



Understanding the stand mosaic of primeval forests as a basis for close-to-nature forest management: lessons from the Rajhenav virgin forest in the Dinaric mountains

Andrej Bončina

Department of Forestry and Renewable Forest Resources, Biotechnical Faculty, University of Ljubljana; Jamnikarjeva 101 - 1000 Ljubljana, Slovenija. andrej.boncina@bf.uni-lj.si

Abstract: In primeval forests, it is possible to recognise patches that differ in structure and composition. These can be delineated and classified to describe the typical stages of forest stand dynamics. The stand mosaic of Rajhenav virgin forests (Dinaric Mountains, Slovenia) was analysed and the patches were classified into seven developmental stages (young growth, pole, mature, with understorey regeneration, multi-layer, two-layer and gap). The mean patch size amounted to 0.35 ha. The size of “older” stands was significantly larger. Mature stands prevail (> 50 % of the total area), approximately half of the area was covered by stands with understorey regeneration and uneven-sized stands. The proportion of gaps and young growth stage in total was quite low. No patches of pole stage were registered. Proportion of developmental stages suggests that the typical dynamics of this forest type is primarily driven by death of individual trees or small groups of trees. This is reflected in the high proportion of stages characterized by dispersed mortality of trees (two- and multi-layered stands, stands with understorey regeneration). The results indicate various possible pathways of stand development; some are just more common than others. By mimicking the dynamics of primeval forests in managed forests, it is possible to manage forest stands in a variety of pathways. Rather than rigidly applying one silvicultural system across the area, it is suggested that elements of various systems are combined. This is at the core of the free-style silviculture concept.

Key words: forest mosaic; stand patch; developmental phase; close-to-nature forestry.

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1. INTRODUCTION

Close-to-nature silviculture should follow the natural stand dynamics (Bončina 2000; Diaci et al., 2010; Nocentini et al., 2021). Therefore, it is crucial to study stand dynamics

in primeval forests with similar site conditions in order to recognize the main spatial and temporal patterns in stand structure. In Central Europe, the limited size or absence of primeval forests (Sabatini et al., 2021; Nagel et al., 2025) often limits such studies. Despite their

limited size, the remnants of virgin forests are valuable for studying natural stand dynamics.

In primeval forests, a mosaic of patches can be recognised, meaning that the stands are not homogeneous, but rather composed of various cohorts and patches of trees. While the differences between patches are sometimes quite visible, changes in stand characteristics are often more gradual. Although the stand structure inside patches is not completely homogeneous, the difference between delineated patches is, on average, larger than the difference inside single patches (Pickett & White, 1985). However, despite clear criteria, terrain analysis and the final delineation of patches may depend to a large extent on the subjective estimation of the researcher (Král et al., 2017). This raises the question of whether the patches actually exist or are merely perceived by the field observer. This is particularly pertinent when mapping is based solely on the visual assessment of forest stands, as was typical of the pioneering research of Central European primeval forests (Leibundgut, 1993).

When studying stand dynamics it is important to monitor changes in forest stands over time. However, the development of a single forest patch can take several centuries. Therefore, analysing the spatial distribution of patches of different ages provides an alternative to long-term observation of individual patches. Delineating patches and classifying them into stand types is a typical example of this approach. Studying the structural characteristics, abundance and distribution of individual stand types provides a basis for understanding the dynamics of forest stands (Pickett & White, 1985; Bončina, 2000; Franklin et al., 2018). Recognised recurring characteristics, i.e. patterns, in the structure and development of forest stands make this knowledge crucial for implementing close-to-nature forestry.

A forest mosaic can be understood as a record of the recent development of forest stands in response to various natural disturbances. The sensitivity of forest stands to disturbance agents, and their responses after disturbance, differ between various forest types; therefore, it makes sense to study stand dynamics in individual forest types (archetypes) (Franklin et al., 2018). These forest types differ in terms of site and climate conditions, tree species composition, the competitiveness of tree species, growth and regeneration processes and the natural disturbance regime.

