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Moderate- to High-Severity Disturbances Shaped the Structure of Primary *Picea Abies* (L.) Karst. Forest in the Southern Carpathians

Andreea Petronela Spînu [1,†], Ion Cătălin Petrițan [2,*], Martin Mikoláš [3,4], Pavel Janda [3], Ondřej Vostarek [3], Vojtěch Čada [3] and Miroslav Svoboda [3]

1. Chair of Silviculture, Faculty of Environment and Natural Sciences, University of Freiburg, 79106 Freiburg, Germany; andreea.spinu@waldbau.uni-freiburg.de
2. Department of Forest Engineering, Forest Management Planning and Terrestrial Measurements, Faculty of Silviculture and Forest Engineering, Transilvania University of Brașov, 500123 Brașov, Romania
3. Department of Forest Ecology, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences, 16500 Prague, Czech Republic; mikolasm@fld.czu.cz (M.M.); jandap@fld.czu.cz (P.J.); vostareko@fld.czu.cz (O.V.); cada@fld.czu.cz (V.Č.); svobodam@fld.czu.cz (M.S.)
4. PRALES, Odtrnovie 563, 013 22 Rosina, Slovakia

* Correspondence: petritan@unitbv.ro

† Part of the work was carried out while A.P. Spînu was a BSc student at Transilvania University of Brașov.

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Abstract: Research Highlights: Past disturbances occurred naturally in primary forests in the Southern Carpathians. High- and moderate-severity disturbances shaped the present structure of these ecosystems, which regenerated successfully without forestry interventions. Background and Objectives: Windstorms and bark beetle outbreaks have recently affected large forest areas across the globe, causing concerns that these disturbances lie outside the range of natural variability of forest ecosystems. This often led to salvage logging inside protected areas, one of the main reasons for primary forest loss in Eastern Europe. Although more than two-thirds of temperate primary forests in Europe are located in the Carpathian region of Eastern Europe, knowledge about how natural disturbances shape the forest dynamics in this region is highly essential for future management decisions. Material and Methods: We established our study in a primary forest valley situated in the centre of the largest temperate primary forest landscape in Europe (Făgăraș Mountains). A dendrochronological investigation was carried out to reconstruct the natural disturbance history and relate it to the present forest structure. Results: The dendrochronological analysis revealed high temporal variability in the disturbance patterns both at the patch and stand level. Moderate severity disturbance events were most common (20–40% of canopy disturbed in 60% of the plots) but high severity events did also occur (33% of the plots). Regeneration was spruce-dominated and 71% of the seedlings were found on deadwood microsites. Conclusions: We conclude that the current structure of the studied area is a consequence of the past moderate-severity disturbances and sporadic high-severity events. The peak in disturbances (1880–1910) followed by reduced disturbance rates may contribute to a recent and future increase in disturbances in the Făgăraș Mts. Our findings show that these disturbance types are within the range of natural variability of mountain spruce forests in the Southern Carpathians and should not be a reason for salvage logging in primary forests from this area.

Keywords: forest dynamics; natural disturbance; dendroecology; Norway spruce; forest management

1. Introduction

In the context of climate change and consequent shifts in natural disturbance regimes [1,2], long term data about ecological processes is highly essential for future management decisions. Primary forests (forests with no direct human influence) are a necessary component of understanding natural forest dynamics. These ecosystems represent a valuable natural heritage, not only for their intrinsic value, but also as a pool of genetic diversity [3] and a refuge for many endangered or forest-specialist species [4]. In contrast, due to changes in structure and dynamics, most of the European managed forests are subject to biodiversity loss [5]. Serving as an inexhaustible source of ecological information [6], primary forests are considered a reference state for sustainable forest management [7–9]. Therefore, many recent studies have been conducted to highlight the importance of such forests [3].

A central issue in applying ecological principles in forest management is to understand and describe the dynamics of primary forests. The whole ecosystem is described by different development phases, which occur temporally and spatially adjacent to one another, creating a structural mosaic [10]. For decades, disturbance regimes were considered a negative agent creating damage in forest stands [11]. Conversely, this autogenic phenomenon which occurs with different intensities and inversely proportional frequencies supports the establishment of regeneration [11,12]. In temperate Europe, windstorms and insect outbreaks arise as part of the forest ecosystem [13,14] with variating severity at landscape scale [15]. Disturbances are not necessarily rare events that occur outside the ecosystem. Instead, they are one of the main drivers shaping stand structure via biological legacies that are left from the pre-disturbance ecosystem [10,16–18]. As a result, unique structures are formed which perform as habitats for many endangered, forest-specialist species [19,20].

Once spreading across the whole European continent, nowadays primary forests are found just in the form of small, disconnected remnants [21,22]. The Carpathian region is optimal for describing the structure and dynamics of these ecosystems because it includes a large and diverse (in terms of forest types) amount of primary forests [6].

