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Forest Structure and Land Use Change in the Bieszczady Mountains

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1. Introduction

It is now widely recognized by ecologists and conservationists that ecosystems are influenced by changes in historic land use activities (Foster et al., 2003; Munteanu, 2014). Land use legacies are ecological features that persist on a landscape due to a past land use (Munteanu, 2014). In the case of forests, land use legacies can manifest in forest structure, species composition, soil characteristics and many other features that have a direct impact on ecosystem functioning and biodiversity (Foster et al., 2003). Studying historic land use and its impact on present forest ecosystems can help us derive conclusions about the recovery potential of disturbed forests, ecological processes of secondary succession and forest management techniques.

The Polish Carpathians are an ideal place to study the effect of land use legacies on forest structure and composition. Frequent changes in political leadership, land ownership structure and economic ups and downs have led to periods with strong anthropogenic pressure alternating with periods of secondary succession of forests (Augustyn, 2004). Land use history and land use legacies in the Polish Carpathians and in the entire Carpathian ecoregion have been intensively studied by Augustyn (2004), Kümmerle et al. (2006, 2009), Hostert et al. (2008), Munteanu (2014), Griffiths et al. (2014) and others.

This paper results from a 2014 study project about forest structure and land use change in the Polish Carpathians at the Geography Department of Humboldt University Berlin. The general aim of the project was to determine whether forests that have never been converted to other uses differ from forests on land that has been used for agriculture at some point during the 19th or 20th century. Literature review gave insights into the land use history of Bieszczady Mountains. Historic forest cover maps were used to classify forests into 3 different age groups. Thereafter the project participants recorded a diverse range of forest parameters including tree size variables, tree density and species occurrence in the field. This paper makes use of a subset of the collected data in order to investigate: 1) basic forest structure, 2) species diversity and 3) species composition and compare these parameters to three different forest age classes.

The general objective of this study is to find out whether differently aged forest patches in the Bieszczady Mountains show characteristic patterns of forest structure and composition.

2. Materials and Methods

2.1. Study area

The study area is located in the north-western part of the Carpathian mountain arch, which forms a distinct bio-geographical region in Europe and ranges from south-eastern Czech Republic in the west to central Romania in the south-east. The Carpathian eco-region is a global biodiversity hotspot with some of the oldest and largest contiguous patches of natural temperate forests in Europe (Oszlányi et al., 2004; WWF, 2014).

Bieszczady Mountains are a mountain range within the border triangle of Poland, Slovakia and Ukraine encompassing an approximate area of 2000km². Altitudes range from about 500m a.s.l. in the valleys up to 1346m a.s.l. on top of Tarnica in Poland. The dominating base rocks of Bieszczady are sandstone, shale and flysch which is typical for the whole Carpathian arch. The area has a temperate continental climate with annual precipitation rates ranging from 900mm to 1300mm and average air temperature of 5.2°C (Augustyn, 2004; Durak, 2010; Eggermann et al., 2008). Roughly, 60% of Bieszczady Mountains are covered by forest, dominated by beech (*Fagus sylvatica*) and fir (*Abies alba*) (Augustyn, 2004; Eggermann, 2008). The Bieszczady Mountains lie within the transboundary Biosphere Reserve "East Carpathians". Each of the adjoining countries has protected a part of the landscape with a National Park (Bieszczady National Park in Poland). The field research for this paper was carried out outside the National Park in the district of Bieszczady close to the town of Lutowiska (Figure 1).

Fig. 1: Study area. Located in Bieszczady District (dark) in the Bieszczady Mountains (box).