The objectives of the study were to i) analyse stand patches in the Rajhenav virgin forest as an example of Dinaric silver fir-European beech forests, and ii) test for differences in the diameter structure and regeneration between developmental stages.

2. METHODS

2.1 Study area

The Rajhenav virgin forest remnant is located on the Rog Mountains ridge in south-eastern Slovenia, at an altitude between 850 and 960 metres above sea level. The area experiences around 1,500 mm of rainfall per year and the terrain is distinctly karstic, featuring a rugged and rocky landscape with predominant south and west exposure. The parent substrate is mainly limestone. The most widespread soil type is brown soil on limestone of varying depths, and rendzina is also present in some areas. This site is a prime example of Dinaric mountain forests (Bončina et al., 2014; *Omphalodo-Fagetum* = *Abieti-Fagetum dinaricum*). The average growing stock in the entire primeval forest is approximately 800 m³/ha. Silver fir accounts for 60% of this, while European beech accounts for 40%. In this part of the Dinaric Mountains, Norway spruce is

present in natural forest vegetation in very low proportions (less than 5% of the total growing stock) (Hufnagl, 1894). Single trees of minor tree species (i.e. *Acer pseudoplatanus*, *Picea abies*, *Tilia cordata*, *Ulmus glabra*) make up less than 1% of the total growing stock.

2.2 Patch mapping and analyses

This study is based on archival data (Bončina, 1997), most of which has not been published (Bončina, 2000). Stand patches were mapped at a scale of 1:2500. Aerial photographs were used to gain insight into the horizontal structure of the forest prior to fieldwork. During the field mapping process, a network of 100 x 100 m reference points marked in the field was used to improve orientation within the forest stands. Patches were delineated based on visual assessment of differences in stand parameters (e.g. tree height and diameter, tree canopy structure, spatial tree distribution, canopy closure and sapling presence). The size of the mapped patches corresponds to

that of the tree group or stand. Due to their recognisability and low tree height, patches of young growth were defined over a smaller area than older stands. The patches were classified into developmental stages (Table 1). Based on literature and our experience of these forest types, we defined seven developmental stages (further divided into sub-stages), enabling us to describe typical patterns of forest stand mosaics and the development of forest stands in these forests.

In the next step, we randomly selected coordinates for the detailed analysis of stand parameters in the selected developmental stages (Table 1). A total of 18 sample plots containing trees with a breast-height diameter greater than 10 cm were analysed. Each plot measured 30 x 30 m. These trees were measured for height (in metres) and diameter at breast height (dbh; to 0.1 cm). Crown characteristics were assessed using a five-rank system for size, crowding and vitality. The composition and height structure of the regeneration were analysed using randomly

Table 1 - The list and description of the developmental stages, along with the number of sampling plots.

Developmental stage	Description	Number of 30 x 30 m plots	Number of 4 x 4 m plots
Young growth	Young growth, saplings, thicket phase < 10 cm in dbh, not sheltered by upper tree layer	-	10
Pole	Trees with dbh 10–30 prevail	-	-
Mature	Trees with dbh > 30 cm prevail (sub-stages: early mature, middle mature, late mature)	9	32
With understory regeneration	Mature stand (approx. height of 40 m) of light canopy with intensive regeneration	3	10
Multi-layered	A stand composed of trees of different sizes within a small area	3	10
Two-layered	In upper layer mature trees (approx. height of 40 m), in lower layer (approx. height of 10-20 m) trees with dbh 10–30 cm	3	10
Gap	No tree or shrub vegetation	-	10

Table 2 - Percentage of developmental stages in total area.