One of the largest mountain primary forest landscapes of the European Union is found in Făgăraș Mountains, Romania, however weakly protected [23,24]. The formerly inaccessible area is important both for its concentration in primary forests, as revealed by its latest inventory [6], but also for the major forest management challenges it presents, due to a significant change in forest land tenure and consequently different pressures related to the forest use. Although Făgăraș Mts. is covered by one of the largest complexes of temperate primary forests in the EU, most of these forests are without protection and are being logged increasingly, mainly by salvage logging [21,25].

Studying historical disturbances, their severity, synchronisation and consequences on present forest structure are needed to guide forest management [26]. Although several studies analysed the disturbance history of primary forests, studies that relate natural disturbance history to present forest structure in European temperate primary forests are rare [27,28]. There are few studies investigating the dynamics of primary forests in the Southern Carpathians [29,30]. This region is also the distribution limit of the continuous and homogenous spruce population *Picea abies* (L.) Karst [31]. In this study, we present a first dendrochronological investigation together with structural analyses conducted in the primary forests in the Southern Carpathians. In particular, two main research questions were addressed:

- What was the range of past natural disturbance variability of montane spruce forests in the Southern Carpathians?
- Is there a relationship between past disturbance regimes and present structural characteristics?

We hypothesize that the current forest structure is a result of variability in timing, severity and intensity of past disturbance regimes.

2. Materials and Methods

2.1. Study Area

The research area is in Făgăraș Mts. (between 45°63′ (45°64′) N and 24.71′ (24°72′) E in the Southern Carpathians, where the largest complexes of mountains forests (ca 10,000 ha) within one mountain range in the European Union have been preserved for centuries by the inaccessibility of the terrain (Figure 1) [6]. Romania is one of the places with the highest likelihood of occurrence of primary forests in the European Union, even though the exact coverage is controversial and yet to be fully mapped and measured [21,23,24].

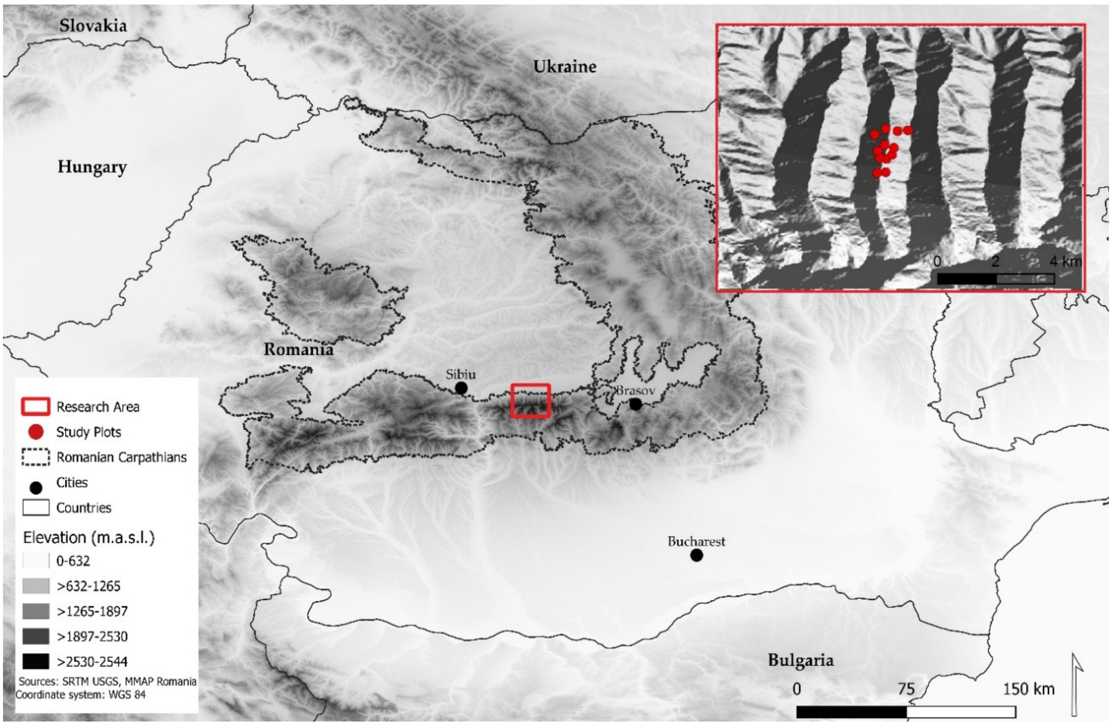

Figure 1. Study area location (European context, Făgăraș Mts., Ucișoara Valley) [32].

The fieldwork was conducted in September 2013 in one of the well-preserved and remote valleys of Făgăraș Mts. (Ucișoarei Valley), situated at an altitude ranging between of 1300–1540 m. The climate is temperate continental with a slight Mediterranean influence. The mean annual temperature is 4.5 °C and the value of mean annual precipitation is 1000 mm. The main soil types of the region are podzols. Since most of the valleys in the northern Făgăraș Mts. show similar site conditions (inclination, orientation, species composition, etc.) and the valley is situated centrally within its range, we considered the valley to be representative for the region in respect to disturbances. The description of the plots can be found in Appendix A.