Augustyn (2004) described the long history of land use change in the Bieszczady Mountains. The Carpathians experienced an era of population increase, industrialization, deforestation and intense human pressure on the environment from the middle ages until the mid-20th century. This trend was reversed in the Bieszczady Mountains during and after World War II when the area was drastically depopulated and changes towards land abandonment, reforestation and re-naturalization through secondary succession occurred. After the fall of the iron curtain in 1989 population density decreased further and economic activity in this very remote area declined. The district of Bieszczady counted a population of 80.000 before World War II, presently it is at 2000. As a result of natural secondary succession but also deliberately managed reforestation, the forested area in the Bieszczady Mountains has almost doubled since the 1950s (Augustyn, 2004). Recent remote sensing analyses captured an overall forest cover increase across the Carpathian eco-region (Griffiths et al., 2014; Kümmerle et al., 2006) since the 1980s but a remarkable change in forest types and disturbance regimes (Griffiths et al., 2014). Depending on the former land use (plantations, agriculture, grazing, etc.) and the present management strategy, the structure and composition of forests can differ greatly. Plantations or other managed forests may not always provide the same ecological services as natural forests (Griffiths et al., 2014).

2.2. Forest classification

Three forest age classes were created using an overlap of three digitized historic forest cover maps (Habsburg Empire, 1860; Military Institute of Geography, 1930, 1970):

1) Permanent forest: forested in 1860, 1930, 1970 and today,

2) Young forest: forested in 1970 and today but not forested in either 1860 or 1930, and

3) New forest: not forested in 1970 but forested today.

2.3. Sampling Design

8 forest patches around Lutowiska were designated for the field analysis (Figure 2). With the help of Q-GIS, 50 sampling plots were generated on each patch, assuming that this would be an achievable workload for the limited time in the field. As most plots are not accessible by car, the distance between the plots had to be walkable. A regular (systematic) point sampling technique was chosen to select the plots, where all plots are located on a rectangular grid at the same distance to their neighbors. This method is commonly used in forest inventories and usually achieves a good coverage of the study area (RGS, 2014).

