dead wood from the locality JAK is 155 m^3/ha. The disturbance history was reconstructed as canopy area removal percentage using tree ring series. Decay class 3,4 and 5 covers a high percentage of lying deadwood volume. The correlation between the total volume of lying dead wood was statistically significant in the early stages of stand development before 1900. We found the statically significant correlation for different decay classes in different periods. The pattern of correlation between the disturbance regime and volume of CWD in different decay classes was not so clear for the locality JAK. We found a clearer pattern in the locality KOP when increasing grade of CWD decay classes was following by temporal pattern shift. The Result from the correlation between the disturbance history and lying dead wood shows that there was an effect of historical disturbance during the stand development. The continuity of dead wood volume in all decay classes is important for biodiversity conservation.

Key words: forest dynamics, temperate zone, primary forest, dead wood, CWD, disturbance, decay class, KOP (high tatras), JAK (large fatras)

Table of Contents

List of tables

List of figure

1 Introduction

Deadwood has a well-acknowledged role in the functioning of the forest and ecosystem: it encompasses an environment for many autotrophs and heterotrophs (Rondeux & Sanchez, 2010, Zhou et al., 2007). Deadwood additionally plays an important character in C and nutrients dynamics (Laiho & Prescott, 2004).

Previous studies in unmanaged and managed European forests examine that, the amount and quality of deadwood been associated with numerous ecological and geographical components . For example, Christensen and Hahn (2005) described higher volumes of dead wood in mountain beech-fir forests in Slovenia than in southern boreal Norwegian spruce forest. Other studies have reported significantly higher volumes of deadwood, larger logs and /or higher fractions of advanced decay stages in forests that have not been managed for a long time (Burrascano et al., 2008).

Deadwood results from a variety of causes, including storms, fire, pathogens, normal ageing and anthropogenic origin-cuttings. This leads to a wide range of dead trees, particularly more in a spruce forest. More than a thousand plant and animal species participate in the process of decomposing dead spruce trees; a large part is specialists at a particular stage. It is estimated that more than 700 species of Norwegian beetles are dependent on the dead wood of forest species in the boreal forest (Müller and Bütler 2010).

At present, several researchers are corroborating to the fact that climate change will affect natural disturbance regimes and thus adversely impact the ecosystem of forest (Easterling et al., 2000). As reported by Frelich (2002), more than a quarter of the world's forests lie in the colder part of the northern and southern hemispheres. Their characteristic mosaics of coniferous trees and hardwood have been created by fire, wind and grazing for thousands of years. Recent changes in disturbance regimes in some regions, such as excessive forest fires and large-scale insect outbreaks in North America, are already attributable to climate change (Bentz et al., 2010; Weed et al., 2013). Thus, Frelich (2002) indicated, to understand how disturbance regimes influences over the forest it is necessary to know the basic concepts and mechanics of disturbance and those will serve to formulate a solid benchmark to restore the forest to a natural condition and to study successional trajectories of the forest. Thus, this study is conducted to strengthen the database relating to the influence of disturbance regimes on forest stands.

2 Objectives and Methodology

2.1 Objectives of the thesis

The main purpose of this study is to evaluate the effect of disturbance regimes on quantitative and qualitative characteristics of coarse woody debris in Norway spruce stands cumulated during the recent period in primary Norway spruce forests in Slovakia. To achieve this objective, two specific objectives are assigned:

1) To assess the effect of disturbance regimes on the amount of coarse woody debris,

2) To assess the effect of disturbance regimes on the qualitative characteristics of coarse woody debris.

2.2 Methodology

The study will be based on previously collected data about the Norway spruce in Slovakian nature reserves. During the fieldwork stand characteristics as amount and quality of CWD, tree density, DBH, crown area and radial increment cores were collected. Disturbance regime will be reconstructed based on radial increment analysis. Two radial growth patterns for disturbance events reconstruction will be used:

1) release from suppression,

2) gap recruitment.

These events will be used for the construction of disturbance regimes. Further, the influence of disturbance regimes on the CWD will be assessed by correlation or linear regressions. The final results will be discussed, and it will be compared with other studies from the similar ecosystems within the region of Central Europe.

3 Literature review

3.1 Basic overview of Norway spruce in Europe

Norway spruce (*Picea abies)* is one of the largest and major coniferous trees in Europe for both economic and environmental aspects. It is endemic to the eastern, northern and central Europe. Norway spruce is broadly planted for its wood and utilized as a Christmas tree in various urban communities around the globe (Svoboda et al.,2010). This species can grow up to 50-60 m high and trunk to 150 cm in diameter, usually, it is planted and logged in 100 years. The crown is generally conical, columnar, with rounded, short and free branches, the upper level rising and the lower inclined. It has a reddish-brown bud of up to 5 mm. The needles are 1-2.5″ mm long with four cross-sections, stiff, light to dark green, with bright white lines (Caudullo et.al, 2016). The species is monoecious, with unisexual flowers usually appearing at the age of 20-30 years, but up to 40 years in a dense stall. Male flowers are mainly found at the base of the previous year's shoot, 1-2.5 cm long, spherical, crimson and then yellow when mature. Female flowers are at the end of the shoot, dark red, 5 cm long, upward before plumage and later stuck. The Cones of Norway spruce are cylindrical, 12-15 cm long, green before maturity, in autumn, it turns to brown.

Norway spruce forests have a long tradition in wood production. Nevertheless, it has recently become increasingly concerned about their role in preserving biodiversity. Usually, the disturbance in Norway spruce is caused by windstorm and bark beetles' outbreak (Janda et. al., 2017). These two factors led to extensive spruce death throughout the region. For instance, at the Tatra National Park in Slovakia in 2004, the wind damaged 12,000 hectares of forest (Mezei et. al., 2014).

3.1.1 Distribution and Origin

Norway spruce is the dominant species of boreal and subalpine coniferous forest. It ranges from Central (in mountains) to Northern and Eastern Europe up to the Ural Mountains, where the species merge with Siberian Spruce (*Picea obovata*) (James E. and Eckenwalder, 2000). In northern Europe, it can grow up to the height of 2400m (Jansson, Gunnar et. al., 2013). Because of its large size distribution, there are many varieties and forms, which can be considered as normal patterns of variation within a large number of species. Historically, the plantation of Norway spruce started from the 18th century. Since that period Norway spruce plantation even out of the natural range it has changed the natural forest into the artificial forest (OECD, 2006). It is now spread in many parts of Europe out of its natural zone including Britain and the Pyrenees Mountains. It has also been introduced in other countries outside Europe (United States, Canada, and Japan) and in the southern hemisphere (South Africa, Tasmania, and New Zealand) (Taylor et. al., 1993).

In central Europe, *Picea abies* could most likely only be found in two little territories of the present Czech Republic around 11 500 BC (Vancura, 1995). It migrated from the Beskids Mountains to the Sudeten land in the Ore Mountains in Germany, which was around 6500 BC though, the Black Forest in south-west Germany was reached about 1500 BC. In Switzerland, Norway spruce settled in the east and south-east of the country about 8,000 years ago and spread to the Alpine valleys in 3500 years (Bonfils and Sperisen 1997). The extension was slower in the north of the Alps.

3.1.2 Habitat and Ecology

Spruce forest is found in various habitats and zones. Basically, spruce forests dominate the northern boreal zone and north-eastern Europe. In Central Europe, spruce forests extend over large mountain areas (mainly planted) and subalpine areas in the lowlands they are more mixed with other species (OECD, 2006). The natural distribution shows the continental tendencies, but due to its strong climatic tolerance, it grows even in extreme oceanic climates (Savill, 2013). Norway spruce is a secondary colonizer but can be both a climax and pioneer species. It shows the good yield and good performance under very different conditions in the field and has been a priority for forestry, especially in the lowlands but also in mountain areas (Huber, 2006). Norwegian spruce is a shade-resistant species and can survive for many years under the closed canopy. This species starts to grow faster after 5 to 10 years. This species is more common and spread on acid soils, preferring deep nutrient soils with fresh enough moisture. (Farjon, 2010).

In the boreal forests, it germinates with European aspen (*Populus tremula*) and birch (*Betula spp.*) with willow (*Salix spp.*) along the rivers and lakes. In the Alps, where it is not in a natural state, it meets the European larch (*Larix decidua*) and the Swiss stone pine (*Pinus cembra*) at high altitudes (about 1800-2100 m) with European beech (*Fagus sylvatica*) and European white fir (*Abies alba*) under moist conditions at medium altitudes (800-1800 m) along with Scots pine (*Pinus sylvestris*) under drying conditions (Ellenberg, 2009). The Norwegian spruce reproductive process is controlled by the climatic condition, especially the temperature which is the major factor at high altitude. Usually, wind birds and animals are responsible for seed dispersion. The symbiotic relationship between the roots of Norwegian spruce and mycorrhizal fungi is important for spruce forest ecosystems, more specifically in dry and marginal habitats (OECD, 2006).

Decaying logs are the main seedbed for trees in the European subalpine forests of *Picea abies* (Bače et al 2012). In the European subalpine forest, the *Picea abies* seedlings population can occupy more than 50% of total regeneration, even in semi-natural forests affected by logging (Svoboda et al., 2010) where, micro topographically elevated sites are highly susceptible for regeneration (Schönenberger, 2001). The vigorous character of bark together with branches and knots offer more suitable sites for seed germination compared to decorticated plain stems. Particularly, broken stems often accumulate water in broken parts which enhance decomposition and offer good conditions and microhabitat for seedlings (Čížková et al., 2011). In managed forests stumps and the other elevated sites like the stones covered by mosses, represent the best (safe place) for the regeneration of spruce (Harper, 1977).

3.1.3 Importance of Norway spruce

The importance of Norwegian spruce for many species is due to its ability to change the soil and to create essential structures due to the size of individuals and their distribution in large continuous forests, as well as its landscape dynamics. In addition, Norway spruce, as a growing tree and decayed wood, provide habitat and nutrients for hundreds of species. On the other hand, wood products are used for a wide range of commodities, such as joinery timber, furniture, veneer and as tone-wood (sound boards of pianos and the bodies of guitars and violins) (Jansson, 2013). This conifer species is not so durable so certain wood treatment must be given to protect from the decay. Norwegian spruce is planted for wind breaks and shelterbelts in western prairies, even though they grow in a wet environment (Collingwood & Brush, 1964). That's why this species is recommended in shelterbelt protection in the humid environment (Barrett, et al., 1961). In many European countries, it is planted for Christmas tree plantation and for ornamental purposes.

The resin from Norway spruce is used to make to swiss turpentine and twigs and needles were used to make antiscorbutic and diuretic beverages (Safford, 1974). Norway spruce is also important for the rehabilitation of the degraded land as it tolerates acidic soils but is not well suited for dry or nutrient deficient soils.

3.2 Concept and definitions of Disturbance

Disturbances according to Pickett and White (1985) are a set of the events in time that disrupts the ecosystem, community, or population composition and changes the resource, substrate availability or the physical environment components. The disturbance has strong control over the species composition and structure of the forests. Disturbance regime is a summary description of disturbances for a given landscape, for a given period. The disturbance is characterized by disturbance type, severity, frequency, intensity and spatial size. Severity is the amount of vegetation killed, and the type of growing space made available for new plants, relative to that present before disturbance. Frequency is the inverse of the return interval. For example, a regime with a 50-year return interval means that 2% (the frequency) of the landscape will, on the average, be disturbed in a given year. (return interval: the average time between occurrences in each stand). Intensity describes the size distribution depending on the landscape and disturbance regime (Frelich 2002). If the forest encounters a series of unique disturbances over time, so the type, frequency, severity and size cannot be characterized, then there is no solid regime. The Apparent stability of the regime, however, is a function of the length of time and size of the area observed (Lertzman and Fall 1998).

