



## Stand structural complexity of mixed old-growth and adjacent selection forests in the Dinaric Mountains of Bosnia and Herzegovina



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### ABSTRACT

Research results on the structure of European OGF are often contradictory; while some researchers stress equilibrium structures, others suggest that this rarely happens due to biomass accumulation. If the former were the case, then there would be a fairly strong argument that OGF should serve as natural references for selection management. At the same time, mountain mixed selection forests are in many regions considered to be the most “natural” type of MF, and thus to a large extent similar to corresponding OGF. However, because there are few old-growth forests (OGF) left in Europe, comparisons between OGF and selection-managed forests (MF) are rare. Since nature-based silviculture should follow natural processes and not exclude any species from its natural range, in this study we compared two mixed OGF and neighboring MF (*Piceo-Abieti-Fagetum illyricum*) in the Dinaric Mountains of Bosnia and Herzegovina. The MF were managed by the single-tree selection system for almost a century. The results indicated that this management approach yielded a statistically significant difference in tree species composition and presence of large-diameter trees. The cumulative diameter distributions, however, were similar in OGF and MF as both exhibited the shapes that are considered to provide demographic equilibrium. On the species level, though, this was the case only for beech. Species occurrence matrices indicated significant dominance of young European beech (*Fagus sylvatica* L.) trees over silver fir (*Abies alba* Mill.) and Norway spruce (*Picea abies* L. Karst) in OGF. Nevertheless, based on the results from MF, the study highlights the crucial role of silvicultural measures that may potentially provide targeted long-term coexistence of the studied broadleaved and coniferous tree species.

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### 1. Introduction

After the disastrous consequences of clear-cut forest management in the mountains of Central Europe in the mid-19th century, many forest scientists shifted their research towards alternative silvicultural systems (Schütz, 1999). One of the first widely applied alternatives was the selection (plenter) system, which introduced demographic sustainability on a very small scale, namely at the stand level (Schütz, 2001). The range of alternative (nature-based) systems was later supplemented by the irregular shelterwood system (Matthews, 1999). Although the share of forests managed by alternative silvicultural systems have increased rather gradually over the last century, in recent years foresters and

ecologists have become increasingly supportive of the idea of nature-based silviculture (Pukkala and von Gadow, 2012; Puettmann et al., 2015). A good example in the sense of a “return to nature” seems to be Germany, which has put great effort into the conversion of monocultures to mixed stands (Spathelf et al., 2015). On the other hand, forest management in the countries of Southeastern Europe was not as intensive in the past as in Central Europe. For instance, older documents indicate that at the beginning of the 20th century more than 50% of forests in Bosnia-Herzegovina were pristine forests (Fröhlich, 1954). Although during the first half of that century old-growth forests (OGF) were gradually converted into managed, mostly selection forests (MF) over large areas of this country, a few untouched remnants have been preserved to the present day.

Currently, there are scientifically justified proposals across Europe to increase structural diversity and preserve tree species

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diversity on a landscape level (e.g. Pach and Podlaski, 2015; Schütz et al., 2016). Such goals were difficult to achieve in the past when rapid wood production and short-term profitability were the prime concerns. Now, climate change is globally acknowledged as one of the main determinants of the development of forest ecosystems (Kovats et al., 2014). In the face of the ongoing changes, even mixed OGF, which are generally believed to be compositionally stable, seem to be struggling to maintain this stability, with several studies indicating the progression of European beech (*Fagus sylvatica* L.) and decline of conifers in a number of European countries (e.g. Bolte et al., 2010; Diaci, 2011; Szwagrzyk et al., 2012; Keren et al., 2014).

On the other hand, apart from environmental factors, the development of managed stands depends largely on the silvicultural approach. Although the selection system has provided a sustained yield in MF so far, since the Rio summit in 1992, the sustained yield approach has been widely questioned due to concern over the sustainability of the entire ecological system, which consists of ecosystem structures, functions, goods and services (Kimmins et al., 2007). Consequently, forest managers are currently facing a variety of old and new demands, while nature-based silviculture is often put forward as a proposal for solving contradictory stakeholder interests. Owing to this fact, comparison of structural and ecological characteristics between OGF and adjacent MF could provide an answer as to what extent the applied system in MF is coherent with natural processes and structures. Unfortunately, there are few pristine forest remnants left in Europe, and therefore studies on OGF characteristics and comparisons with MF have been more the exception than the rule. Due to the lack of comparative research on managed and unmanaged forests, we currently lack knowledge about the differences between natural forest structures and those that have occurred as a result of selection silviculture.