The tree layer was strongly dominated by *Picea abies* (L.) Karst with an admixture of *Sorbus aucuparia* (L.), *Acer pseudoplatanus* (L.), *Abies alba* (Mill.) and with an understorey of *Vaccinium myrtillus* (L.), *Calamagrostis villosa* (Chaix) J.F.Gmel. and *Luzula sylvatica* (Huds.) Gaudin.

Potential study sites were first selected using a previous inventory of primary forest remnants in Romania [6]. During a terrestrial inventory of this map, we chose one spruce forest, in Ucișoara Valley, which showed no sign of human impact (no evidence or past logging or grazing) and indicated high levels of naturalness (e.g., coarse woody debris in various stages of decay, pit-and-mound topography). The valley was later mapped by WWF and proposed for inclusion in the National Catalogue of Virgin Forests, confirming the concurrence to the primary status of the studied forest stand [33]. After the data collection, salvage logging was carried out in parts of the forest due to bark beetle outbreaks (Figure 2).

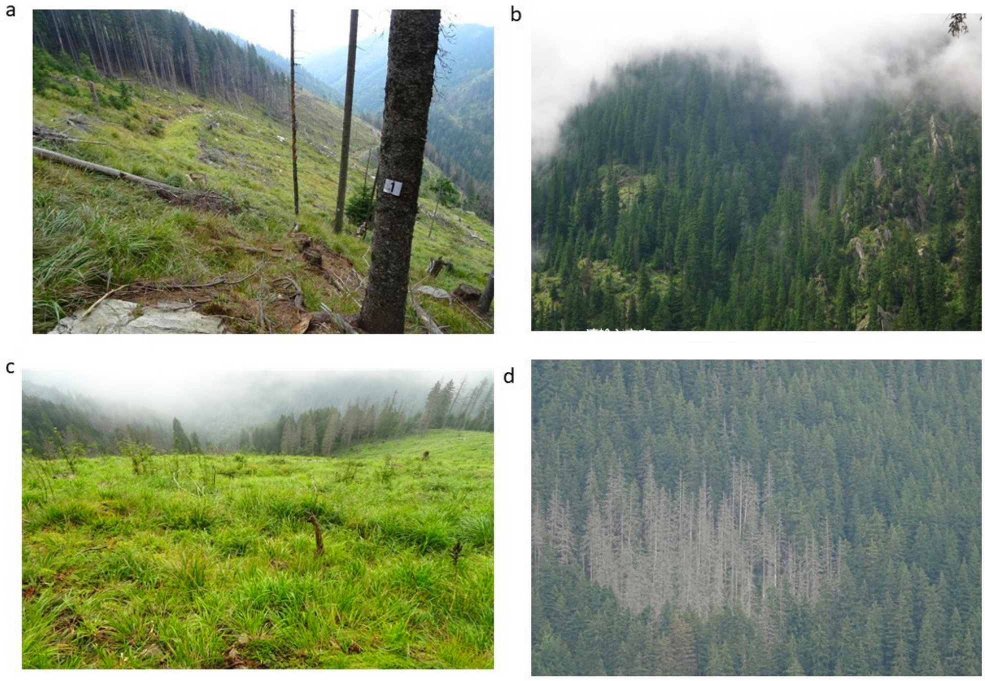

Figure 2. Current situation of the forest stands in the Făgăraș Mountains: (**a**) salvage logging of permanent study plot inside of the primary forest valley Ucișoara (5 years after plot establishment); (**b**) primary forest stands in old-growth stage; (**c**) problems with spruce regeneration after salvage logging; (**d**) recent patches of bark beetle outbreaks.

2.2. Experimental Design

We established twelve circular plots of 1000 m^2 in the studied area, on both sides of the valley by a GPS using stratified random sampling. Each study plot was randomly placed within the inner 0.49 ha core zone of a 2-ha grid. Each plot was described by topographic attributes (slope, elevation, aspect, landform and hillform). In each sample plot, all living trees above 10 cm diameter at breast height (hereinafter "DBH") were sampled, measured (DBH, height) and stem-mapped using the Field Map Data Collector [34] and their coordinates were recorded. Each tree was recorded by condition (alive or dead), canopy layer (upper layer when the tree reaches 80% of the average plot height or lower layer), and status of suppression (released/canopy tree, suppressed tree). Deadwood methodology was based on *Line Intersect Sampling of Coarse Woody Debris* [35,36]. Deadwood was classified as one of five wood decay stage classes [35] (see Table 1).

The natural regeneration was assessed over the whole 1000 m^2 plot. Individuals were counted on height classes (from 50 cm to 1.3 m, from 1.3 m to 2.5 m, above 2.5 m, but below 10 cm DBH) and classified by microsite origin (pit, mound, rock, deadwood).