Developmental stage	Percentage in total area (Bončina, 2000)	Average patch size (hectare)
Young growth	2.1	0.04
Pole	-	-
Mature (together)	51.4	1.20
With understory regeneration	18.9	0.32
Multi-layer	15.2	0.28
Two-layer	11.2	0.36
Gap	1.2	0.02
Total	100.0	0.35

selected 4 x 4 m plots. In each developmental stage, at least ten plots were sampled (Table 1). All tree saplings with $h > 1.3$ m were recorded per one-meter height class (hc) (hc 2: 1.3–1.9; hc 3: 2.0–2.9; hc 4: 3.0–3.9, etc.). The coverage (abundance) of vertical layers of forest vegetation was also assessed (%).

3. RESULTS

3.1 Stand mosaic

The stand mosaic was quite patchy. The mean size of the patches was 0.35 hectares. However, the size of “older” stands was significantly larger, while gap patches and patches with young growth were small (see Fig. 1 and Table 2). The patches were classified into seven main developmental stages. No patches at the pole stage with evenly sized trees were recorded. Mature stands covered over 50% of the total area. Around quarter of the area was covered by uneven-sized stands. The proportion of gaps and the young growth stage in total was quite low. Patches of the same developmental stage were not found within one block, but rather dispersed across the area (Fig. 1).

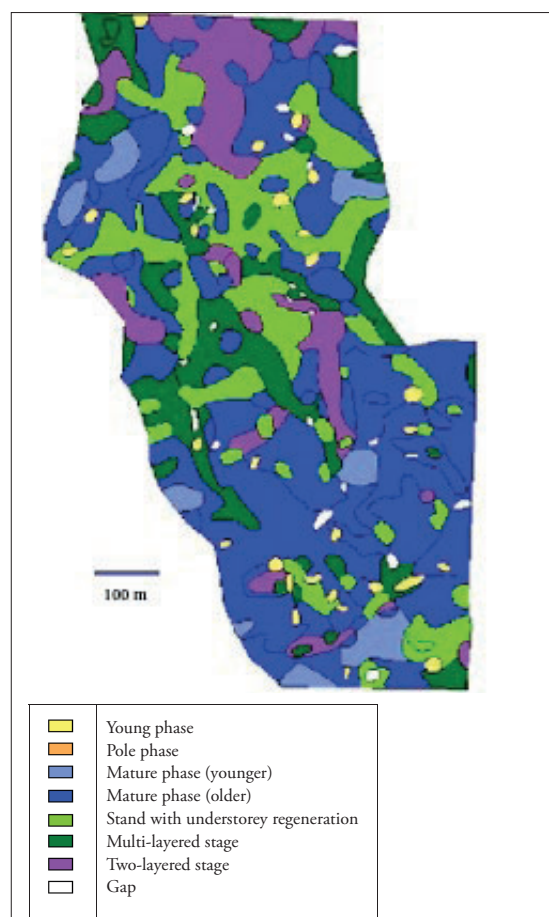


Figure 1 - Map of stand patches (black delineations) and developmental stages.