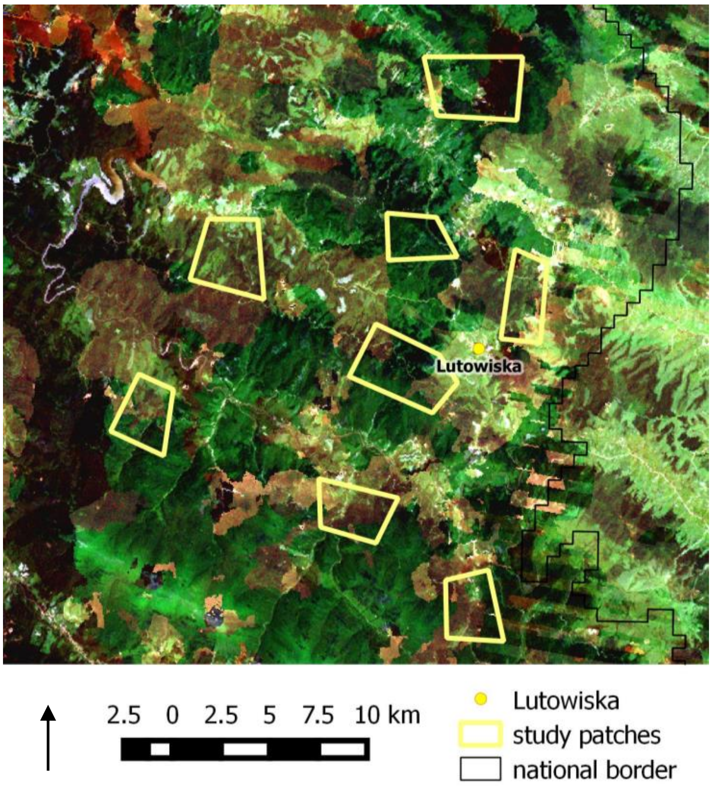


Fig. 2: Original 8 forest patches

2.4. Field Methods

For the field analysis of forest structure and composition Bitterlich's point sampling method was applied. This technique is widely used in forestry and allows a reliable prediction of total or species-specific basal area per unit area of forest without having to measure every single tree (Zimmermann, 2011). Bitterlich's point sampling method is based on a plot of indefinite area that is not laid out physically on the ground (Bay, 1960) but instead dependent on the diameter of the tree being measured. The user stands at the exact center of the plot (sampling point), examining every tree in the surrounding with a Bitterlich plate. Using the 4-factor opening in the Bitterlich plate (i.e. BAF = 4.0), each tree that completely fills the opening will represent 4m² of basal area per hectare. Hence, to obtain the total basal area per hectare the number of trees that are “in” is multiplied by 4. The Basal Area Factor (BAF) is chosen depending on the general stand structure. The smaller the BAF, the more trees are counted “in”, therefore a smaller BAF was applied for stands with low stem density or young trees in order to reach a representative sample of at least 5 trees per plot (Zimmermann, 2011). In this study a BAF of 2.0 or 4.0 was applied in all but 5 plots.

This study does not require a high degree of accuracy in the calculation of the total basal area, therefore no correction factor for slope was applied as suggested by Bitterlich (Zimmermann, 2011).

For each tree that was considered “in”, the following parameters were recorded using the below mentioned tools.

1. Species or genus with the help of Kosmos Baumführer Europa (Spohn & Spohn, 2011).
2. Diameter at breast height (DBH) using a diameter tape. DBH is measured in whole even centimeters at 1.3m off the ground.
3. Total height (m) and merchantable height (in 2.5m logs) using a Merritt hypsometer. Merchantable height refers to the length of the usable tree and is measured from 30cm stump height to the cutoff point in the top of the tree (Dennis-Perez, 2012). It is measured in logs of 2.5m and was converted to meters in the analysis.

2.5. Data Analysis

The data collected in the field was assembled and slightly edited. Dead trees, hazel trees (*Corylus avellana*) and stems with a DBH below 10cm were eliminated from the list to ensure homogeneity. Trees of known genus but partly unknown species were assembled into a general *Genus sp.* class to avoid overestimation of the number of species.

Forest structure

For each of the three forest age classes (permanent, young, old) the following forest structure parameters were calculated and averaged *on plot level*: total basal area (m^2/ha), total volume (m^3/ha), the proportion of softwood and hardwood in the total volume (%) and density (stems/ha). Likewise, the following basic forest structure parameters were calculated and averaged *on tree level*: DBH (cm), merchantable height (m) and tree volume (m^3). To compare the three forest age classes the results were transformed into bar charts and boxplots using Microsoft Office Excel and STATA.

Species Diversity

A wide array of indices are available to describe and compare species diversity. In this paper, species richness and Shannon diversity index were calculated. Species richness is the total number of species identified in the sample, e.g. the forest age class (Magurran, 2011). However, as the sample sizes (number of surveyed plots) are not equal in this study and the number of species invariably increases with sample size and sampling effort (Magurran, 1988), simple species richness is not a good indicator in this case. Rarefaction, which allows to upscale species richness for the entire community based on a rarefaction curve (Magurran, 2011), would go beyond the scope of this analysis. The Shannon Diversity Index (H) is one of the most commonly used expressions of species diversity (Magurran, 2011). It is a combination of species richness and species evenness:

$$H = \sum_{i=1}^{S} -(Pi*\ln(Pi))$$

where Pi is the fraction of the entire population made up of species i and S is the total number of species. The values for each variable were derived on subplot basis and later averaged across the plots of each forest age class.

Species Composition

In order to compare species composition and dominant forest types at differently aged sites, species were grouped into classes according to their successional and functional characteristics. The classification is based on information about successional status and functional traits from various sources (Adamowski, 2011; EEA, 2007; UK Forestry Commission, 2014; USDA Forest Service, 2014). The classification intends to give a rough picture of common tree communities and composition types but does *not* attempt to present a valid categorization of tree species communities according to their successional status.

Climax: plots with a proportion of more than 70% of stems per hectare of obligate climax species such as silver fir (*Abies alba*), European beech (*Fagus sylvatica*), Norway spruce (*Picea abies*).

Intermediate: plots with a proportion of more than 70% of stems per hectare of intermediate species such as sycamore (*Acer pseudoplatanus*), European ash (*Fraxinus excelsior*).