Dendroecology is a useful tool to reconstruct the impact of natural and anthropic disturbances in forest dynamics [37,38]. Thus, 25 to 30 canopy spruce individuals per plot were randomly selected for increment core extraction at 1.0 m above ground level. Trees with a significant part of the crown projection receiving direct sunlight from above were classified as canopy trees [39,40].

The experimental design follows the work of Svoboda et al. [15] and Janda et al. [41]. No landscape analysis was carried out and hereinafter we will refer to the studied forest as the "stand level" and to the 1000 m^2 plots as the "patch level".

Table 1. Deadwood volume (total, downed, standing), snag density and distribution on decay classes (mean values (± SE) (min–max).

Decay Classes	Volume of Deadwood ($m^3 \cdot ha^{-1}$)		
	Downed Deadwood	Standing Deadwood	Total
1. hard wood, completely covered with bark, fresh phloem sometimes present	6.92	0	6.92
2. wood mostly hard, most of the bark left, but no fresh phloem present.	14.10	13.66	27.76
3. wood partly decayed on the surface or in the center, large piece of bark usually loosened or detached, branches still present.	21.90	8.08	29.98
4. most of the wood soft, the central parts can remain hard, while the surface layers of the wood can be missing.	16.92	1.05	17.97
5. wood very soft, usually covered by field-layer vegetation.	1.47	1.23	2.69
Total (mean ± SE) max.–min.	61.31 ± 14.03 (17.54–163.85)	24.01 ± 4.75 (5.72–61.2)	85.32 ± 12.55 (38.99–168.57)

2.3. *Data Measurements*

Increment cores were dried, secured on wooden mounts and shaved with a razor blade. The pith was reached in most of the samples. For cores that missed the pith; the number of missing rings was estimated using Duncan's [42] method. Annual ring widths were measured to the nearest 0.01 mm using a stereomicroscope and LintabTM sliding-stage measuring device in conjunction with TSAP-WinTM software [43]. Cores were first visually cross-dated using the marker year approach [44] and then confirmed with COFECHA software [45].

Past disturbance regime was reconstructed by dendrochronological data analysis, by using tree ring data from 347 trees. Timing, frequency and severity were noted.

2.4. *Data Analysis*

2.4.1. Structure Analysis

The total volume of the living trees was calculated by logarithmic equation [46]. The volume of dead standing trees was estimated according to measured DBH and height. Downed deadwood volume was calculated using the following formula: $V = (\pi^2 \sum d^2/8L) \times 10{,}000\ m^2 \cdot ha^{-1}$, where d = piece diameter, L = length of sample line (120 m) [47].

The statistical analysis and tests for differences between tree layers (nonparametric Mann–Whitney U for not normally distributed data) were performed using SPSS 24 [48].

2.4.2. Dendrochronological Analysis

The disturbance history was reconstructed following Janda et al. [41]. Chronologies of inferred canopy disturbances were based on classifying the radial growth patterns of non-suppressed trees in two patterns: (1) open canopy recruitment indicated by rapid initial growth or (2) release-trees that most likely established in a shaded environment and recruited to the canopy through gap formations in the canopy, as depicted by slow initial growth followed by an abrupt release [15,28,39] (Appendix B). The disturbance history was reconstructed from the analysis of 347 increment cores. Tree juvenile growth rates indicated trees that had open canopy recruitment [49]. Open canopy recruitment was assessed when the juvenile growth rate overcame threshold 1.6 mm/year [41]. The growth rate threshold that best-separated populations growing in open and closed canopy conditions [15] was then estimated using logistic regression and the intersection of specificity—an expression of the likelihood of false negatives and sensitivity—the likelihood of false positives [50].

Releases from suppression were identified by the absolute increase method [51]. Differences between running means of adjacent ten-year intervals greater than 1.25 standard deviations (approximately 90% of variability) above the mean for the tree were considered release events [51]. The events with an absolute increase of over 0.595 mm were counted as released. To avoid climatically induced events (several extreme growth years), increased growth rates had to be sustained for seven years to be deemed a release event [51]. Since the dominant species (*Picea abies*) is moderately shade-tolerant [52] and in order to reach the canopy, it can require more disturbances, multiple canopy accessions in the disturbance chronologies were considered. The DBH of 23 cm (calculated through logistic regression of suppression status as a function of DBH according to Schurman et al. [29] was the threshold to indicate whether an individual reached canopy status at the time of release [29,40].

Disturbance chronologies were then reconstructed by linking current crown areas of released trees to the year the detected release occurred, assuming that the crown area of trees that responded to the original gap formation approximates the size of the original gap [40]. Crown areas were predicted from a statistical relationship between crown areas estimated on cored trees and DBH ($(0.0069260 \times \mathrm{DBH} + 1.8698166)^2$). Timing and severity of the disturbances at patch level were calculated by combining crown area estimates with growth release dates for initially suppressed seedlings and the timing of open-canopy recruitment [28]. We used predefined severity classes for disturbance events, following Frelich and Lorimer [39]: low (0–10% of the canopy area disturbed), moderate (20.1–40%), high (40.1–60%), very high (greater than 60%) and did not assess the spatial extent of the events. The analysis was performed using the library *nlme* from the R language and environment for statistical computing [53,54]. The pre-set significance level for all tests was 0.05.