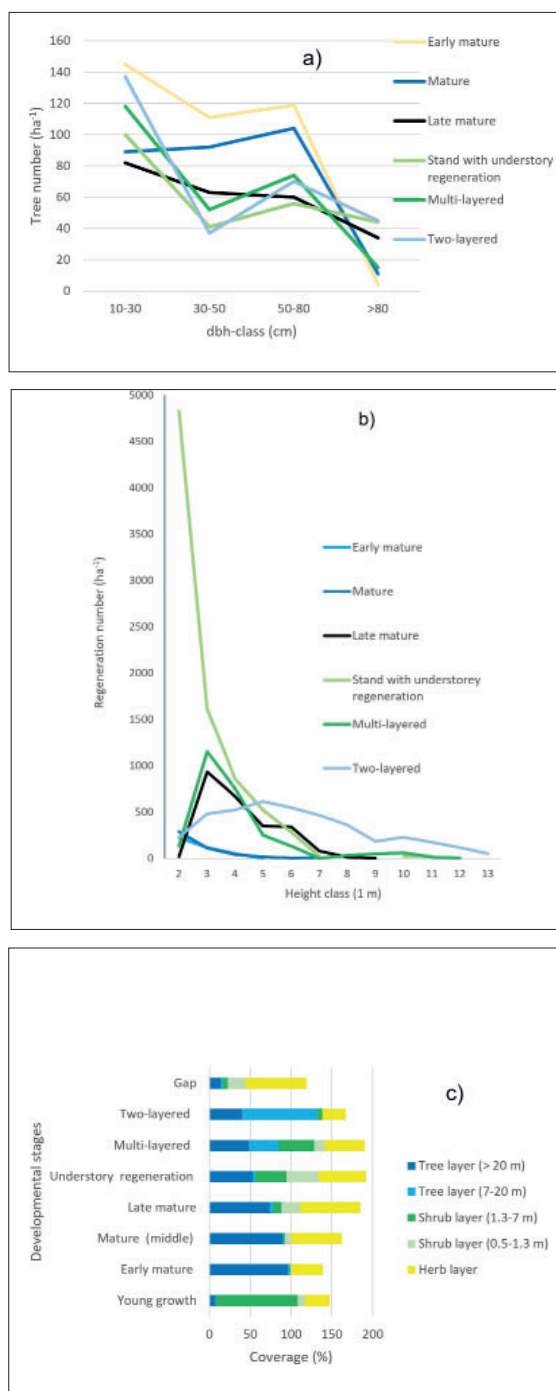


Figure 2 - Stand characteristics of developmental stages: a) diameter structure of stands; b) height structure of regeneration (sampling number per 1 m height class (hc): hc 2 = 1.3-2 m; hc 3 = 2-3 m; ...); c) coverage of vegetation layers in the observed developmental stages.

The developmental stages differ significantly in terms of their diameter structure (Chi-square = 142.99; $df = 15$; $p = 0.0000$). Early mature stands have the largest number of medium-sized trees, while large-sized trees are more abundant in late mature stages, stands with understory regeneration, and uneven-sized stands (Fig. 2a). The abundance of regeneration differs significantly between stages (Chi-square = 11165.70; $df = 15$; $p = 0.0000$) (Fig. 2b). There are also significant differences between developmental stages in the vertical structure of forest vegetation (Chi-square = 1018.55; $df = 28$; $p = 0.0000$) (Fig. 2c). The upper tree layer is most abundant in mature stands, whereas it is much less abundant in stands with understory regeneration and uneven-sized stands. The medium tree layer is most abundant in stands with understory regeneration.

4. DISCUSSION

We used methods common in landscape ecology to analyse stand patches and describe forest mosaics. Stand patches are constantly changing in terms of quality and quantity due to processes such as tree growth, regeneration and mortality, which are directly or indirectly influenced by natural disturbances. Therefore, the current mosaic of stand patches - a snapshot of the ongoing development of forest vegetation in terms of the size, type and form of patches - is the result of recent stand development processes and their response to natural disturbances.

Patches are a useful tool for understanding and describing typical patterns in stand mosaics and stand development. They are not merely the perception of field observers. Random sampling of diameter structure, vegetation layers and regeneration showed significant differences between developmental stages, indicating that mapping patches is a reasonable way to describe

differences in stand structure and forest stand dynamics.