As demonstrated by several studies, the Structural analysis of forest ecosystems has shown that the interaction of time and space between individual tree mortality and larger disturbances on different scales, ranging from small gaps to landscape, creates many development paths (Runkle, 1982). The type and number of stages of development may depend on different spatial scales, forest species, and disturbance patterns before the so-called "old-growth stage" is reached (Franklin et al., 2002). Although there are many definitions exist at this stage, most scientists agree that the old-growth stands develop later in long term periods without the influence of human or major natural disturbances and show three main structural characteristics: old and large trees, abundant coarse woody debris in different decay stages and a multi-layered vertical structure (Franklin et al. 2004). Characterization of the old-growth stage and complete forest development cycle is particularly difficult in regions, such as central-southern Europe, where anthropogenic effects have been sustained and interacted with natural factors to such an extent that the effects of natural disturbance and human pollution activities are now almost indistinguishable (Barbati et al., 2012). In this region, land use by the human has been the main driving force. Prioritizing the importance of deadwood for regeneration and restoration of forests from disturbance, it is known that removing deadwood can reduce future natural regeneration. Therefore, the removal of dead and dead trees in forests must be carefully considered against possible detrimental effects on the natural regeneration of spruce forests and biodiversity.

3.3 Overview of Disturbance in Norway spruce forest

The concept of disturbance regime has become useful for describing the dynamics of all forests and the range of forest variability. The disturbance regime is defined by frequency, severity (proportion of the eliminated population), and magnitude of disturbance affect species composition and the horizontal and vertical distribution of trees (Frelich, 2002). In addition, it is important to understand the prevalence of disturbance regimes that are important for the adequate supply of many ecosystem services, such as wood production, biodiversity conservation, carbon sequestration, soil and avalanche protection, water and nutrient cycling (Bengtsson et al., 2000). At the global level, spruce forests show heterogeneous disturbance regimes that range from systems caused by frequent and severe chronic fires (for example, *Picea mariana* in the North American boreal zone, (Frelich, 2002) exposed to severe storms or outbreaks of insects (for instance, *Picea engelmannii* in the sub-alpine zone of North America, (Veblen, 2000). The natural dynamics of a forest is largely based on studies that characterized disturbance regimes from two opposing points of view: either the dynamics of small-scale areas, traditionally observed in old-age forests of the temperate zone or large infrequent disturbance, related to boreal forests (Korpel, 1995). The variability of landscape disturbances has been demonstrated in terms of scale, magnitude and impact on forest ecosystems, depending on geographic features, history of previous disturbance and the severity of new disturbance (Bouchard et al., 2006).

The changes in the disturbance especially prevail in the Norway spruce in central Europe where the disturbance is mainly caused by fire, windstorm and various climatic conditions. However, In the absence of frequent fire disturbances, forest stand disturbances are usually caused by wind (Panayotov et al., 2011). Wind storms are caused by irregularly distributed winds that create gaps in size from the area of each tree to several hundred hectares. The severity of wind power is strongly influenced by the stand's topography and other factors (Kulakowski and Bebi, 2004). Furthermore, Norway spruce can also die due to bark beetle *Ips typographus* attacks, which can quickly increase in numbers under favourable conditions. In case of disturbances caused by windstorms following epidemics outbreak of *Ips typographus* can affect whole landscapes (Økland and Bjørnstad, 2006).

Another important factor of tree growth is the climate, while in mountainous conditions the growth of trees is predominantly sensitive to temperature (Buntgen et al., 2007). High temperatures can increase the radial growth of Norwegian spruce, mainly due to the positive influence of warmer weather and longer growing season (Vaganov et.al.,1999). Wind damage can also act as a predisposing factor for new disturbance, especially when forest stands are exposed to repeated strong winds due to topographic or attractive beetle conditions (Panayotov et al., 2015). Combining more environmental changes can significantly affect growth trends and may affect the climate response of tree growth (Pretzsch et al., 2014). Forest ecosystems will, therefore, need to adapt not only to a relatively rapid change in long-term trends but also to increased climate variability, including frequent occurrences extreme climatic events.

Appropriate management of spruce forests can be achieved by understanding the natural dynamics of disturbances at both stand and landscape level (Lindenmayer et al., 2006). Such information provides the foundation of sustainable forest management (Seymour and Hunter, 1999). Removing dead, dead or damaged trees during thinning or restoration is a common practice for spruce stands in Central Europe. The Practice is justified by reducing their susceptibility to attacking various pests or their vulnerability to damage as soon as they are attacked (Wermelinger, 2004). Repeated ingress of these actions led to a drastic reduction in coarse woody debris (Bütler et al., 2004, Lachat and Bütler, 2009). As a result, the quality and quantity nurse log suitable for spruce regeneration are sufficiently low, dramatically reducing the density of advanced regeneration. Each breakdown event creates a biological legacy that is often necessary to support the biodiversity of many species that are dependent on frequent disturbances (Frelich 2002). One of such legacies is the increased availability of dead wood. The natural regeneration density in subalpine European spruce forests is usually reduced (Streit et al., 2009) with most of the regeneration concentrated on favourable microsites such as dead wood or decay. The number of spruce seedlings (*Picea abies*) occupying dead wood can account for up to 80% of the total regeneration (Svoboda et al., 2010).

In these areas, the issue of regeneration and survival in the case of fallen round stems is necessary for forest dynamics. Environmental conditions change after a major disorder that leads to the death of the parent, creating open canopy conditions that allow for greater exposure to light and consequently more favourable conditions for increased regeneration (Metslaid et al., 2007). Furthermore, after a disturbance event, the increase in surface temperature (Hais, Kuera 2008), combined with drier weather in previous years (Mathematics 2011), may cause the further mortality of the saplings and reduces the moisture from the logs. Every log has different qualitative characteristics that offer different conditions for growing trees (Zielonka 2006).

3.4 Disturbance on CWD and its effects

According (Yan E et al., 2006) Coarse woody debris (CWD) are defined as snags and rotting logs, dead or dying trees and stumps and coarse roots at all stages of decay. CWD has great ecological importance and contributes significantly to key ecological processes in the forest ecosystem and plays a key role in forest production, nutrient cycles, carbon storage community regeneration, biodiversity and geomorphological stability. It refers to the dead trees and the remains of large branches on the ground in the forests.

More than a third of our wildlife species are dependent on deadwood for their survival. An important feature of natural forests is that they have a large amount of dead wood in all degrees of decomposition as well as high proportions of old and living trees with dead elements (Harmon et al., 1986). Deadwood has been identified as the most important manageable biotope for forest biodiversity (Huston, 1996), supporting a wide range of organisms, including birds, mammals, insects, nematodes, bryophytes, lichens, fungi, and bacteria. Of this, fungi and insects are the richest among all species (Siitonen et al., 2000). Fungi are an important part of this biodiversity and are one of the main groups decomposing wood on dead trees and living trees around the world (Dix and Webster, 1995). They also play a key role in the diversity of other organisms associated with deadwood, such as Saproxylic insects (Wilding et al., 1989). This is an important functional and structural component of forest ecosystems and plays an important role in the nutritional cycle, long-term carbon storage, tree regeneration and ecological heterogeneity and biodiversity conservation (Stevens 1997; Sturtevant et al. 1997). Over the past decades, several studies have attempted to combine the characteristics of CWD with the forest succession community composition and forest management (Idol et al., 2001; Carmona et al.2002).

A general understanding of the quantity and quality of CWD is essential for assessing the multiple functions of CWD in forest ecosystems (Sefidi, Marvie 2010). CWD characteristics, such as quantity and type (i.e. logs, snag, and stumps), size classes, decay state and nutrients stocks, are often used to reflect the structure of the stand, ecosystem function and forest management history (Siitonen et al. 2000; Ekbom et al. 2006). (Currie and Nadelhoffer 2002) compared CWD in natural deciduous forests with natural coniferous forests and showed that almost all CWD classes existed in deciduous forests. In contrast, the majority of biomass in coniferous plantations was accumulated in the lowest size classes (Sefidi, Marvie 2010). In temperate forests of southern South America, the most disturbing old forests had the largest CWD biomass (Carmona et al., 2002).

In natural forests, CWD input is the result of tree mortality. In managed forests, CWD is also influenced by logging activities and management practices (e.g., left-over stumps and branches) (Petrillo et al. 2015). In both natural and managed systems, the input rate is dependent on the occurrence of major disturbances, such as wind storms or pathologic dieback that can occasionally introduce further amounts of deadwood (Harmon et al. 2013). Depending on the forest ecosystem, CWD can greatly vary, accounting for 10 to more than 30% of the aboveground biomass of forests (Bobiec 2002). On a global level, it represents 8% of the forests' C stock (Pan et al. 2011). For North America and Europe, an increase in woody biomass (Risch et al. 2013) coupled with an increased environmental disturbance regime (Seidl et al. 2014) may lead to a larger amount of CWD in the short-term. However, a decrease in CWD could be expected as a response to climate warming, due to enhanced decomposition rates (Kueppers et al, 2004).

Decay mechanisms of CWD are driven by physical, chemical and biological processes (Harmon et al. 1986). However, it is often difficult to differentiate between the factors controlling the decay mechanisms (Risch et al. 2013, Harmon et al. 2013). The general problem of the precise determination of the CWD disintegration processes seems to be even more fundamental. To get an overview of CWD and decay mechanisms on a wider area relatively simple tools are required to characterize and quantify the processes. In the field, the different steps of CWD decomposition are often described by so-called decay classes that are determined by visual assessment of the wood (Lombardi et al. 2013). The five decay-class systems are the one most commonly applied (Bütler et al. 2007, Harmon et al. 2013, Lombardi et al. 2013 – see Table. 3.1).

Table 3 1 Five decay class system adopted for deadwood assessment (Bütler et al. 2007).

Decay class	Description
1. Recently dead	Bark still attached. Small branches (diameter < 3 cm) present. Wood consistency intact. Fungus mycelium absent or poorly developed
2. Weakly decayed	Bark is loose but not fragmented. Small branches are only partially present. Wood consistency intact but fungus mycelium under bark well developed. Presence of rotten areas but narrower than 3 cm
3. Medium decayed	Bark is fragmented. Small branches absent. Wood consistency reduced but the log still has a hardcore. Rotten areas wider than 3 cm
4. Very decayed	Bark and small branches absent. Rotten throughout the log. Wood consistency compromised, and the log is irregularly shaped under the effects of its own weight
5. Almost decomposed	Bark and small branches absent. Wood consistency is lost (dust). Rotten areas are large, the log is fragmented in sections and maybe mossy

Some authors have tested the effectiveness of using a different number of classes (Teodosiu & Bouriaud 2012). Unfortunately, the detailed chemical characterization of such disintegration classes is often lacking in specific tree species and is based on purely macromorphological observations. As suggested by several authors (Ganjegunte et al. 2004, Lombardi et al. 2013), wood densities, carbons, nitrogen's and phosphorous contents together with lignin and cellulose concentrations may be used to better assess the decay patterns of CWD in relation to specific site conditions (Rock et al. 2008).

Over the past decades, the quality and quantity of CWD have been studied intensively in some countries and they have developed unique perspective for evaluation in stands using a number of CWD characteristics (i.e., CWD amount, CWD type, diameter class and decay class) which are recognized to reflect the past and present stand features to some extent (Yuan J et al., 2014).

The differences in CWD characteristics among stands are particularly associated with stand age, structure, productivity, natural disturbances and management history.

The studies reviewed here suggest that CWD is one of the fundamental factors for maintaining the forest ecosystem and forest disturbances in different stages are responsible to change the dynamics of the forest.