Pioneer: plots with a proportion of more than 70% of stems per hectare of pioneer species such as grey alder (*Alnus incana*), silver birch (*Betula pendula*), Scots pine (*Pinus sylvestris*), European larch (*Larix decidua*).

Fruit: plots with a minimum of one fruit tree (i.e. *Malus domestica, Prunus avium, Pyrus pyraster*) of traditional human use, disregarding the remaining species composition. Fruit trees in the midst of forests suggest former agricultural use on the land.

Undefined: plots that do not fit in any of the above categories.

3. Results

Unfortunately the number of forest patches and the number of plots per patch as determined during sampling design turned out to be too high. Data collection was carried out by 5 groups of students, each group working on only one of the 8 forest patches. Due to the limited time in the field and difficult accessibility in some areas, none of the groups managed to complete all 50 plots. Only between 19 and 29 plots per patch were surveyed (Figure 3).

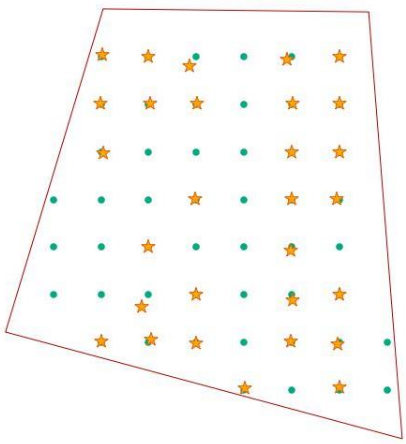


Fig. 3: Exemplary sampling design patch 4. Blue dots – regular sampling design plots, yellow stars - surveyed plots.

In total 107 plots were assessed. 10 of them turned out not to be forested, which leaves 97 plots being surveyed. Their distribution in the different age classes is shown in Table 1. All in all, 621 trees were examined and 18 tree species recorded.

	Permanent Forest	Young Forest	New Forest	Total
No. of surveyed plots	22	62	13	97
No. of recorded trees	148	402	71	621

Table 1: Distribution of surveyed plots and recorded trees in age classes

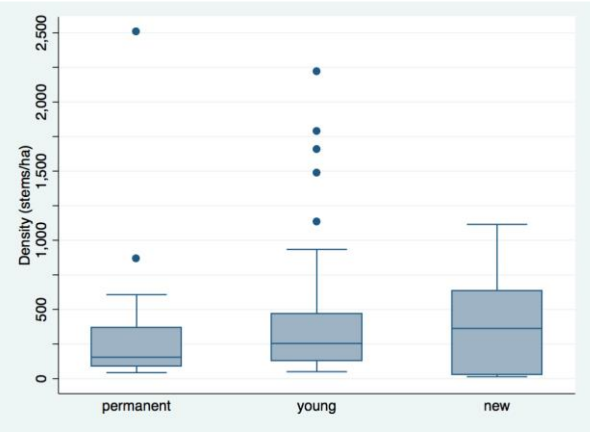
3.1. Forest structure

Table 2 shows the descriptive statistics of the measured, respectively derived values for all relevant forest structure variables. They are averaged for the respective forest age class. Figures 4 to 7 display the range of values and outliers. Interestingly, an upward/downward trend always parallels increasing/decreasing forest age. For all variables except density permanent forests display the highest and new forests the smallest values. Average stem density is highest in young forests. Considerable differences in values are apparent for DBH, height and tree volume. The largest trees are found in forests that have never been converted to agriculture (permanent), whereas new forests tend to host trees with a relatively low mean DBH, merchantable height and tree volume. However, permanent and new forests also display a large variations in DBH and merchantable height, indicating trees of different sizes. Variability is highest in permanent plots for all variables, indicating a higher diversity in tree and forest structure. For all three forest age classes the variations in the total basal area are quite high. As an interesting outlier, the tree with the highest recorded DBH of the entire survey (DBH=140cm) lies within a new forest plot.

Interestingly, the proportions of hardwood and softwood of the total volume differ greatly among the three forest age classes (Figure 10). While in permanent and young forests 79%, respectively 75% of the total volume is made up of softwood (coniferous species like fir, spruce or pine), they account for only 25% of the total volume in new forests.