Classifying stand patches is useful for describing the main patterns in stand dynamics of Dinaric mountain forests. Evidently, the mature stage prevails across the entire area. Only a few small patches were classified as gaps or young growth, and none were classified as the pole stage. This suggests that the dynamics of silver fir - European beech forests are primarily driven by the disturbance or replacement of individual trees. The presence of large patches of gaps and young growth would indicate larger-scale disturbances, which could also occur in this forest type (Nagel et al., 2017). The prevailing stand dynamics, based on single-tree replacement, are reflected in the high proportion of two- and multi-layered stands, as well as stands with understorey regeneration. Dispersed tree mortality is typical of all these stages. The origin of two-layered stands is probably related to the mortality of individual trees across the stand over a relatively short period. This can be linked to the intensive dieback of silver fir in the previous century (Diaci et al., 2010; Bončina et al., 2014) and, consequently, to the regeneration and ingrowth of new trees (mainly beech) within the stand. Multi-layered stands originate from the permanent, yet weak, mortality of individual trees distributed non-uniformly across the stand, as well as the permanent regeneration and ingrowth of trees within the stand. The composition of tree species strongly influences these differences in stand dynamics (Bončina, 1997), since the susceptibility of trees and stands to natural disturbances depends on tree species mixture.

The key contribution of this study to ecological forestry is recognising that forest stand structure assessed by stand patches differs significantly at a small spatial scale. This means that pathways of stand development driven by natural disturbances differ. There is not just one pa-

thway of stand development, but many. Some are more common than others, resulting in different proportions of developmental stages.

This recognition is important for close-to-nature forestry. By mimicking the dynamics of primeval forests in managed forests, a variety of management approaches can be employed. In the Dinaric fir-beech forest region, the irregular shelterwood silvicultural system is primarily used alongside elements of the selection system (tree- and group-based). In the virgin forest, a mosaic of patches with even-sized stands is mixed with patches with more uneven-sized stands. In close-to-nature silviculture, this concept is known as free-style silviculture. Rather than applying one silvicultural system rigidly across the entire area, it advocates combining elements of various systems on a small spatial scale (Bončina, 2011). This is important when considering differences in stand structure and site conditions on a small spatial scale.

One limitation of the study should be mentioned. The study revealed some significant patterns in the structure of primeval forests. However, the area of the study site is too small to generalise the natural stand dynamics of the entire forest type. Considering the regional spatial scale, severe disturbances, although rare, are also part of the natural disturbance regime of the observed forest type (Nagel et al., 2017). This broadens the view of natural stand dynamics. In addition to the natural stand dynamics observed in the Rajhenav virgin forest, pathways of stand dynamics characterised by larger gaps and larger areas of young forest stands can also be part of the natural process, albeit with a rare occurrence.

The concept of age class categories is not suitable for describing forest stands in close-to-nature forestry. It is more appropriate to use a classification of forest stands based on developmental stages. Similar (same) developmental stages to those found in virgin forests are pres-

ent in managed forests, which is a consequence of practising close-to-nature forest management in Slovenia for decades. As expected, there are significant differences in stand density and the amount of dead wood between stands of the same developmental stage in managed forests and virgin forests (Bončina, 2000). However, stand dynamics, i.e. the cycle of stand development stages, are similar in both types of forest. In managed forests, this cycle is mainly driven by silvicultural activities, while in virgin forest it is driven by natural disturbances.

Due to management objectives, the proportion of young growth and pole stage stands is significantly larger in managed forests. In forest management, stand mapping is a useful tool for describing forest mosaics at landscape and regional scales. It is an important indicator of forest sustainability and can be used to monitor changes in forest area.

In recent decades, stand mapping based on aerial photographs and LIDAR data has emerged as an alternative to terrestrial-based mapping. Using LiDAR data for stand seg-