O'Hara and Gersonde (2004) indicated that the most common approach for stocking control in North American selection MF describes the desirable (equilibrium) stand structure with a negative exponential or reverse-J diameter distribution, which in Europe is often called a plenter structure. We would assume that if OGF indeed exhibited such structure, then setting it as a target structure for achieving management goals in MF would be justified. Nevertheless, Korpel (1995) stated that due to biomass accumulation, the plenter structure is rarely found in natural forests. Similarly, Schütz (2002a) indicated that plenter forests would probably evolve slowly towards uniformity if unexploited over a long period, and for this reason intensive and recurring silvicultural interventions would be necessary to maintain a plenter structure. On the other hand, some newer studies (e.g. Král et al., 2014, 2016) presented the opposite arguments.

Angers et al. (2005) stated that the single-tree selection system is similar to a natural gap disturbance regime in OGF; hence, both provide structural- and species diversity. However, there is still a lack of evidence on what extent selection management mimics the structures and tree species composition of natural primeval OGF. Information on this issue is scarce in Europe because few studies have focused on the comparison of stand structural parameters between selection MF and corresponding OGF (e.g. Bončina et al., 2014; Motta et al., 2015; Adamic et al., 2016). If management is nature-based, then we can expect the structure and species composition in MF to resemble those found in neighboring OGF. We therefore addressed the above-described problems in the present study by comparing two Bosnian OGF of pristine character with adjacent selection MF in terms of (i) structural diversity, including the presence of developmental phases and analyses of diameter distribution shapes and (ii) tree species composition and mixing patterns.

## 2. Methods

### 2.1. Study site

The research was conducted in two OGF (Janj and Lom) and ten adjacent selection-managed forest stands in the Dinaric Mountains of Bosnia. Among the managed stands chosen for comparison purposes, five were in close proximity to OGF Janj, and another five in close proximity to OGF Lom. All research sites were classified as forest association *Piceo-Abieti-Fagetum illyricum (dinaricum)*, representing a mixture of European beech, silver fir (*Abies alba* Mill.) and Norway spruce (*Picea abies* (L.) Karst) with small shares of noble broadleaves. The geographic position of the core area of OGF Janj (57.2 ha) is located at 44°08'N, 17°17'E, and the core area of OGF Lom (55.8 ha) is located at 44°27'N, 16°27'E. The core areas of both OGF are surrounded by buffer zones (Janj 237.8 ha, Lom 297.8 ha). In OGF Janj the approximate mean annual rainfall amounts to 1200 mm and mean annual temperature is around 6 °C, whereas for OGF Lom the respective precipitation and temperature values are 1600 mm and 5 °C. Game density may significantly limit the recruitment of some species such as fir (Ficko et al., 2016), but the damage on the regeneration in the study area was negligible, probably due to excessive hunting in the last several decades.

Managed stands were chosen based on their environmental characteristics (site conditions, aspect, etc.) being similar to those of OGF. Dolomite bedrock was mostly present in the Janj area and limestone in the Lom area, whereas brown soils prevailed in both areas. Rocky outcrops were mostly present in OGF Lom (15% of the area), whereas in MF their share ranged from 0% to 10%. The altitude of OGF ranged between 1240 and 1400 m a.s.l. and that of MF between 1000 and 1400 m a.s.l. The terrain inclination was also similar in both forest types, reaching a maximum of 10°. Furthermore, the cutting intensity in MF was typical for the selection system (it did not exceed 20% of the growing stock in ten-year cutting cycle), and the last cut was carried out at least four years prior to fieldwork. Selection management within the research area has been applied since the early 20th century. Early on it was more traditionally oriented (Hufnagl, 1983), but after WWII it was based on the principles of the control method (Biolley, 1901; Matic, 1963). This system has been the most preferred by domestic foresters to the present day. Careful attention is given to the selection of trees for cutting. Namely, every tree with diameter at breast height (DBH) > 7 cm is marked in the field a few months before the actual cutting takes place. It is thereby important to note that regulation of species composition and tending below the inventory threshold (<7 cm DBH) was not performed, which means that the regeneration developed "freely". However, it is also important to emphasize that within the applied plenter system in Bosnian forests, the regulation of tree species composition plays a significant role; hence, young beech trees of 7–25(30) cm DBH are usually cut more intensively than conifers of the same size.

### 2.2. Data collection

Regular 100 m grids in the core areas of OGF Janj and Lom were superimposed, resulting in 80 sampling plots (40 in each OGF). In each managed stand 12 plots were set so that the total number of plots in both MF was 120. The centers of plots in MF were located at least 25 m from the nearest forest road. Each grid intersection defined the center of a sampling plot, where the following inventories were carried out: in a 452 m<sup>2</sup> circular plot (radius = 12 m) species DBH (to the nearest 0.01 m) was measured for all living trees having a DBH greater than 7.5 cm, whereas one

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