	No. Plots	Density (stems/ha)	Total Volume (m^3/ha)	Total Basal Area (m^3/ha)	DBH (cm)	Merchantable Height (m)	Tree Volume (m^3)	Total Volume Hardwood (%)	Total Volume Softwood (%)
Permanent	22	322	239,66	27	53	21,0	2,61	20,91	79,09
Young	62	398	187,05	24	42	17,0	1,57	25,36	74,69
New	13	395	138,51	21	36	14,1	1,17	74,49	25,79

Table 2: Summary of mean forest structure parameters



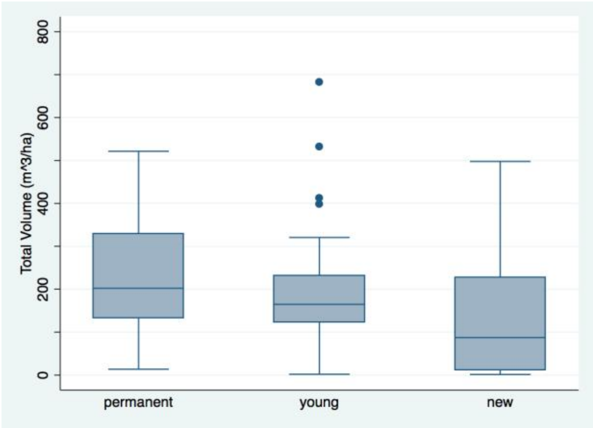
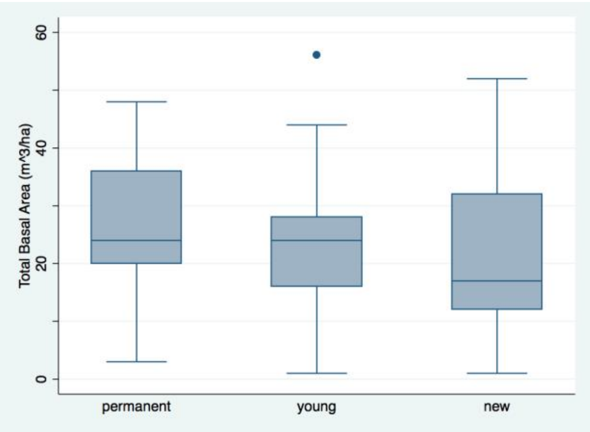


Fig. 4: Density (stems/ha) for different forest age classes

Fig. 5: Total volume (m³/ha) of all trees for different forest age classes



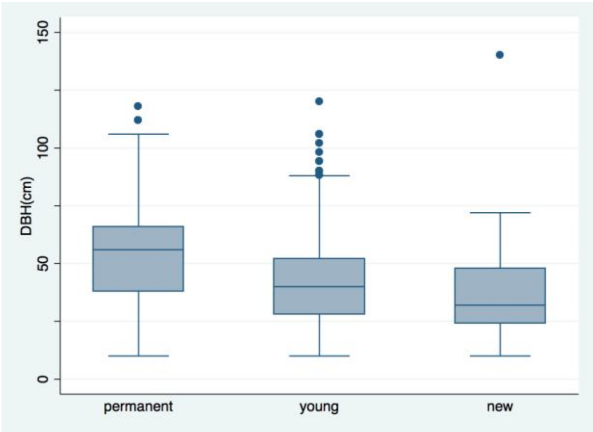
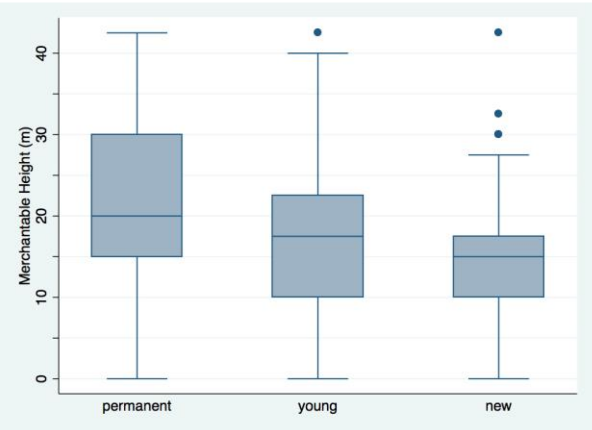