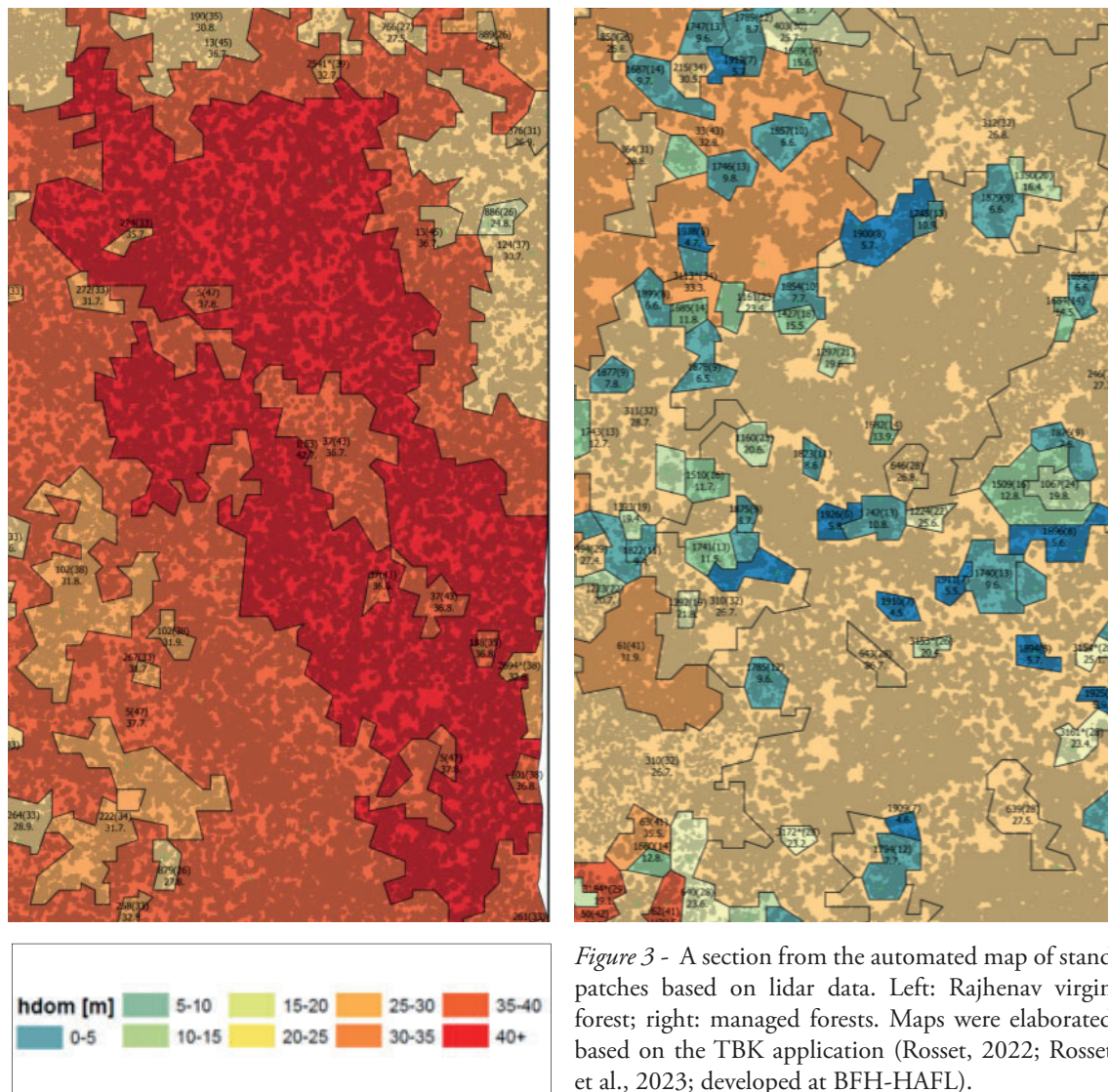


Figure 3 - A section from the automated map of stand patches based on lidar data. Left: Rajhenav virgin forest; right: managed forests. Maps were elaborated based on the TBK application (Rosset, 2022; Rosset et al., 2023; developed at BFH-HAFL).

mentation contributes to the objectification of stand mosaic studies (Rosset, 2022). It is now tested in the selected areas in Slovenia (Fig. 3) (Bončina et al., 2024b). The research on the stand mosaic of the Rajhenav virgin forests (Rosset et al., 2023; Bončina et al., 2024a), based on LiDAR data (Fig. 3), reached similar conclusions regarding stand dynamics as in the presented study.

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