Because of intensive forest management, the largest and oldest trees that would otherwise be naturally killed are eliminated (Linder, Ostlund 1992). The area of natural forests prevails in the northern high latitudes. The diversity of structures present in natural forests is essential for sustainability and ecosystem quality (Angelstam, Kuuluvainen 2004; Hytteborn et al., 2005). Large amounts of dead wood in different disintegration classes present in natural forests are essential for biodiversity (Siitonen et al., 2000). It takes decades for a managed forest to achieve some of the features of natural forest and over 100 years to produce the entire spectrum of structures (Fraver et al., 2008). Natural Norway spruce forests, in contrast to managed forests, have a higher age of trees; the stands are formed by trees of various ages and dimensions and contain high amounts of dead wood in different decay classes (Lilja et al. 2006). Natural structures are generated by disturbances depending on the location of forest properties and regional climatic conditions (Angelstam, Kuuluvainen 2004, Hytteborn et al., 2005). Natural disturbances can be divided into four groups based on successive processes: (i) the dynamics of replacement, which is evident after large-scale disturbance, when all the trees died at the same time (e.g. fire); (ii) the dynamics of the cohort, which is related to the partial change of the composition of the stand spatial scale after average disturbance, the mortality of the trees with specific characteristics; (iii) patch dynamics - tree mortality at intermediate scale (> 200 m2) and (iv) dynamics of mortality at small scale (<200 m2) (Kuuluvainen, Aakala 2011). Gap dynamics disturbance in natural Norway spruce (*Picea abies*) is the most common type (Kuuluvainen, Aakala 2011) in the boreal forest. Gap dynamics are caused by the mortality of individual trees or small groups of trees. Creating gaps when an individual or small group of trees die are caused by wind, snow break and trees reaching the maximum age (Aakala, 2011). Such small-scale disturbances (formation of gaps in the canopy) create a heterogenic (mosaic structure) forest pattern (Shorohova et al. 2009). Gaps are an indication of natural disturbance processes, through which trees suffer mortality naturally without human influence (Leemans 1991). Fire, which contributes to the turnover of minerals and creates dead wood is rarely found on Norwegian spruce stands. In the natural Norway spruce forests where regeneration and mortality are in equilibrium, there is a typical distribution of J-shaped age with a larger number of trees in lower age classes (Groven et al., 2006).

3.5 Overview of amount of deadwood in European landscape (Central Europe)

Deadwood is one of the most important structural and multifunctional components of many forest ecosystems and it has a great role in conserving biodiversity. In central Europe, it is an indicator of sustainable forest management (Lassauce et. al., 2011). Recognizing the importance of dead wood for biodiversity has led to the incorporation of quantitative parameters into the biodiversity monitoring program (Humphrey et al., 2005). For example, the European Environment Agency includes dead wood as one of the 15 basic indicators of biodiversity (Kristensen, 2003).

Several studies have revealed the correlation of species richness with the amount of dead wood (Müller & Bussler, 2008). Generally, it is agreed that 20-30 m3/ha is the required amount that can protect the entire spectrum of species dependent on dead wood (Angelstam et al., 2003; Vandekerkhove et al., 2009). Many authors have presented the different values of the required amount of deadwood. Some authors presented the higher values whereas some authors have shown the lower value. For instance, according to Müller and Bussler (2008), the critical threshold for saproxylic Coleoptera is between 40 and 60 m3·ha-1 in southern Germany. Other studies indicate that for some taxa, the diversity of dead components and their continuity in space and time is more important than their quantity (Heilmann-Clausen and Christensen, 2004). Therefore, for the conservation of biodiversity, it is also important to balance the proportions of the different types of deadwood and decay stages because each type representing entirely different habitats, adapted to different species (Hagan and Grove, 1999).

Considering the Norway spruce in central Europe, the amount of deadwood varies considerably between forest types, standing volume of the stands, decay rate, and vegetation zones, and is influenced by forest management regimes. However, there are some significant differences between the amounts of dead wood from the same regions in Poland, Czech Republic and Slovakia (Svoboda 2008). As reported by (Svoboda 2008), the amount of deadwood in the Norway spruce stands from Czech Republic, Slovakia and Poland are shown in table 3.2.

Table 3 2 Amount of dead wood in selected old-growth Central-European Norway spruce forest (Svoboda 2008).

Location	Volume (m^3/ ha)	Source
Šumava Mts., Czech Republic	142	Svoboda (2008)
Krkonoše Mts., Czech Republic	114	Vacek (1982)
Beskydy Mts., Czech Republic	132	Jankovsky´ et al. (2004)
Babı´ Hora Mts., Slovakia	158	Korpel' (1995)
Tatry Mts., Slovakia	159	Korpel' (1995)
Oravske´ Beskydy Mts., Slovakia	74–218	Saniga and Schutz (2001)
Babı´ Hora Mts., Slovakia	188–240	Saniga and Schutz (2001)
Babı´ Hora Mts., Slovakia	147	Merganicˇ et al. (2003)
Nothern slope of Babia Gora Mts., Poland	131	Holeksa (2001)
Polana Mts., Slovakia	144	Holeksa et al. (2007)
Tatry Mts. and Babia Go´ra Mts., Poland	191	Zielonka (2006a, b)

There is a fluctuation in the amount of deadwood. The variation may occur due to differences in sampling methods. In addition, some of the studied areas were probably influenced by the extraction of wood in the past (Jankovsky´et al., 2004). In three similar spruce forests in Poland and Slovakia, it was reported that the volume of dead wood ranged from 131 to 191 m^3/ha (Holeksa, 2001; Holeksa et al., 2007; Zielonka, 2006a). Although the volumes reported from these areas are comparable, there are some differences. There are several possible explanations for this. In some areas, studies that were reported as old-growth may be affected by wood extraction in the past. In Central Europe, the most severely protected and remote areas were at least partly influenced by human activity in the past. Another important reason is the different decomposition rates of dead wood in the spruce forests (Svoboda 2008). Under Central Europe, the process of decaying dead wood is probably faster in comparison to the boreal spruce forest of Fennoscandia, because it lasts from 60 to over 100 years for a spruce log to disappear completely from the surface of the soil in Poland's old-growth spruce forests (Holeksa, 2001; Zielonka, 2006a). Many studies have demonstrated the effect of past forest management on the amount of dead wood (Rouvinen et al., 2002 and Motta et al., 2006). In southern Finland, in the boreal forest, less deadwood was in managed forests (14 m^3/ ha) compared to old forests

(111 m^3/ha) (Siitonen et al., 2000). So, it means that there is a clear difference in the amount of deadwood between managed and old growth forest.

In North America, the volume of coarse woody debris in old-growth forests can exceed 1,000 m^3/ha (Harmon et al., 1986), where, as in Europe, mean values between 40 and 200 m^3/ha have been reported (Christensen et al., 2005; Vandekerkhove et al., 2009). Higher values (more than 400 m^3/ha) were found in virgin forests in Central Europe, for instance, in Slovakia (Saniga and Schütz, 2001), Poland (Bobic, 2002) and Slovenia (Debeljak, 2006). Even in Europe, there is high variability in the accumulation of dead wood, when the northern boreal and southern Mediterranean forest are characterized by a lower amount of deadwood than mixed forest types in Central Europe (Hahn & Christensen, 2005).

There are many publications that discuss how much dead wood should be left in the forest. However, the variation of the proposed values is relatively high. Older studies suggest at least 3 m^3/ha (Utschick, 1991) or 5-10 m^3/ha (Ammer, 1991), which represents 1 to 2% of the total stand volume. In a recent study, the suggested value is higher and varies between 15 and 30 m^3/ha (Bütler et al., 2004; Jankovský et al., 2004) or 5-10% of total stand volume (Bütler et al., 2004). It is obvious that very small values are too low to be important for the conservation of nature (Scherzinger, 1996). Given the wide variation in values of deadwood from natural forests, which are management benchmarks, there is no universal value valid worldwide (Jankovský et al., 2004).

3.6 Qualitative characteristics of deadwood.

An important characteristic of natural forests is that they possess large amounts of dead trees at all stages of decay and high proportions of old trees alive with dead parts (Harmon et al. 1986). The presence of dead wood in forest ecosystems is one of the key indicators for the protection of environmental biodiversity (Stevens 1997, Müller and Bütler 2010). The diversity of fungi can be regarded as an important indicator of biodiversity of dead trees. Leaving dead trees in coniferous stands, especially in spruce stands, supports the enormous occurrence of Cambio- and xylophagous insects. While in broad-leaved forests, the amount of coarse woody debris and dead standing trees does not significantly affect the origin and development of secondary pests (Stevens 1997). In forests with non-production functions related to the protection of the natural environment, the presence of dead standing and lying trees is positively correlated with the time of their protection.

The abundance of dead trees is not the only vital information about the diversity of nature. The form, arrangement and decomposition rate of the dead matter are also important from the point of view of preferences of various organisms that use dead trees (Stevens 1997). The presence of dead wood of a certain shape and size is essential for the survival of many endangered species (Piotrowski and Wołki 1975). The decomposition of coniferous species is slower than the deciduous trees and they remain longer in the stand (Christensen et al. 2005, Ekbom et al. 2006). Decomposition of dead trees is also one of the basic elements to determine the biodiversity of the environment. The rate of decomposition of dead trees depends on the species and parameters of trees and on prevailing climatic conditions (Müller-Using and Bartsch 2009). A rapid rate of decomposition of dead coarse woody debris and small standing trees are recorded during warm, humid climates and frost (Stevens 1997). Decomposition of trees can take several years to several hundred years. Along with the gradual decomposition of dead trees, the structure, wood and bark colour, and the accompanying generation of organisms all are changed (Pasierbek et al. 2007). In the forest of Poland, most of the coarse woody debris is in the III stage of decomposition (29.5%) (Holeksa and Maciejweski 2009). According to (Zielonka 2006) the decay stages of CWD units were identified according to the eight-degree scale. (Table 3.3).

Table 3 3 Characteristics of logs in different decay stages (Zielonka 2006).

Stage of decomposition	Surface	Shape	Depth of penetration of knife	Branches	Bark
1	Smooth	Round	Wood hard	All branches present, elevated above ground	Intact
2	Smooth	Round	Surface bends under the pressure of knife	Branches over 2 cm	Partial intact
3	Crevices several mm deep	Round	To 1 cm	Over 3 cm thick present	Remains on upper side of log
4	Crevices ca. 0.5 mm deep	Round,	To 4 cm	Only base part present	Usually lack
5	Crevices ca. 1 cm deep	Round,	To 5 cm	Only thickest base parts present	Lack
6	Several cm thick pieces tear off	Slightly flattened	Solid only in central part of log	Only thickest base parts present	Lack of any remains
7	Whole log cover with several cm deep furrows	Distinctly flattened	Through	Lack of any remains	Lack of any remains
8	Most often covered with vegetation	Flattened, covered with vegetation	Through	Lack of any remains	Lack of any remains

Regarding *Picea abies*, decomposing wood is a very important substrate for the regeneration (Holeksa 2001 and Zielonka & Piątek 2004). Simultaneous colonization of logs with epixylic mosses and liverworts (Hörnberg et al. 1997) and vascular plants (Zielonka & Piątek 2004) can also enhance regeneration due to mycorrhizal interactions (Miller et al. 1983). It is also worth noting that the density of seedlings decreases at the most decayed log (decay stage 8). In the sub-alpine forests, two main factors are responsible for the mortality of *Picea abies*, the most important factors, wind and snow, are responsible for the uprooting and breaking of stems. In this case, the stems are immediately part of the forest floor, which speeds up the process of decomposition. The other cause of *Picea abies* mortality is due to pathogenic fungi and bark beetles (*Ips typographus*), which lead to the formation of standing snags. The snags of *Picea abies* can remain for up to 20 years before falling (Storaunet & Rolstad 2002), which can significantly prevent the decomposition of wood. This can explain the variability in the decay rate, particularly in the case of the initial decay phase. However, it was impossible to estimate the lag between death and the fall of the tree.