3. Results

3.1. Disturbance Patterns

Release and gap-origin events were recorded in all the study plots, showing a history of the past mixed severity disturbance regime. The reconstructed chronologies spanned the early 19th century to the end of the 20th with a tendency of a higher number of moderate pulses in all plots, but also sporadic high severity events (Figure 3).

Data showed high temporal variability in the disturbance patterns both at stand and patch level, but peaks in the disturbance activity clearly appeared in the period 1850–1910 and 1960–1980 (Figure 3). The temporal variation of disturbances is higher at the patch level than at the stand level. Moderate events were recorded in 60% of the cases (20–40% of canopy disturbed in seven plots) and high disturbance events were identified during the periods 1960–1970, 1870–1910 and 1820–1830 in four plots (40–60% of canopy disturbed). (Figure 3)

The oldest trees' recruitment originated from the beginning of the 18th century (1710s, 1730s). Significant peaks in the chronology occurred in the 1900s after two sudden growths around the 1820s and 1850s (Figure 3).

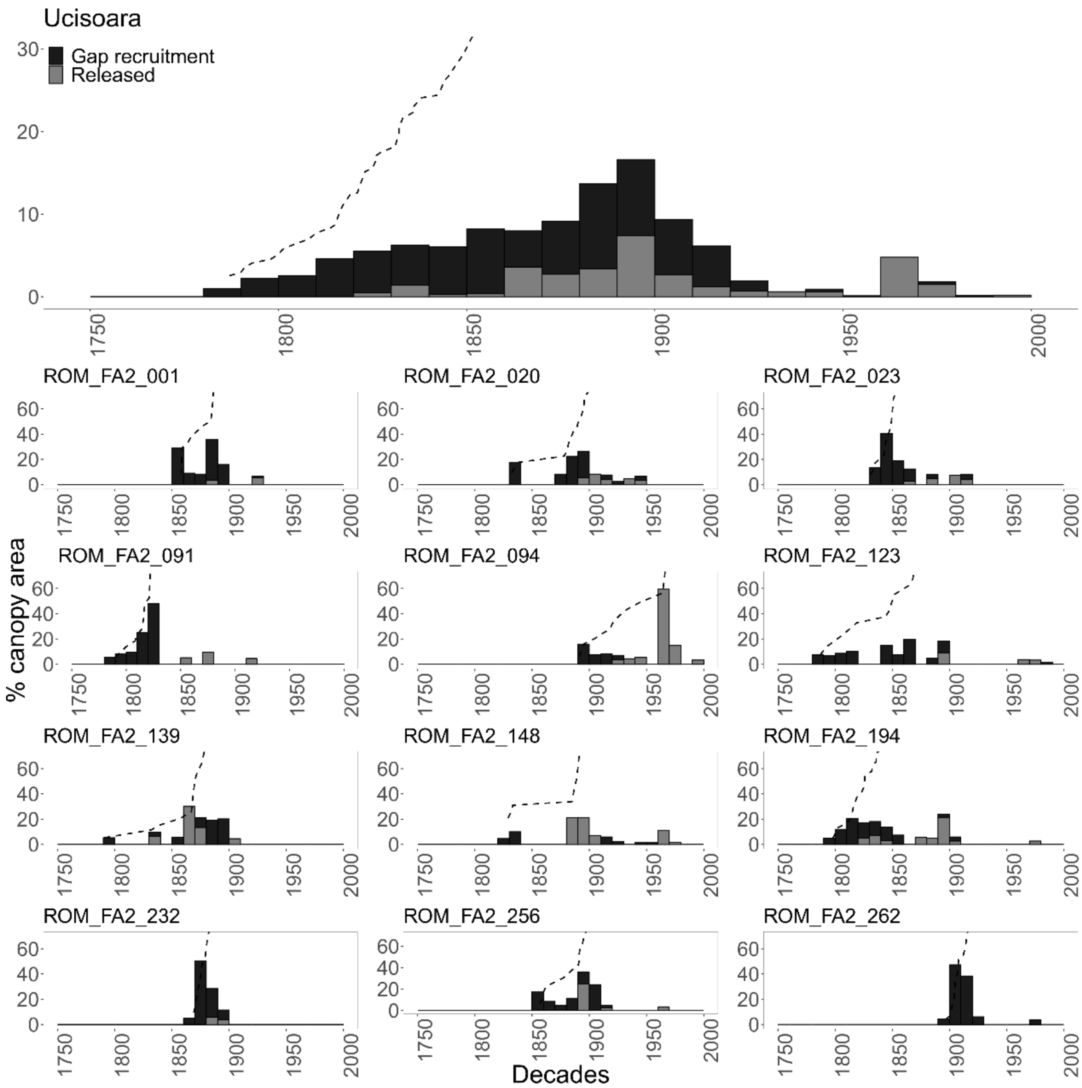

Figure 3. Disturbance history reconstruction summed per decade as a percent of canopy disturbed for the Southern Carpathian region: all plots pooled (**top**) and at stand level (**down**). Sample depth (**dark grey line**) represents the cumulative number of trees contributing to the chronology. The chronologies were derived from analysing two types of events characteristic for disturbances: gap recruitment and growth releases.