Fig. 6: Total basal area (m²/ha) of all trees for different forest age classes

Fig. 7: Mean DBH (cm) for different forest age classes



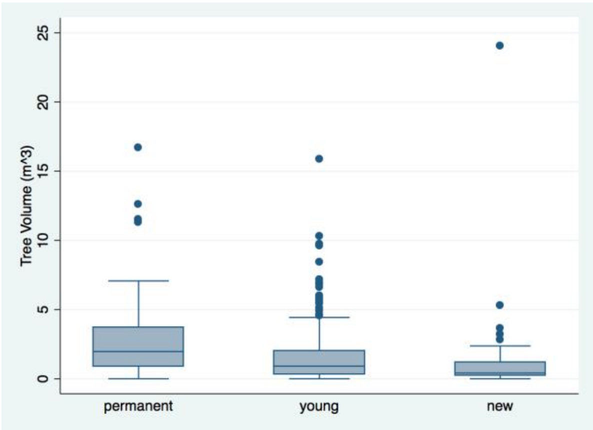


Fig. 8: Mean merchantable height (m) for different forest age classes

Fig. 9: Mean volume of single tree (m³) for different forest age classes

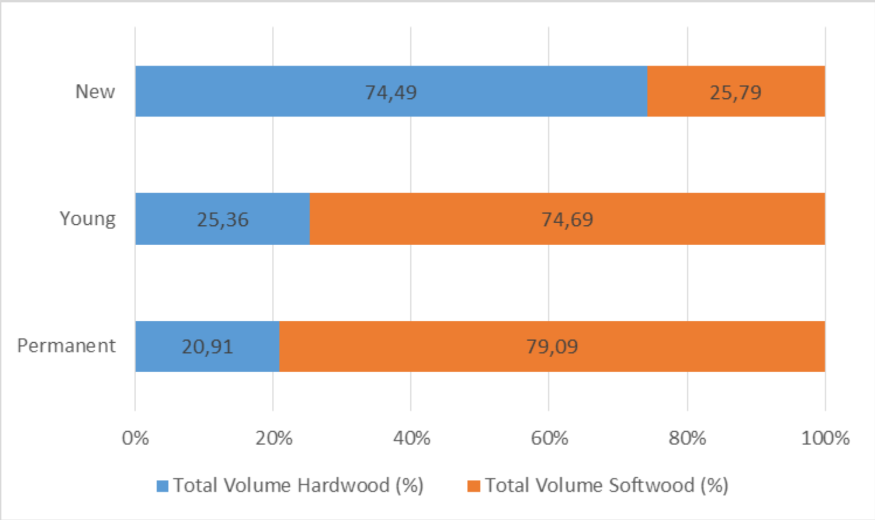


Fig. 10: Proportions of hardwood and softwood in total stem volume for different forest age classes

3.2. Species diversity

Table 3 shows the values for total and mean species richness as well as descriptive statistics for the Shannon Diversity Index (SDI) for all three forest age classes. Young forests yield the highest average values in both richness (18 tree species in total) and diversity (H = 0.4). The highest SDI of all plots is found on a new forest plot with H=1.7. Permanent forests are dominated by *Abies alba* and *Fagus sylvatica* and count only 5 tree species in total, which yields an average Shannon Index of 0.32. However, new forests have the highest proportion of plots with only one species (H=0; 38.46%).