In controlled forests, mainly trees of large diameter trees are harvested and logging waste (e.g. branches), which is left behind in the forest, is of small dimensions (Kirby et al. 1998). Advanced decomposition stages develop only after a long period of time without any human interference or natural disasters such as storms or bark beetle infestations (Jonsson et al. 2005). However, qualitative characteristics in the investigated forest reserves, have been identified to host a wide diversity of beetles, fungi, bryophytes and lichens (Brin et al. 2011). In a virgin beech forest in Slovakia, the largest dead wood volumes of deadwood were recorded during the decomposition stages (Saniga and Schütz 2001). Large deadwood is rare in managed forests but is particularly important for many species as it forms a continuous habitat. Large diameter trees (larger log diameter >30 cm) and advanced decay stages (class IV+V) are especially important to a wide variety of species (Lachat and Bütler, 2009). Large diameter trees should, therefore, be a priority for the promotion of forest biodiversity and be left in the forest so that all decomposition classes can develop.

4 Empirical analysis

4.1 Methods

4.1.1 Study site

The research was developed in the mountain forest in central Slovakia, two study areas located respectively in JAK - Janosikova kolkaren and KOP - Koprova dolina. All 2 sides represented long term unmanaged high mountain forest dominated by Norway spruce. Having said that, both of this area is composed by a large number of flora and fauna including the endemic species. Coniferous species such as Swiss pine *(Pinus cembra*), European larch (*Larix decidua*) and Mountain pine (*Pinus mugo*) and animals like Tetra Chamois (*Rupicapra rupicapra tatrica*), Eurasian brown bear (Ursus arctos arctos), Eurasian lynx (*Lynx lynx*), wolf (*Canis lupus*), Foxes, and the alpine marmot (*Marmota marmota*) are mainly found in that area. Among the species, Tetra Chamois is an IUCN critically endangered species (Caprinae 2002). The mean annual air temperature of Koprova Dolina (KOP) and Janosikova kolkaren (JAK) is 0-2 °C and 2-4 °C respectively**.** Also, the mean annual temperature of Koprova Dolina (KOP) is 2000-2400 mm and Janosikova kolkaren (JAK) is 1200-1600 mm. Soil group is Leptosols in Koprova dolina (KOP) dominated by granitoids whereas soil group is podzols in Janosikova kolkaren (JAK) in which the soils are granitoids. The more detailed information about the study area is given below in table number 4.1 and 4.2.

Table 4 1 *General characteristics of Koprova Dolina (KOP) study plots*

Plot	Altitude (m a.s.l.)	Slope (degrees)	Aspect (degrees)	Northness (-)
SLO_KOP_124	1402	36	240	-0.5018379
SLO_KOP_165	1367	35	260	-0.1759133
SLO_KOP_188	1484	30	266	-0.0721041
SLO_KOP_208	1501	28	288	0.3065925
SLO_KOP_268	1404	29	278	0.1367369
SLO_KOP_310	1415	36	330	0.8645618
SLO_KOP_350	1377	17	216	-0.8101389
SLO_KOP_351	1390	34	195	-0.9663709
SLO_KOP_352	1430	21	248	-0.3766402
SLO_KOP_372	1433	25	191	-0.9819482
SLO_KOP_373	1456	27	214	-0.8300949
SLO_KOP_393	1500	35	216	-0.8101389
SLO_KOP_412	1432	37	312	0.6670765
Average	**1430.0769**	**30**		**-0.2730938**

Table 4 2 General characteristics of Janosikova Kolkaren (JAK) study plots

Plot	Altitude (m a.s.l.)	Slope (degrees)	Aspect (degrees)	Northness (-)
SLO_JAK_053	1297	39	350	0.984265
SLO_JAK_054	1319	26	330	0.864562
SLO_JAK_055	1336	25	310	0.640684
SLO_JAK_056	1386	22	290	0.339608
SLO_JAK_070	1223	33	315	0.705133
SLO_JAK_071	1256	24	345	0.965131
SLO_JAK_072	1303	28	280	0.171208
SLO_JAK_088	1271	24	250	-0.3441
SLO_JAK_089	1319	25	250	-0.3441
SLO_JAK_106	1316	22	255	-0.261
SLO_JAK_120	1273	24	340	0.938659
SLO_JAK_121	1325	33	340	0.938659
SLO_JAK_133	1253	35	320	0.764221
SLO_JAK_134	1300	32	315	0.705133
SLO_JAK_135	1334	34	290	0.339608
SLO_JAK_146	1244	34	280	0.171208
SLO_JAK_147	1299	31	280	0.171208
SLO_JAK_148	1386	28	280	0.171208
SLO_JAK_161	1309	27	340	0.938659
SLO_JAK_177	1356	30	270	-0.00239
Average	**1305.25**	**28.8**		**0.442879**

To study the effects of disturbance regimes, the inventory was done in 2013-14, where the structure of the plot, deadwood structure, species composition, disturbance history in every 10-years periods (1800-2000) was reconstructed using the tree cores, deadwood volume was observed. And the study was conducted in a primary spruce forest. The map of the study area is shown in figure 1.

Figure 1 Map of the study areas, source: (google map 2019)

4.1.2 Data collection

Data were collected using a Stratified random sampling method. The study was conducted in two landscapes, Large Fatras and High Tatras range in 2 stands for the survey, Altogether, 33 plots were established. A grid of 144*144-m or 100*100-m cells was overlaid on every stand by the help of GIS A circular sample plot of 1000 m^2 was established in each grid cell at a restricted random position. The center of the plot was limited to 0.25 inside and 0.49 ha of the core in each cell of 1 ha or 2 ha, respectively. The circular plot 500 m^2 can be used in two cases depending on the types of the stand, one is with smaller trees on plots that were recently disturbed, and another is trees having the high density of regeneration. Likewise, elevation, aspect, slope, the position of the slope was recorded. In addition, more details about the structure of the trees i.e. diameter at breast height (DBH), species composition, and social status (non-suppressed – at least one half of the crown projection when there is open canopy condition: suppressed) of all trees with DBH ≥ 10 cm were recorded. To measure the amount of downed deadwood with DBH ≥ 10 (CWD) the line intersect method was used, (Harmon and Sixton, 1996) using a total transect length of 100 m per plot, divided into five sub-transects of 20 m each. A five decay class assortment model was used for classification of deadwood**:** 1)

Recently dead (bark is attached, hardwood, present of small branches); 2) Weekly decayed (bark is loose but not separated, absence of fresh phloem); 3) Medium decayed (fragmented bark, partly decayed wood, rotten area larger than 3 cm); 4) Very decayed (lack of bark and branches, rotten throughout the log); 5) Almost decomposed (log is fragmented and covered by mosses and lichens). In Every plot, all individuals in the regeneration layer is ordered and recorded by three high classes (0.5-1.3 m; 1.3-2.5 m; > 2.5 m and <10 cm in DBH). We selected 25 Canopy *Picea abies* trees per plot for incremental core extraction where non-suppressed trees were cored at a height of 1 m above the ground (15 for 500 m^2plots). Trees with an important part of the crown projection receiving direct sunlight from above have been classified as canopy trees (Lorimer & Frelich 1989). Suppressed trees were excluded because their growth patterns may lack information important to reconstruct the history of disturbance (Svoboda et al. 2012). One core per tree was taken perpendicular to the direction of inclination and prepared by standard dendrochronological procedures. The width of the tree ring was measured using a Lintab (TM) slide stage measuring apparatus (Rinntech, Heidelberg) with a resolution of 0.01 mm. The cores were visually cross-checked and verified through COFECHA (Holmes, 1983). In case the pith is absent from the core, the estimate of the missing rings was obtained using Duncan's (1989).

4.1.3 Dendrochronological analysis

As per Svoboda et. al., (2014) two frameworks of radial growth were used to reassemble the disturbance history. One is the recruitment of an open canopy, where the rates of fast growth if radial shows the recruitment in the former canopy gap and another is turnout, where sustained growth of the radial showing the former canopy mortality (Frelich and Lorimer 1991). During the growth of suppressed trees usually increases immediately after the mortality of maximum overtopping canopy trees, the creation of new trees after gap formation disorders can vary from year to decades (Ramming et al. 2006). *Picea abies* is tolerant tolerance to shade and is higher during the juvenile phase and decrease with the age (Tjoelker et al., 2007). In *Picea abies* forests, for instance, the absence of progressive regeneration in closed-canopy stands, coupled with the slow establishment and growth of seedlings, can result in an incident of gap recruitment (at 1.3 m) takes up to 40 years after a major disturbance event. Hence, disturbance histories are built mainly from the gap recruited trees (Svoboda et al. 2012).

Open forest canopy recruitment has been defined by a threshold separating open canopy trees from those found under closed forest cover, based on their growth rate of juveniles (Svoboda et. al. 2014). Here in this research, empirical data on juvenile growth rates of sampled seedlings developed under a closed canopy and different sizes of canopy openings were used, comparing their growth rates for five years. Logistic regression method was used to calculate growth rate thresholds (Svoboda et. al., 2012). Saplings with growth rates higher than 1.7 mm yr^{-1} is examined as open canopy recruited, which corresponds to gap sizes of greater than 500 m^2 (Janda et.al., 2017). Boundary line criteria were used for growth release identification (Black and Abrams 2003, Svoboda et.al., 2014). Concrete boundary lines were constructed for all data from this study

(PGC = 1664.2567 * e (-7.1423 * PG) + 684.7334 * e (-0.8271 * PG) where,

PGC refers to Percentage Growth Change.

PG stands for Prior Growth (Black and Abrams 2003).

A release event is a possible growth change value over 20% of the boundary line, when an increasing growth rate is maintained for at least 7 years it is examined as a valid release where shorter recovery time to prior growth rates was not considered to be a release (Svoboda et al., 2014). We used the DBH value where we divided the trees into two groups to eliminate the overestimation of disturbances discovered from mature trees already in the crown, according to the probability of their presence or absence in the canopy (Lorimer and Frelich,1989). The limit value was evaluated in the same way as in the case of open canopy recruitment, where the DBH distribution of the canopy and the lower canopy trees were categorised. Here in our study, the trees were supposed to be in the canopy, if their diameter during the event exceeds 25 cm, which is determined by the logistic regression and suppressed diameters of trees (Svoboda et.al.,2014). *Picea abies* is especially resistant to shadows mainly during the juvenile stage, so in order to gain the canopy status, one or more disturbance may be required (Lorimer and Frelich 1989). Hence, numerous releases from the same trees were granted in chronological order of disturbance (Janda et.al 2017).

4.1.4 Construction of disturbance chronologies

Canopy accession events were summed every ten years to build a disturbance time series at the plot level (Janda et. al., 2017). Gap recruitment or the first major release is used to define the canopy accession. The number of growth releases and gap recruitment events was converted into total canopy area that was disrupted every decade following the approach and argument of Lorimer and Frelich (1989). To predict a canopy area from DBH based on the current vegetation in permanent sampling plot we use Linear regression analysis (Svoboda et. al., 2014). The disturbance chronologies were shortened when the percentage of canopies available for tree ring samples dropped below 10% over a period of time.

4.1.5 Evaluation of past disturbance impact on the age and current forest structure

We separately analysed 2 groups of stands (the High Tatras and Large Fatras) with different disturbances timeframe, to determine the impact of past disturbances on the current forest structure. Correlation between the disturbance history after 1850 and the total volume of lying deadwood was calculated for both stands High Tatras and Large Fatras. A period of 20 years, 30 years, 40 years 50 years and 100 years were analysed. After comparing the correlation between different periods and values we found the best interrelation in 50 years' time frame, so we decided to use that value for farther analysis. On the other hand, the correlation between the disturbance history after 1860 and volume of lying dead wood in different decay classes (for different decay stages) from 1 to 5 was calculated for both stands. A period of 10 years, 20 years, 30 years, 40 years and 50 years were analysed. After comparing the correlation value, we found out the best results in decadal approach, so we decided to the decadal approach for further analysis.