3.2. *Structure*

3.2.1. Age Structure

The mean age of the stands was 140 years. The highest age values were recorded to be over 300 years in three plots (8% of the trees were over 200 years old, 2% over 300 years, Figure 4). There was no significant difference in age between the canopy layers (Mann–Whitney U, $Z = -0.537$, $p = 0.592$), even though the layers displayed different tree characteristics (see Section 3.2.2.)

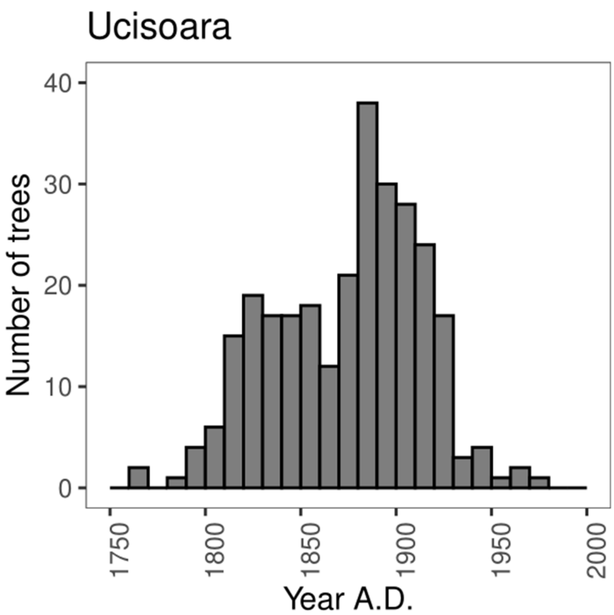

Figure 4. Tree establishment distribution.

3.2.2. Tree Characteristics

The tree layer was dominated by Norway spruce with an admixture of other species of 1%. The mean stock density of living trees was 603 N·ha^{-1}. The total mean basal area accounted for 65.54 m^2·ha^{-1} and the mean growing stock volume was 575.55 m^3·ha^{-1}.

Large trees (with DBH over 50 cm) were present in each plot, ranging from 10 to 100 N·ha^{-1}, with a density of 50 ± 10.3 N·ha^{-1}. The largest Norway spruce tree had a DBH of 91.3 cm and the tallest measured 39.2 m.

The majority of trees were situated in the upper layer (65%) and presented significantly larger diameters and heights compared to the lower layer (t-test for unequal variances for DBH, t = 21.968, df = 466.8, $p < 0.01$; Mann–Whitney U for height, Z = 5.038, $p < 0.01$). (Figure 5a, Table 2).

Table 2. Characteristics of the studied forest differentiated by canopy layers. A tree is considered in the upper layer when it reaches 80% of the average plot height.

Layer		Basal Area (m^2·ha^{-1})	Density (Trees Per ha)	DBH (cm)	Height (m)
Upper	mean (± SE) min.–max.	48.5 ± 3.46 (25.1–65.3)	389.2 ± 55.47 (110–830)	41.25 ± 2.38 (24.8–52.4)	26.29 ± 1.3 (19.73–34.4)
Lower	mean (± SE) min.–max.	8.13 ± 0.73 3.3–13.2	214.2 ± 35.03 70–490	22.26 ± 1.15 14.82–31.15	12.86 ± 1.97 8.5–19.4
Total	mean (± SE)	65.54 ± 3.3 31.6–70.95	603.3 ± 84.4 230–1320	31.75 ± 1.62 19.8–39.2	19.57 ± 1.43 11.21–27.7

Overall, the diameter distribution was Liocourt type, with the number of tree individuals decreasing from lower to higher diameter classes. Comparing the DBH distribution of living and dead trees, the latter were concentrated towards the lower diameter classes (Figure 5b). The dead-to-live wood ratio found in our investigation was 14.82%.