	No. plots	Total Species Richness	Mean Species Richness	Mean Shannon Diversity Index (H)	Max. Shannon	No. plots with H=0	No. plots with H=0 (%)
Permanent	22	5	1,68	0,32	0,90	8	36,36
Young	62	18	2,18	0,52	1,70	20	32,26
New	13	10	1,92	0,40	1,12	5	38,46

Table 3: Summary of diversity statistics for different forest age classes

3.3. Species composition

Species composition differs greatly between the permanent, young and new forests (Figure 11). Permanent and young forests are dominated by climax species, mainly *Abies alba* and *Fagus sylvatica* but also *Picea abies*. Only one plot (5%) in the permanent forest class contains mainly intermediate species such as *Acer pseudoplatanus* or *Fraxinus excelsior*. Young forest plots are more diverse; all species composition types can be found. Pioneer species, mainly *Alnus incana* and *Betula pendula*, dominate 46% of plots in new forests, closely followed by fruit plots (39%). Climax species prevail in only 2 plots (15%).

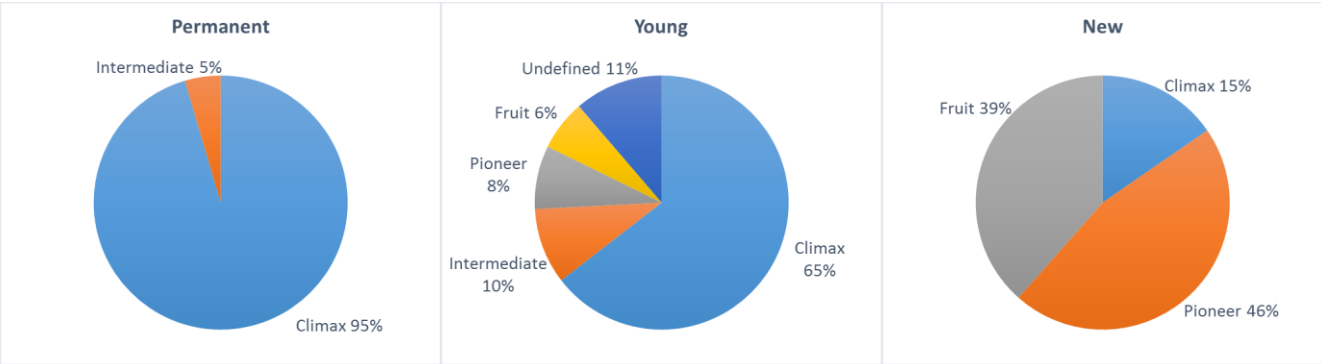


Fig. 11: Comparison of species composition types in different forest age groups

4. Discussion

The aim of this study is to assess the impact of land use history on forest structure and composition in the Bieszczady Mountains. A closer look at the results reveals that indeed older forests do show a different structure and composition than younger forests.

Forests that have existed since at least 1860 (permanent) tend to display a distinct structure with a relatively low total stem density but high total volume. Individual trees in permanent forest plots are of different sizes but on an average rather tall and wide in diameter. Assuming that trees grow in DBH and height with age, permanent forests hence have a diverse age structure, with old and young trees mixed. Permanent forest plots are strongly dominated by fir (*Abies alba*) and beech (*Fagus sylvatica*), but softwoods outnumber hardwoods by close to 80% in volume. They rank low in species richness and diversity. Mature Carpathian forest is naturally dominated by beech (EEA, 2007). However, the impact of management practices must not be underestimated. Even if management systems use shelterwood (old trees left standing to give shade and protection to seedlings) for natural or artificial regeneration, forestry practices have substantially decreased (or eliminated) admixing tree species in beech forests, resulting in low-diversity forest stands (EEA, 2007). The timber industry in Bieszczady has for a long time favored coniferous species like fir and

spruce, but is now moving on to a more near-natural species composition, a trend that is clearly visible in the permanent forest plots (Anfodillo et al., 2008).
Forests that have existed since at least 1930 (young forests) score highest in species richness and diversity. However, this perception could result from a fallacy derived from the high number of sampled young plots compared to the other age classes. Although more than half of the plots are dominated by climax species, all other species composition types can be found there too. One must not forget that the presence of old-growth fir and beech trees in a forest does not necessarily imply a natural forest in its climax state, it can just as well be a strictly managed forest plot for fir/beech timber production. This idea is also supported by the dominance of coniferous softwood species which are naturally only dominant in high altitudes of the Bieszczady range (EEA, 2007).