5 Presentation and analysis of result

5.1 Stand characteristics of locality KOP

The table below (Table number 5.1) presents information about the stand features of High Tatras (KOP) where the data containing the living trees density, Dead trees density, Mean DBH of living trees, Mean DBH of dead trees, Basal area of living trees, Basal area of dead trees, lying dead wood volume and Mean age including their mean, standard deviation and the disturbance history (percentage of canopy area removal) from 1870 till 2000 (Table number 5.2) are given.

The maximum basal area of living trees is 67.79 m2/ha and the least are 26.59 m2/ha. Likewise, 21.65 m2/ha is the maximum basal area of dead trees where 2.5 m2/ha is the lowest. Considering the lying dead wood volume, 358.52 m3/ha is the largest volume and the smallest is 80.26 m3/ha. 195.78 years is the maximum mean age and 39.76 years is lowermost mean age.

Table 5 1 Stand characteristics of High Tatras (KOP)

Plot	Living trees density (n/1*ha	Dead trees density (n/1*ha)	Mean DBH of living trees (cm)	Mean DBH of dead trees (cm)	Basal area of living trees (m2/ha)	Basal area of dead trees (m2/ha	Laying dead wood volume (m3/ha)	Mean age (years)
SLO_KOP_124	830	140	18.5	34.7	26.59	15.15	219.6949266	39.7666667
SLO_KOP_165	1520	200	17	32	38.74	21.65	215.6565312	69.8387097
SLO_KOP_188	290	70	36	31.1	37.2	7.02	358.5275674	117.88
SLO_KOP_208	300	70	34.6	41.8	33.69	10.69	338.2394852	152.692308
SLO_KOP_268	720	110	26.3	21.1	49.2	4.51	126.0104209	157.064516
SLO_KOP_310	650	60	25.4	29.9	38.91	5.02	185.6969769	111.193548
SLO_KOP_350	670	70	29.6	22.2	54.43	3.4	80.26381757	130.8
SLO_KOP_351	860	110	26.5	19	57.48	3.56	111.4393071	147.1875
SLO_KOP_352	530	140	38.7	21.9	67.46	6.98	191.6794376	195.78125
SLO_KOP_372	630	40	32.1	26.3	59.57	2.5	157.4402995	178.852941
SLO_KOP_373	740	20	23	46	39.54	3.34	235.8866294	87.7741935
SLO_KOP_393	670	90	29.2	19.4	53.7	4.18	94.18094674	142.848485
SLO_KOP_412	660	130	34.4	18	67.79	4.68	175.1459997	167.064516
Average	**697.6923077**	**96.1538462**	**28.5615385**	**27.9538462**	**48.02307692**	**7.129230769**	**191.5278728**	**130.672664**
SD	**300.6424744**	**48.7405481**	**6.63243777**	**8.96675484**	**13.19435004**	**5.600143542**	**85.04099462**	**44.5676195**

Taking the mean DBH of living trees 38.7 cm is the topmost density and 18.5cm is the lowest. Also, 46 cm is the highest mean DBH of dead trees 18 is the lowest. However, 200 n/ha is the highest dead trees density and 20 n/ha is the lowest. On the other hand, 1520 n/ha is the largest living trees density and 290 n/ha is the lowest.

Overall, living trees density have the highest mean value which is 697.69 n/ha following lying dead wood volume (191.52 m3/ha), Mean age (130.67 years), Dead trees density (96.15 n/ha), Basal area of living trees (48.02 m2/ha), Mean DBH of living trees (28.56 cm) and Mean DBH of dead trees (27.95cm) respectively. Whereas, the basal area of dead trees has the lowest mean value which is 7.12 m2/ha.

Table 5 2 Disturbance History (percentage of canopy area removal) in High Tatras (KOP)

Years	1870	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
Average	11.19	4.98	5.06	1.85	1.97	3.74	2.65	3.23	4.68	8.42	5.83	5.4	1.11	0.78
SD	11.24	6.16	5.05	2.84	2.29	4.38	4.83	4.12	6.28	12.98	7.08	10.55	1.57	1.56

5.2 Stand Characteristics disturbance history of locality JAK

The table (Table number 5.3) represents the main stand characteristics from the area called Large Fatras (JAK) in all the 20 plots including their average, standard deviation and percentage and also the disturbance history (percentage of canopy area removal) from 1870 till 2000 (Table number 5.4).

Table 5 3 Important stand characteristics of Large Fatras (JAK)

Plot	Living trees density (n/1*ha	Dead trees density (n/1*ha)	Mean DBH of living trees (cm)	Mean DBH of dead trees (cm)	Basal area of living trees (m^2/ha)	Basal area of dead trees (m^2/ha	Laying dead wood volume (m^3/ha)	Mean age (years)
SLO_JAK_053	280	50	32.5	29.3	29.25	5.27	89.10204831	98.27778
SLO_JAK_054	180	10	38.4	71.2	25.79	3.98	160.3508459	111.5
SLO_JAK_055	180	10	47.3	60.7	38.37	2.89	160.399577	124.8
SLO_JAK_056	220	60	50.1	36.5	46.39	6.56	60.24159786	144.7222
SLO_JAK_070	180	80	50	24.6	40.67	6.57	44.51685065	147.8571
SLO_JAK_071	430	60	31.8	30.4	50.13	6.8	214.8489508	145.6667
SLO_JAK_072	200	20	40.9	42.3	31.17	4.44	184.5739393	139.7222
SLO_JAK_088	350	150	41.5	21.9	49.98	5.88	122.1435099	119.6923
SLO_JAK_089	200	60	45.2	48.4	35.59	12.19	298.6939543	173.6111
SLO_JAK_106	160	130	40.4	38.1	21.51	16.95	273.076039	163.3571
SLO_JAK_120	280	50	30	48	28.43	10.84	235.5874571	82.96
SLO_JAK_121	190	60	21.1	48.1	7.99	12.35	128.3519846	52.26667
SLO_JAK_133	330	30	32.4	14.1	36.73	0.47	125.9198673	99.11765
SLO_JAK_134	350	20	34.3	16.1	42.39	0.41	160.9409248	116.4
SLO_JAK_135	190	70	46.5	42.3	35.74	17.14	250.3178416	146.75
SLO_JAK_146	390	50	38.6	19.8	52.22	2.03	60.89545915	109.9
SLO_JAK_147	370	110	36.4	28.6	44.14	8.53	136.6693469	142.5926
SLO_JAK_148	180	50	44.9	40	30.58	7.15	95.48854595	160.1429
SLO_JAK_161	170	10	47.6	57	35.68	2.55	145.76172	116.9167
SLO_JAK_177	190	40	51.2	37.2	43.34	4.88	161.8726155	149
Average	**251**	**56**	**40.055**	**37.73**	**36.3045**	**6.894**	**155.4876538**	**127.2627**
SD	**87.4733042**	**38.443397**	**8.0242707**	**15.1722774**	**10.77981665**	**4.848025534**	**70.98701997**	**29.82406**

Comparing all the data, living trees density has the highest mean value with 251 n/ha followed by, lying dead wood volume (155 m^3/ha), Mean age 127.26 years, dead trees density which is 56 n/ha, mean DBH of living trees 40.05 cm, mean DBH of dead trees 37.73 cm and basal area of living trees 36.30 m^2/ha. Nevertheless, basal area of dead trees has the lowest mean density which is 6.89 m^2/ha.

Furthermore, considering the individual characters, 430 n/ha and 160 n/ha is the highest and lowest **living trees density** whereas, 150 n/ha and 10 n/ha is the maximum and minimum **dead trees density.** Nevertheless, the highest **mean DBH of living trees** is 51.2 cm and the smallest are 14.1 cm. In the same way, the **highest mean DBH of dead trees** is 60.7cm and lowest is 14.1 cm. Similarly, 52.22 m^2/ha and 7.99 m^2/ha are the maximal and **minimal basal area of living trees** where 16.95 m^2/ha and 0.14 m^2/ha are the uppermost and lowermost **basal area of dead standing trees**. Likewise, the uppermost **lying dead wood volu**me is 298.69 m^3/ha and 60.24 m^3/ha is the lowermost volume, which is quite less as compared to High Tetras. We got a superlative mean age of 173.61 years and the littlest is 82.96 years.

Table 5 4 Disturbance History (percentage of canopy area removal) in Large Fatras (JAK)

Years	1870	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
Average	13.92	11.77	7.69	3.33	3.03	5.56	5.85	4.32	1.8	1.55	1.61	1.57	1.38	1.12
SD	11.4	16.15	11.87	4.55	4.15	6.3	6.21	6.95	2.19	2.34	3.17	2.08	2.19	1.93

5.3 Comparison of the characters between High Tatras (KOP) and large Fatras (JAK)

By comparison of the important characteristics between High Tatras (KOP) and Large Fatras (JAK), we found the variations between the important characters. To test the differences between the means of two groups of the data variation t-test was performed. Mean DBH of living trees, mean DBH of dead trees, mean basal area of living trees, mean Basal area of dead trees, lying dead wood volume and mean age was tested.

The difference between the Mean DBH of the living trees was statistically significant ($t = 4.4727$, p-value = 0.000109) and the mean DBH of JAK (DBH = 40.06 cm) stand is higher than the mean DBH of KOP (28.56154 cm). There was a significant difference in the mean DBH of dead trees ($t = 2.3241$, p-value = 0.02689) where the mean value of dead trees from the locality KOP (27.95385 cm) is less than the mean of JAK which is 37.73000 cm. In KOP, the mean of basal area of living trees (48.02308 cm) is greater than in JAK ($t = -2.6743$, p-value = 0.01384) where the mean basal area of dead trees is 36.30450 cm. Additionally, there is not a big difference between the mean basal area of dead trees in both stands where the mean basal area of dead trees of KOP (7.129231cm) is pretty higher than the mean basal area of dead trees (6.894000 cm) in JAK. Mean basal area of dead trees was not-statically significant (t = -0.12419, df = 23.08, p-value = 0.9022). Subsequently, the mean age of living trees in KOP (130.6727 years) is to some extent more than the mean age of living trees in JAK (127.2627 years). Non-statically significant result (t = -0.24279, df = 18.987, p-value = 0.8108) was seen between the differences of mean age of living trees.

5.4 Lying Dead wood volume of High Tatras (KOP) in accordance to Decay classes

The table below (Table number 5.5) shows the dead wood volume in each decay classes, 1 to 5 from the locality High Tatras (KOP) along with their Average, Standard Deviation and percentage. It is clear from the table that the largest volume of dead wood is in decay class 3 which is about 29.18% from the total amount of CWD volume with an average of 55.89 m^3/ha. On the other hand, decay class 1 contains the lowest deadwood volume which is about 7.48% with an average of 14.34 m^3/ha. Out of five decay classes, the dead volume is almost similar in decay class 2, 4 and 5 which is 21.40%, 21.23% and 20.69 % and the mean is 41.00 m^3/ha, 40.66 m^3/ha and 39.62 m^3/ha respectively. Decay class 4 and 5 indicates the slight decreasing trends of dead wood volume.

Table 5 5 Total volume (m3/ha) of dead wood in each decay classes from 1 to 5.