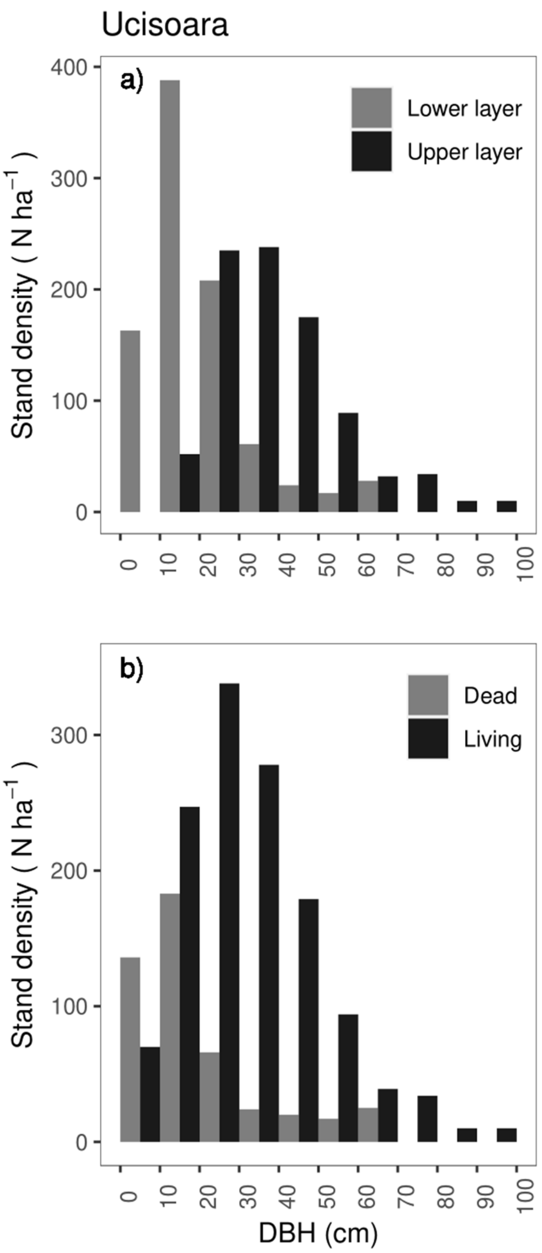

Figure 5. Diameter distribution on canopy layers (**a**) and of living/dead trees (**b**).

3.2.3. Deadwood Structure

The mean deadwood volume was 85.32 (±12.55) $m^3 \cdot ha^{-1}$, varying between the plots. Downed deadwood accounted for 71% of the total amount. The snag density was estimated to a mean of 170 per ha. The distribution in decay classes of the coarse woody debris was concentrated mostly in mid-classes with fewer values in high or low classes (Table 1).

3.2.4. Regeneration

The mean density of spruce seedlings per hectare was 117 $N \cdot ha^{-1}$. More than 50% of regeneration was found on deadwood microsites (Mann–Whitney U, Z = −1.203, $p = 0.229$). The highest level of regeneration was reached by seedlings of *Picea abies* with a height over 250 cm (39%) and 130–250 cm (38%). The admixture of other species than *Picea* was *Sorbus* (17%), *Acer* (8%), *Abies* (4%).

4. Discussion

Understanding the role of historic disturbance patterns in order to create a solid baseline for management solutions to ongoing and future changes in the forest dynamics represents a key challenge in forest ecology. We conducted the first study in the Southern Carpathians linking the past natural disturbance history to present forest structure within one of the largest temperate primary forest complexes of the EU—the Făgăraș Mts. The disturbance regime was characterized by high variability in disturbance severities and timing that affected the present structure of the primary forests. These findings have strong implications for forest management and conservation.

4.1. Disturbance Regime

Data analysis confirms that initiation of stands follows disturbance events, a mixed-severity-driven system. Windthrows most-likely following bark-beetle outbreaks are confirmed to be the main disturbance agent in the region [14,30].

Individual events with different severity and timing appeared in all plots of the stand. After a severe disturbance, the establishment of the new trees can last decades due to the absence of advanced regeneration altogether with specific slow establishment and growth of seedlings [27,55,56]. In addition, since the events were split in decadal bins in the methodology, the response of the recruitment could appear delayed. Therefore, the observed peaks of tree establishment around 1860, 1880, 1900 (Figure 4) was most likely initiated by a series of frequent moderate disturbances during the second half of the 19th century and by high-severity events from two plots in 1820s and 1870s (Figure 3). The oldest three individuals originate from early 18th-century gap events.

In mountain Norway spruce stands, saplings need good light conditions in order to develop. Regeneration is encouraged by the availability of light through canopy removal [57]. Thus, the even-aged structure shows a simultaneous-establishment of trees confirming the high severity of these disturbance events.

Similar studies have shown similar disturbance regime patterns. Both moderate and high-severity disturbances were identified in the Carpathian region by several studies [15,29,30]. There are no official records dating disturbances before the 19th century. However, historical disturbances in the Carpathians were noted in similar periods as the identified events from our dendrochronological analysis: 1840, 1880, 1900, 1960 [15,30].

Growth releases of some trees constitute a response to canopy openings [39,41]. In the studied plots, these are most probably caused by the mortality of larger trees, which survived even severe disturbance events and consequently affect the dynamics of the post-disturbance stand.

4.2. Stand Structure

In general, the average forest characteristics of primary Ucisoara Forest (stem density, basal area) are higher than those of other studied primary Norway spruce Carpathian forests (Table 3). Some of the study plots present attributes of old-growth forests (high standing volume, high amounts of downed and standing deadwood, several canopy layers) [58]. The volume of coarse woody debris is less than the volume found in Slovakia [59]. This difference may be due to the fact that the studied forest from Romania is relatively young and will accumulate more deadwood as it develops and is subject to more disturbances [60].