Forests on plots classified as young are covered by forest since at least 1970, thus for a maximum of 45 years. Accordingly the mean diameter and height of individual trees observed in these plots is substantially smaller than in permanent and young plots. They also show a very high stem density, characteristic for non-mature forests. The largest part of the new plots are dominated by pioneer species, which suggests that they are undergoing a relatively natural secondary succession. Shade-tolerant species like fir or beech usually thrive only after several decades (USDA Forest Service, 2014). Hence, young plots dominated by climax species are most probably managed for timber production. The high amount of plots containing fruit trees in new forests indicate that these plots were used for agriculture (farming or grazing) before. Meadows with dispersed fruit trees are a common sight in the Polish Carpathians up to today and are a clear answer that current forest structure can be directly influenced by past land use.

4.1. Limitations and Uncertainties

There are a number of limitations and uncertainties to this study that can lead to fallacies or misinterpretation. In retrospect, the regular grid sampling method - although simple and suitable for the group work of the study project - is not entirely appropriate for the research question. The workload was underestimated which led to only a part of the sampled points actually being surveyed. Thus the surveyed points do not follow a regular grid pattern anymore. Moreover, the number of sampled plots is different for each forest age class. This probably has a pronounced effect on the number of recorded species as increasing sample size and sampling effort usually leads to higher numbers of observed species (Magurran, 1988).

Angle count sampling after Bitterlich might not be the ideal method for biodiversity assessments as it analyzes only a small, circular fraction of the 1ha plots and may hence leave a number of species of low abundance undetected (Zimmermann 2011; Chao, 2009). Therefore, biodiversity analysis makes up only a small part of this paper.

In this paper differently are forests were compared regarding their species composition. However, species composition is not only dependent on forest age but also on a large number of factors like location (slope, altitude), ecosystem type or management practices which were not taken into account here.

Uncertainties in the forest structure results also occur due to the possibly biased data collection and interpretation of the different groups in the field. As an example, some groups have recorded the shrub *Corylus avellana* in their tree assessment because it is an important pioneer species, but other groups have not. Tree height measurements using visual methods like the Merrit hypsometer are highly subjective as well.

4.2. Outlook

The data collected during the study project offers a wide range of possibilities for further analysis. In a biodiversity context, more indicators and statistical measures to assess species diversity, evenness or similarity could be applied to compare the three forest age classes. Growth factors for different tree species could be used to analyze tree age structure. Species importance values or the relationships between particular tree species and their age could be calculated. In order to cross-validate the results, multivariate statistical analyses involving location variables like slope or altitude could be used. Other location parameters like soil type or closeness to water bodies could be recorded in the field to detect correlations with forest structure. Future field assessments that are biodiversity-focused should include the degree of layeredness, i.e. ground vegetation, shrubs and herbs in the survey and also assess juvenile trees, regenerated seedlings and saplings.

An interesting extension for this paper would be to observe forest management practices and human use to explore whether differently aged forests are managed and used differently.
The analysis of forest structure depending on forest age could be upscaled to other districts in the Polish Carpathians, including protected areas like Bieszczady National Park to get a wider picture of the effects of land use legacies.

5. Conclusion

The aim of this study is to assess the impact of land use history on forest structure and composition in the Bieszczady Mountains. Field work was carried out in 5 forest patches in Bieszczady District in south-eastern Poland. The following aspects were investigated: 1) basic forest structure, 2) species diversity and 3) species composition. Subsequently, differently aged forests were compared to detect patterns for the derived parameters. Going back to the research question, the results of the study affirm that forests on land that has never been converted do differ from forests on land that has been used for agriculture at some point during the 19th or 20th century. Permanent forests tend to display trees of bigger but very variable size, a low species diversity and climax species composition. Young forests are very variable in structure and composition but yield the highest values in species diversity. New forest tend to contain smaller trees but usually have a high stem density. They are diverse on a species and composition level, but pioneer species and fruit trees play an important role.

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