Plot	Decay class 1	Decay class 2	Decay class 3	Decay class 4	Decay class 5	Lying dead wood volume (m3/ha)
SLO_KOP_124	75.3513454	37.9441876	51.9396568	16.9398189	37.51991798	219.6949266
SLO_KOP_165	0	35.4222569	86.0297638	74.4709766	19.73353378	215.6565312
SLO_KOP_188	0	146.147128	129.39952	64.2453263	18.7355934	358.5275674
SLO_KOP_208	0	162.422846	119.596535	45.8258069	10.39429725	338.2394852
SLO_KOP_268	0	7.36432869	30.7172931	36.3303839	51.59841518	126.0104209
SLO_KOP_310	24.9678785	7.04739102	78.7862144	9.89723929	64.9982537	185.6969769
SLO_KOP_350	36.0271403	21.4687336	5.7151178	11.0817152	5.971110663	80.26381757
SLO_KOP_351	0	10.1970285	25.6156946	27.5332354	48.09334855	111.4393071
SLO_KOP_352	40.1901395	43.1996286	51.1022208	17.4869651	39.7004837	191.6794376
SLO_KOP_372	0	24.7732005	16.1063308	68.165163	48.39560518	157.4402995
SLO_KOP_373	0	0	56.88914	61.0043949	117.9930945	235.8866294
SLO_KOP_393	0	0	32.1011351	30.8301767	31.24963493	94.18094674
SLO_KOP_412	9.93536064	37.0281649	42.6079458	64.7866741	20.78785427	175.1459997
Average	**14.3439896**	**41.0011457**	**55.8928129**	**40.6613751**	**39.62854947**	**191.5278728**
SD	**23.5201744**	**52.5200196**	**37.9990365**	**23.6064997**	**29.33404883**	**85.04099462**
Percentage	7.48924391	21.4074041	29.1826	21.230004	20.69074798	100

5.5 Lying Dead wood volume of Large Fatras (JAK) in accordance to Decay classes

The following table (Table number 5.6) represents the total volume of dead wood in each decay classes and their respective mean, standard deviation and Percentage share from the area called Large Fatras. According to the table, we can see that decay class 3 contains the maximum amount of dead wood volume which is exactly 35.27% with an average of 54.54 m^3/ha and decay class 1 represents the lowest amount of lying dead wood which is just 1.18% with an average of 1.83 m^3/ha. Similarly, the volume of dead wood has increased in decay class 2 with a mean value of 20.26 m^3/ha which is about 13.03%. The dead wood volume has increased in decay class as compared to decay class 1. Likewise, the trends continue in decay class 4 and 5 also with the rising amount of dead wood. The percentage of dead wood volume in decay class

4 is 23.41% with a mean of 36.41 m^3/ha. Moreover, in decay class 5, the average amount of dead wood is 42.00 m^3/ha which is 27.01%.

Table 5 6 Total volume (m3/ha) of dead wood in each decay classes from 1 to 5

Plot	Decay class 1	Decay class 2	Decay class 3	Decay class 4	Decay class 5	Lying dead wood volume (m3/ha)
SLO_JAK_053	0	1.25849793	3.0798101	25.6530758	59.1106646	89.10204831
SLO_JAK_054	0	0	12.986919	48.9655748	98.3983521	160.3508459
SLO_JAK_055	0	29.0257663	32.002192	63.9278951	35.4437233	160.399577
SLO_JAK_056	11.103305	2.77582624	15.53229	27.2524452	3.5777316	60.24159786
SLO_JAK_070	2.08495393	13.434999	24.999708	3.99718978	0	44.51685065
SLO_JAK_071	0	25.0935926	86.178918	17.252562	86.323878	214.8489508
SLO_JAK_072	0	68.5197286	55.516525	20.7385062	39.7991797	184.5739393
SLO_JAK_088	0	7.52668369	50.075412	40.1671926	24.3742218	122.1435099
SLO_JAK_089	0	19.1364227	189.03327	70.1884319	20.3358264	298.6939543
SLO_JAK_106	0	0	104.04784	140.807425	28.2207767	273.076039
SLO_JAK_120	0	20.232689	84.594847	69.3956559	61.3642654	235.5874571
SLO_JAK_121	0	10.091177	41.90449	35.7305587	40.6257591	128.3519846
SLO_JAK_133	0	0	11.779496	22.4860431	91.654328	125.9198673
SLO_JAK_134	0	29.4495425	31.089747	34.326114	66.075521	160.9409248
SLO_JAK_135	0	11.103305	134.34999	44.4132198	60.451327	250.3178416
SLO_JAK_146	1.23370055	0	23.464984	23.4156364	11.5474371	60.89545915
SLO_JAK_147	22.32998	8.99367701	31.533386	7.01975613	65.5588472	136.6693469
SLO_JAK_148	0	54.1284883	27.83981	6.53182756	6.98842014	95.48854595
SLO_JAK_161	0	54.2088022	70.999467	10.3754216	10.1780295	145.76172
SLO_JAK_177	0	50.2834138	65.825573	15.6354273	30.1282011	161.8726155
Average	**1.83759697**	**20.2631306**	**54.841734**	**36.413998**	**42.0078245**	**155.4876538**
SD	**5.43015549**	**21.210024**	**46.596614**	**31.8029101**	**30.1927041**	**70.98701997**
Percentage	1.18182822	13.0319868	35.270796	23.4192214	27.0168232	100

5.6 Relationship of the decay classes between High Tatras (KOP) and Large Fatras (JAK)

Overall, it is clear from table number 5.5 and 5.6 that the quantity of lying dead wood volume was more in the High Tatras as compared to Large Fatras. The average amount of lying dead wood volume in the High Tatras was 191.52 m^3/ha whereas the volume in Large Fatras was lower with an average of 155.48 m^3/ha. The difference of the total volume of lying dead wood wasn't statistically significant ($t = -1.2677$, p-value = 0.2179). In the same way, except decay class 5, the percentage of lying dead wood was a little bit more in decay class 1,2,3 and 4 in the High Tatras. On the other hand, the amount of dead wood in decay class 5 was slightly higher in Large Fatras in contrast to the High Tatras. In both High Tatras and Large Fatras, no statically significant differences between the dead wood volumes were found in all decay classes (decay class 1, t = -1.8848, p-value = 0.0823; decay class 2, t = -1.3537, p-value = 0.1964; decay class 3, t = -0.070923, p-value = 0.9439; decay class 4,t = -0.4394, p-value = 0.6635;decay class 5, t = 0.22505, df = 26.331, p-value = 0.8237)

5.7 Comparing historical disturbance with present situation

For both stands, the High Tatras and Large Fatras, the correlation between the history of disturbance after 1850 and lying deadwood was calculated. A period of 20 years, 30 years, 40 years, 50 years and 100 years were analysed (see the results in table 9.1-9.5 in the appendix). After comparing the correlation between different periods and values, we found the best interrelationship over a 50-year period. So, we decided to use this approach. Table 5.7 shows the correlation between disturbance history and lying dead wood (CWD volume).

Table 5 7 Correlation between disturbance history and lying dead wood

where, white - No correlation (-0.3-0.3), Light Blue - negative moderate correlation (-0.6- -0.3), Green- negative strong correlation (-0.6- -1), (the numbers in bold represent statistically significant correlation at the level α=0.05)

Years (50)	**1870-1910**	**1880-1920**	**1890-1930**	**1900-1940**	**1910-1950**	**1920-1960**	**1930-1970**	**1940-1980**	**1950-1990**	**1960-2000**
High Tetras (KOP)	**-0.62149**	**-0.56493**	-0.13889	0.076116	0.100233	0.188552	0.197114	0.191699	0.246153	0.288172
Large Fatras (JAK)	**-0.40496**	**-0.43446**	-0.30407	-0.07255	-0.04082	0.101147	0.086457	0.047781	0.070907	0.136645

In both stands, a large number of interdependences was seen in the past before 1900 but no positive correlation was seen. There was a negative moderate correlation in Large Fatras between 1870 to 1930. Although it's a negative correlation strong correlation was seen in the High Tatras between 1870 to 1910 and a moderate correlation was seen between 1880 to 1920. However, there was no correlation in both areas after 1930.

5.8 Comparing lying dead wood with different decay classes

The relationship between the lying dead wood and different decay classes was calculated in both the High Tatras and Large Fatras. We decided for the decadal approach due to high temporal resolution, further because we didn't find any significant difference in other approaches (see table 9.6-9.10 in the appendix). Here also, we focused on the values after 1850 because all the précised information was available after that period. The correlation between lying dead wood and different decay classes is presented in table 5.8.

Table 5 8 Correlation between lying dead wood and different decay classes

where, White - no correlation (-0.3- 0.3), Light Blue - negative moderate correlation (-0.6- -0.3), Green - negative strong correlation (-0.6- -1), Grey -positive moderate correlation (0.6-0.3), Light orange -positive strong correlation (0.6-1), (the numbers in bold represent statistically significant correlation at the level α=0.05)

Decay Class	Name of stand	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
Decay class 1	High Tetras (KOP)	-0.10931	-0.40368	-0.29351	-0.39793	-0.1357	0.089446	0.301954	**0.714543**	0.278542	-0.04042
	Large Fatras (JAK)	0.024081	-0.25109	-0.33322	-0.20785	-0.13128	-0.23624	-0.1814	-0.1537	-0.21444	-0.20807
Decay class 2	High Tetras (KOP)	-0.25474	-0.20307	0.054303	-0.2621	-0.2675	-0.12282	-0.09483	0.011251	**0.617225**	0.463564
	Large Fatras (JAK)	0.000271	**0.49065**	0.330444	-0.14712	-0.25159	-0.1362	-0.25627	-0.27691	-0.32183	-0.05751
Decay class 3	High Tetras (KOP)	-0.21818	-0.12384	0.187918	-0.03405	0.177224	0.216	0.060412	0.201073	**0.711187**	0.32537
	Large Fatras (JAK)	-0.28435	-0.04133	-0.01589	-0.12174	**-0.37944**	-0.02139	-0.11154	-0.13021	-0.20331	0.071433
Decay class 4	High Tetras (KOP)	-0.18377	0.269531	0.380853	-0.00417	0.374334	0.35673	0.051494	-0.4261	-0.30451	0.226532
	Large Fatras (JAK)	-0.28586	-0.12011	-0.02439	0.089604	-0.07454	0.039524	0.147585	-0.01005	0.131558	0.00327
Decay class 5	High Tetras (KOP)	0.284436	**0.692402**	**0.592204**	0.470523	0.41869	0.072143	0.213319	0.061375	-0.13246	-0.13819
	Large Fatras (JAK)	-0.13231	0.073813	0.121282	0.248084	**0.554781**	**0.733957**	**0.428151**	**0.497913**	**0.509304**	0.275349

5.8.1 Decay class 1

In both stands, large Fatras and the High Tatras we obtained some interdependence between the lying dead wood and decay classes. However, we found a strong correlation in 1980 in the High Tatras but in the same period, we got a negative value without correlation in Large Fatras. Just before 10 years in 1970, Positive moderate correlation was seen in the High Tatras whereas, in Large Fatras, there were not any interconnection between dead wood volume and decay classes. In 1950 and 1960 we got a minimum value without any relationship in both the stand. In 1940 we found a negative moderate correlation in the High Tatras where no correlation was seen in Large Fatras. Moreover, in 1930 we didn't see any strong correlation in both stands but we found a negative moderate correlation in Large Fatras. Also, in 1920 no solid correlation was seen, we just found a negative moderate correlation in High Tetras, but no correlation was seen in Large Fatras. Furthermore, no interdependence between the deadwood volume and decay classes prevailed in both stands.

5.8.2 Decay class 2

After comparing all the correlation value from decay class 2, the high degree of correlation was seen in 1990, where we found a strong positive correlation in the High Tatras and negative moderate correlation was seen in Large Fatras and in 2000 we got a positive moderate correlation in the High Tatras but in the same year we didn't get any correlation coefficient in Large Fatras. In addition, from 1940 to 1980 and also in 1910 we didn't see any correlation between decay classes and Coarse woody debris volume. In 1920 and 1930 we got a positive moderate correlation in Large Fatras, but no correlation is obtained in the High Tatras.

5.8.3 Decay class 3

While talking about the decaying class 3, it is clear that the largest or strongest correlation was achieved in 1990 and a positive moderate correlation was found in 1930 in the High Tatras, which means in the present situation. Nevertheless, from 1910 to 1980 we lacked interrelation between lying dead wood and decay classes in the High Tatras. On the other hand, in Large Fatras, we accomplished a negative moderate correlation in 1950. After all, we didn't see any correlation in the rest of other years before 1940 to 1910 and 1960 to 2000.

5.8.4 Decay class 4

It is evident from the table number 5.8 that, we didn’t get any strong correlations in this decay classes in both areas and in Large Fatras, from 1910 to 2000. We didn’t find any correlation between coarse woody debris volume and decay classes while comparing the historical disturbances with the present situation. Although in the High Tatras, we achieved negative moderate correlation in 1980 and 1990 whereas, we found a positive moderate correlation in 1930,1950 and 1960. Following other periods, we didn’t achieve any correlation in 1910,1920,1940 and 1970 in 10 years decadal period.

5.8.5 Decay class 5

Overall, we got an interesting result in this decay classes. No correlation was formulated in High Tetras from 1960 to 2000 which illustrated that no interrelation between dead wood and decay classes in this timeframe. Whereas, we got a powerful correlation in Large Fatras in the same period of time. Data was highly significant in 1960 following a positive moderate correlation in 1970, 1980 and 1990 in Large Fatras. On the other hand, in high Tatras, we found a strong correlation in the past decades in 1920, following a positive moderate correlation in 1930, 1940 and 1950 but no correlation was found in 1910. However, we got a positive moderate correlation in Large Fatras in 1950 and the rest from 1910 to 1940 and 2000 data were not interrelated in spite of having some good values.

6 Summary of finding and Discussions

The purpose of this research is to estimate the effect of disturbance on both qualitative and quantitative characters of dead wood in Norway spruce forest in Slovakia from the two different stands in the mountain ranges of the High Tatras and Large Fatras. It is important to know the disturbance types and the history of disturbance for the further close to nature management (Nagel and Svoboda 2008) of the forest and there is a close relationship between forest disturbance and the amount and quality of coarse woody debris.

6.1 Stand characteristics and disturbance regimes of the study plots

Basic stand parameters such as mean DBH of living trees, mean DBH of dead trees, basal area of living trees, basal area of dead trees, the mean age of living trees and lying dead wood volume from both the High Tatras and large Fatras stands were compared. Mean DBH of living and dead trees, mean basal area of living trees was different as productivity of the forest is directly related to the gradients of elevation (Moser et. al., 2007), while the mean stand age was not statistically different. In average, the mean DBH of living and dead trees are a little bit higher in Large Fatras as compared to the higher elevated site in the High Tatras. Elevation has a direct influence on forest productivity because temperature decrease with the increasing elevation as decreasing temperature limits the tree growth (Körner & Paulsen 2004). But the mean age of the living trees and mean basal area of the dead trees were not different.

The percentage of canopy area removal (disturbance history) in both of our study site shows that the disturbance regimes is comprehensive and changes with time and decades indicating the variation between the severity and frequency of the disturbance regimes. A diverse and uncertain disturbance history was found in both the High Tatras and Large Fatras as the forest was dominated by low severity and moderate-severity disturbance. Particularly a peak of canopy disturbance was seen in the middle of the 19th and 20th century in the High Tatras especially in 1870’s and 1960’s whereas, disturbance level was at the top in Large Fatras in decades 1870’s and 1880’s. Mixed-severity disturbances result in very heterogeneous DBH and age pattern, showing high temporal variability in establishment and structure close to those present in old-growth forests (D'Amato et al. 2008). Similar results were found by Trotsiuk et. al., (2014) suggesting that forests do not come from one stand-replacing event, nor by the dynamics of stable individual tree mortality, but rather influenced by numerous events of varying severities, scale and timing that resulted in a complex pattern of disturbance regimes.

6.2 Quantitative characteristics of CWD

There is not a difference between two stands from the perspective of quantitative characters of the total volume of lying dead wood. On average, my findings of lying dead wood volumes are comparable or even exceed volumes reported from unmanaged forests of different tree species composition across Europe (table 5.1 and 5.3). Saniga and Schutz (2001) found that the total volume of dead wood in Oravske´ Beskydy Mts., in Slovakia varies from 188-240 m^3 ha^1.

In addition, the volume of dead wood varies greatly when the decay rates and changes in the disturbance regimes are faster (Aakala 2011), depending for example on the type of forest (Hahn and Christensen 2005), on-site conditions (Sippola et al. 1998), exceptional events such as storms or periods of dry weather (Kirby et al. 1998), development phases (Saniga and Schutz. 2001) or decomposition conditions (Korpel' 1995). Possible wood extraction in the past, human interference in the forest resources and the different decomposition rates of the deadwood could be responsible for the changes in the amount of dead-wood.

In this research, there is a negative correlation between the forest disturbance history and the amount of lying dead wood volume at the end of the 19th century and the beginning of the 20th century, in both of our study site (High Tatras and Large Fatras), it is in agreement with the presence of severe disturbances in central Europe in that time (Janda et. al 2017). The negative correlation between the current volume of lying dead wood and the disturbance history means that, if there was a high disturbance in the past then there will be young or mid-aged stands at the present time. This stand would be less susceptible to disturbances with a low amount of CWD. In opposite, the positive correlation shows that, if there was a low disturbance in the past there will be old stands in the current time and the stands are more susceptible to a disturbance with higher amount of CWD.

In the second half of 20th century, it is hard to predict the influence of disturbances on the volume of dead wood in the current forest structure (table 5.7) because of the presence of low severity disturbances with low impact on the forest structure. It shows that there is a considerable variation in the amount of lying deadwood without connection to detected disturbances in the part of forest development. The disturbance may be small-scale gap disturbance for example, due to self-thinning, disturbance by wind and snow, fungal infection, insect attacks (Kuuluvainen 1994).

In general, we found that the historical disturbance has some impact on the composition of the current forest structure.

6.3 Qualitative characteristics of CWD

In general, the combination of site productivity and degradation rates determines the long-term average deadwood supply, while regional or local disturbance patterns cause the temporary inflow of deadwood to stands (Siitonen 2000). In Both of our study sites (High Tatras and Large Fatras) (table number 5.1 and 5.3) the mean diameter of living trees and dead trees and other characters were fairly distributed, and greater diameter was presented in Large Fatras.

Comparing the CWD volume of different decay classes in between the High Tatras and large Fatras (our study area), no significant difference was found. Decay class 3, 4 and 5 shares a higher amount of lying dead wood than in other decay classes in both of our study areas. The lower amount of CWD in decay class 1 can be explained by the definition of this class. Only freshly uprooted trees fulfil the definition and it takes only a few years to switch to the next decay class. Further, the next reason is due to the long-term presence of standing dead trees. The snags of *Picea abies* can remain for up to 20 years before falling (Storaunet & Rolstad 2002) when the falling snags could fulfil advanced characteristics of decay classes (decay class 2, 3 or 4).

In old-growth forests of *Picea abies* in Finnish Lapland, Decomposition Classes 3 and 4 are mostly present in ground-level deadwood volumes (Sippola et al. 1998) and we got similar results. However, the dead wood volume in all decay classes in this research shown the continuity of dead wood which plays a vital role in the biodiversity and ecosystem functioning (Harmon et.al., 1986). In the unmanaged forest, CWD volume is more in advanced decay stages (4, 5).

In both of our study sites, we tried to connect the periods of disturbances with the recent volume of CWD. We found a rather clear connection in the High Tatras locality while in the Large Fatras only clear trend on decay class 5 was detected. In the High Tatras first three decay classes were connected to recent disturbances, while for the decay class 4 and 5 older disturbances were important. Our findings are in accordance with the results of Zielonka (2006) when he found a positive relationship between the age of logs and decay stage. We found a correlation between the volume of recent CWD with the decay class 5 up to 1920's in the High Tatras while in Large Fatras the correlation was detectable only up to 1950's. This difference could be explained by a higher decomposition rate of deadwood in lower elevated Large Fatras locality.

7 Conclusions and management implications

This diploma thesis examines the role of disturbance history (percentage of canopy area removal) on the total volume of CWD and volume of lying dead wood (amount of dead wood) in different decay classes and the stand characteristics from the 2 different forest stands dominated by Norway spruce**.** Deadwood of large quantities with varying quality characteristics provides habitat for a wide range of forest species, many of which are endangered and is recognized as a good indicator of the forest's naturalness and for forest regeneration. Following are the key conclusion and management implications.

1. Overall, my findings of lying dead wood volumes are comparable to dead wood volume reported from unmanaged forests of the same tree species composition across Europe showing the continuity of dead wood.
2. The disturbance history from both of our study area concludes that disturbance regimes are comprehensive and changes with time and decades indicating the variation between the severity and frequency of the disturbance regimes. Current forest stands in our study areas are influenced by the historical disturbance in the past with mixed severity disturbances.
3. Deadwood volume was higher in advanced decay stages that are important for the conservation of biodiversity and close to nature forest management approaches.
4. There is a positive relationship between the age of log and decay stages. In this study, we found a correlation between the volume of recent CWD with the decay class 5 up to 1920's in the High Tatras while in Large Fatras the correlation was detectable only up to 1950's. This might be because of higher decomposition rates of deadwood in lower elevated Large Fatras locality.
5. A small area of mountain forest from central Slovakia was studied. To formulate a strong benchmark about the required amount of deadwood and also to study the dead wood quality and quantity, larger areas should be studied on both stand and landscape level. Similar patterns of dead wood quality and quantity was found on both study sites showing on some general studied patterns.
6. The observed values about the dead wood quality and quantity provide a baseline for unmanaged forest and show how this value can be related in managed condition. Continuity of dead wood in this research indicates there is a continuity of dead wood depending organisms and continuity of biodiversity.

7. To promote the wood decaying organisms in the managed forest we should increase the insufficient amount of CWD in a managed forest. In our studied forest we found in average 170 m^3/ha of CWD while in the managed forest there is usually up to 5 m^3/ha CWD.

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9 Appendixes

Table 9 1 Correlation between disturbance history and lying dead wood

30 yrs	1860-1880	1870-1890	1880-1900	1890-1910	1900-1920	1910-1930	1920-1940	1930-1950	1940-1960	1950-1970
High Tetras (KOP)	**-0.51939**	-0.037	0.137313	0.112691	0.164107	0.127526	0.167824	0.217427	0.258306	0.33066
Large Fatras (JAK)	**-0.41555**	-0.18411	-0.03342	0.09105	0.03431	0.036815	0.091733	0.143235	0.057637	0.080845

Table 9 2 Correlation between disturbance history and lying dead wood

40 yrs	1880-1910	1890-1920	1900-1930	1910-1940	1920-1950	1930-1960	1940-1970	1950-1980	1960-1990	1970-2000
High Tetras (KOP)	**-0.6395**	-0.3645	0.151193	0.060531	0.140925	0.194995	0.14232	0.211263	0.257294	0.303689
Large Fatras (JAK)	**-0.43323**	-0.37035	-0.08952	-0.02473	0.062295	0.081477	0.050019	0.078815	0.120391	0.084434

Table 9 3 Correlation between disturbance history and lying dead wood

20yrs	1900-1910	1910-1920	1920-1930	1930-1940	1940-1950	1950-1960	1960-1970	1970-1980	1980-1990	1990-2000
High Tetras (KOP)	-0.07433	-0.08884	0.215764	0.147687	0.031353	0.15937	0.174366	0.201175	0.269962	**0.69294**
Large Fatras (JAK)	-0.32249	-0.12663	0.104343	0.070618	-0.02926	0.082433	0.181547	0.064872	0.031898	0.098314

Table 9 4 Correlation between disturbance history and lying dead wood

Years (50)	1870-1910	1880-1920	1890-1930	1900-1940	1910-1950	1920-1960	1930-1970	1940-1980	1950-1990	1960-2000
High Tetras (KOP)	**-0.62149**	**-0.56493**	-0.13889	0.076116	0.100233	0.188552	0.197114	0.191699	0.246153	0.288172
Large Fatras (JAK)	**-0.40496**	**-0.43446**	-0.30407	-0.07255	-0.04082	0.101147	0.086457	0.047781	0.070907	0.136645

Table 9 5 Correlation between disturbance history and lying dead wood

100 yrs	1820-1910	1830-1920	1840-1930	1850-1940	1860-1950	1870-1960	1880-1970	1890-1980	1900-1990	1910-2000
High Tetras (KOP)	**-0.49365**	**-0.52165**	**-0.52324**	**-0.52944**	**-0.5392**	-0.3766	-0.07907	0.129292	0.269506	0.282791
Large Fatras (JAK)	-0.21867	-0.21911	-0.21944	-0.2195	-0.21911	-0.21863	-0.21897	-0.22043	-0.22115	-0.22134

Table 9 6 Correlation between lying dead wood and different decay classes (10-year period)

Decay Class	Name of stand	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
Decay class 1	High Tetras (KOP)	-0.10931	-0.40368	-0.29351	-0.39793	-0.1357	0.089446	0.301954	**0.714543**	0.278542	-0.04042
	Large Fatras (JAK)	0.024081	-0.25109	-0.33322	-0.20785	-0.13128	-0.23624	-0.1814	-0.1537	-0.21444	-0.20807
Decay class 2	High Tetras (KOP)	-0.25474	-0.20307	0.054303	-0.2621	-0.2675	-0.12282	-0.09483	0.011251	**0.617225**	0.463564
	Large Fatras (JAK)	0.000271	**0.49065**	0.330444	-0.14712	-0.25159	-0.1362	-0.25627	-0.27691	-0.32183	-0.05751
Decay class 3	High Tetras (KOP)	-0.21818	-0.12384	0.187918	-0.03405	0.177224	0.216	0.060412	0.201073	**0.711187**	0.32537
	Large Fatras (JAK)	-0.28435	-0.04133	-0.01589	-0.12174	**-0.37944**	-0.02139	-0.11154	-0.13021	-0.20331	0.071433
Decay class 4	High Tetras (KOP)	-0.18377	0.269531	0.380853	-0.00417	0.374334	0.35673	0.051494	-0.4261	-0.30451	0.226532
	Large Fatras (JAK)	-0.28586	-0.12011	-0.02439	0.089604	-0.07454	0.039524	0.147585	-0.01005	0.131558	0.00327
Decay class 5	High Tetras (KOP)	0.284436	**0.692402**	**0.592204**	0.470523	0.41869	0.072143	0.213319	0.061375	-0.13246	-0.13819
	Large Fatras (JAK)	-0.13231	0.073813	0.121282	0.248084	**0.554781**	**0.733957**	**0.428151**	**0.497913**	**0.509304**	0.275349

Table 9 7 Correlation between lying dead wood and different decay classes (20-year period)

Decay Class	Name of stand	1900-1910	1910-1920	1920-1930	1930-1940	1940-1950	1950-1960	1960-1970	1970-1980	1980-1990	1990-2000
Decay class 1	High Tetras (KOP)	-0.34184	-0.39548	-0.38906	-0.39153	-0.29662	0.016502	0.180491	**0.633717**	**0.695076**	0.153045
	Large Fatras (JAK)	-0.12342	-0.18036	-0.34141	-0.36863	-0.2044	-0.22281	-0.237	-0.18143	-0.21182	-0.27
Decay class 2	High Tetras (KOP)	0.0375	-0.28884	-0.07653	-0.10474	-0.32839	-0.17502	-0.12393	-0.03622	0.095003	**0.692386**
	Large Fatras (JAK)	-0.07382	0.376356	**0.480929**	0.108012	-0.18568	-0.23053	-0.23765	-0.28156	-0.34372	-0.25292
Decay class 3	High Tetras (KOP)	-0.05797	-0.20442	0.044693	0.098245	0.115633	0.209367	0.17674	0.166934	0.282392	**0.664463**
	Large Fatras (JAK)	-0.27097	-0.17541	-0.03358	-0.09911	-0.19789	-0.23343	-0.08479	-0.12664	-0.19217	-0.09535
Decay class 4	High Tetras (KOP)	-0.00906	0.14851	0.368887	0.233336	0.277494	0.373185	0.273185	-0.27047	-0.43347	-0.05086
	Large Fatras (JAK)	-0.23496	-0.23658	-0.08492	0.049441	0.054237	-0.01871	0.117717	0.090552	0.071695	0.09129
Decay class 5	High Tetras (KOP)	0.073851	**0.721965**	**0.719724**	**0.614565**	**0.543573**	0.190618	0.133866	0.141369	0.038253	-0.17331
	Large Fatras (JAK)	-0.0239	-0.01028	0.113909	0.259891	0.34682	**0.777497**	**0.646135**	**0.485298**	**0.577279**	**0.510454**

Table 9 8 Correlation between lying dead wood and different decay classes (30-year period)

Decay Class	Name of stand	**1890-1910**	**1900-1920**	**1910-1930**	**1920-1940**	**1930-1950**	**1940-1960**	**1950-1970**	**1960-1980**	**1970-1990**	**1980-2000**
Decay class 1	High Tetras (KOP)	-0.27293	**-0.52684**	-0.38675	-0.43615	-0.33133	-0.0691	0.103432	0.447178	**0.639087**	**0.692196**
	Large Fatras (JAK)	0.111211	-0.24294	-0.29116	**-0.40129**	-0.33885	-0.23947	-0.22541	-0.2257	-0.2049	-0.25873
Decay class 2	High Tetras (KOP)	-0.44721	-0.11815	-0.13635	-0.15429	-0.21155	-0.22569	-0.16673	-0.0886	0.026432	0.158847
	Large Fatras (JAK)	-0.09466	0.248829	**0.421793**	0.324515	0.042681	-0.19829	-0.26784	-0.2662	-0.31438	-0.30247
Decay class 3	High Tetras (KOP)	-0.4277	-0.12874	-0.01521	0.020378	0.159254	0.195647	0.183573	0.220856	0.231775	0.328027
	Large Fatras (JAK)	-0.33243	-0.21974	-0.12626	-0.0949	-0.15826	-0.18095	-0.19653	-0.10518	-0.16067	-0.12571
Decay class 4	High Tetras (KOP)	-0.38597	0.185368	0.292407	0.271382	0.353471	0.360817	0.310389	0.020636	-0.29122	-0.40411
	Large Fatras (JAK)	-0.2889	-0.24237	-0.1718	-0.02248	0.027465	0.057858	0.063259	0.084051	0.110341	0.059435
Decay class 5	High Tetras (KOP)	0.378448	**0.544292**	**0.736688**	**0.70785**	**0.629421**	0.285373	0.214525	0.127706	0.123216	0.019475
	Large Fatras (JAK)	-0.122	0.028255	0.054828	0.231708	0.329096	**0.488079**	**0.68317**	**0.64096**	**0.526929**	**0.582895**

Table 9 9 Correlation between lying dead wood and different decay classes (40-year period)

Decay Class	Name of stand	**1880-1910**	**1890-1920**	**1900-1930**	**1910-1940**	**1920-1950**	**1930-1960**	**1940-1970**	**1950-1980**	**1960-1990**	**1970-2000**
Decay class 1	High Tetras (KOP)	-0.1114	-0.38921	**-0.48739**	-0.4387	-0.39416	-0.12979	0.033215	0.348503	0.46155	**0.639912**
	Large Fatras (JAK)	0.29998	0.008956	-0.32558	-0.33629	**-0.38636**	-0.3605	-0.23208	-0.21678	-0.23495	-0.23402
Decay class 2	High Tetras (KOP)	-0.3871	-0.41934	-0.0486	-0.19807	-0.23505	-0.19296	-0.20729	-0.13357	-0.04812	0.07283
	Large Fatras (JAK)	-0.16694	0.10066	0.328658	0.277473	0.256232	0.013229	-0.21946	-0.28213	-0.29561	-0.29214
Decay class 3	High Tetras (KOP)	**-0.51468**	-0.36751	0.012103	-0.02381	0.092852	0.220858	0.173333	0.225657	0.264909	0.26596
	Large Fatras (JAK)	-0.31053	-0.33642	-0.16784	-0.16061	-0.14611	-0.15113	-0.1688	-0.18802	-0.13725	-0.12352
Decay class 4	High Tetras (KOP)	**-0.53164**	-0.14997	0.311754	0.223008	0.371531	0.415132	0.302163	0.099504	0.000854	-0.27086
	Large Fatras (JAK)	-0.35617	-0.32529	-0.18817	-0.09913	-0.0322	0.033171	0.082765	0.046994	0.101379	0.098209
Decay class 5	High Tetras (KOP)	0.022993	**0.602896**	**0.649555**	**0.73323**	**0.726145**	0.394676	0.289396	0.199792	0.118153	0.110381
	Large Fatras (JAK)	-0.1078	-0.08867	0.074474	0.161076	0.298345	**0.447955**	**0.488053**	**0.665369**	**0.640443**	**0.535402**

Table 9 10 Correlation between lying dead wood and different decay classes (50-year period)

Decay Class	Name of stand	**1870-1910**	**1880-1920**	**1890-1930**	**1900-1940**	**1910-1950**	**1920-1960**	**1930-1970**	**1940-1980**	**1950-1990**	**1960-2000**
Decay class 1	High Tetras (KOP)	0.018923	-0.23966	-0.41404	**-0.51784**	-0.40057	-0.20159	-0.0236	0.289051	0.362941	0.463723
	Large Fatras (JAK)	**0.406231**	0.249748	-0.10973	-0.35906	-0.32893	**-0.40924**	-0.34115	-0.22632	-0.22505	-0.25639
Decay class 2	High Tetras (KOP)	-0.31742	-0.41683	-0.29765	-0.127	-0.26828	-0.22214	-0.1832	-0.17007	-0.09943	-0.01861
	Large Fatras (JAK)	-0.2042	-0.04845	0.209422	0.214065	0.222348	0.224121	-0.04517	-0.23353	-0.30245	-0.27901
Decay class 3	High Tetras (KOP)	**-0.47776**	**-0.50354**	-0.20464	-0.00203	0.056513	0.184668	0.196579	0.219134	0.264096	0.288722
	Large Fatras (JAK)	-0.21589	-0.33625	-0.31461	-0.19116	-0.20027	-0.14379	-0.1508	-0.16734	-0.19906	-0.10861
Decay class 4	High Tetras (KOP)	**-0.60039**	-0.38232	0.038341	0.243571	0.333074	0.445223	0.352591	0.098178	0.08258	0.015528
	Large Fatras (JAK)	-0.24881	-0.40443	-0.30739	-0.12033	-0.10185	-0.02455	0.060111	0.071089	0.067822	0.092174
Decay class 5	High Tetras (KOP)	-0.14654	0.260647	**0.696458**	**0.669878**	**0.750845**	**0.508479**	0.379987	0.265606	0.192059	0.110432
	Large Fatras (JAK)	-0.29336	-0.09398	-0.03851	0.165502	0.224599	**0.40507**	**0.468392**	**0.501847**	**0.65743**	**0.636632**