Table 3. Comparison of structural characteristics with results from other studies of primary forests.

Region	Altitude	Mean Temperature	Mean Precipitation	Basal Area	Stem Density	DBH	Coarse Woody Debris
	m.a.s.l.	°C	mm	$m^2\ ha^{-1}$	$N\ ha^{-1}$	cm	$m^3\ ha^{-1}$
Slovakia [59]	1350	2.8	1105	41	290	42.4	144
Romania [61]	1250	4.9	755	42.1	348	39.2	-
Romania (Călimani) [15]	1484–1626	2.4–4.0	1100–1650	55.1	565	24.3–39.7	-
Romania (Giumalău) [15]	1430	2.4–4.0	1100–1650	47.3	518	32.3	-
Valea Ucișoarei Present study	1269–1519	4.5	1000	65.54	603	31.8	85.32

The high density of trees and the homogenous age structure of the trees, regardless of their canopy position can be attributed to synchronic recruitment of trees following moderate and high-severity disturbances. Differences in diameter and height increment of trees from the two canopy layers with the same age confirm that suppressed trees may survive up to 150 years under suppression [62].

Overall, the distribution of coarse woody debris decay classes was balanced which agrees with the recent findings of Meigs et al. [60]. Compared to results from another similar study [57], the dead-to-live wood ratio found in our investigation is smaller, probably because of the variability in decomposition factors and a shorter period of decomposition.

In the absence of recent disturbance events, the density of tree recruitment was rather low. In our study, more than half of the regeneration was found on deadwood microsites such as lying logs and decayed stumps. This spruce recruitment pattern is in agreement with previous studies [63]. These microsites are called nurse logs, stipulating the necessary regeneration conditions in cool-wet environments such as high-elevation forests: providing nutrients, moisture, mechanical protection and reducing weed competition [63,64]. The admixture of other species was low, present either in the gaps (*Sorbus* sp.) or under the canopy (*Acer* sp. and *Abies* sp.). The present regeneration and deadwood structures were most likely affected by smaller disturbance events that appeared after the main peaks in disturbances during the last centuries.

4.3. Management Implications

The structural characteristics of primary forests are far more complex than those of managed forests developed under similar site conditions [10,65]. Managed forests with similar site conditions, species and age composition are rare, since usually these forest types are found at high elevation, hard to access. We compared the mean standing volumes of the studied area and of a managed stand with similar site conditions and age structure (Valea Ilvei Management Plan found at the Forest District Unit Valea Ilvei). The standing volume was lower in the managed forest (194–268 $m^3{\cdot}ha^{-1}$), compared to the primary forest (575.55 $m^3{\cdot}ha^{-1}$). We assume that the difference in volume and most likely other differences in structural characteristics between primary and managed forests are due to salvage logging and consequent deadwood removal (Figure 2). This is a common silvicultural operation recommended after windstorms [66], which is being applied also within primary forests that are not strictly protected across many regions in South-eastern Europe [21].

Salvage logging influences not only the standing structure of the forest, but its entire dynamics and biodiversity, altering forest communities [67–69]. By removing the deadwood or damaged trees, the availability and quality of nurse-logs are also affected leading to a decrease in recruitment rate, especially for species such as *Picea abies* [70]. Our findings show a successful regeneration after mixed-intensity past disturbances. In the context of increasing frequency of disturbances due to changing climate [1], these events should not be seen as negative agents in primary forests and their consequences should be allowed to occur without human interference [68,71].

Nowadays, there is a tendency to emulate natural processes for sustainable forest management [7,72]. Ecosystem values of managed forests can be enhanced by incorporating natural disturbance regimes and their biological legacies into the management system [73,74]. However, information on structure and dynamics should be carefully used in such decisions [70]. This study shows that both moderate and high-severity disturbances are within the ecosystem variability of a forest stand in the Făgăraș landscape, but also emphasizes the particular characteristics of primary forests: availability of coarse woody debris and presence of large, old trees. Such biological legacies are not found in the clearcutting systems, which for a long time was considered to mimic stand-replacing disturbances [73] and neither in continuous cover forestry systems since trees are harvested before their biological maturity [75,76].

5. Conclusions

The relationship between the dendrochronological analysis and the structural values in this study clearly indicates that the present state of the studied area resulted from widespread moderate and high-severity disturbances and local mortality events. The release growth and gap recruitment rates show past disturbance synchronicity in the Ucișoara Valley, confirmed by the recent tree density and unimodal age structure in primary spruce forests. Regeneration and thus ecosystem recovery after disturbances profited from deadwood availability and quality.

We conclude that sporadic disturbances are thus within the range of natural variability of mountain spruce forest ecosystems in the Southern Carpathians. To complement our findings, more research is needed in other areas from the Carpathians Mts., and specifically in different forest types (such as pure beech, mixed stands).

This study highlights the importance of the Făgăraș landscape as a representative region for forest natural dynamics. As a result, salvage logging and consequent deadwood removal should not be practiced in these parts of Făgăraș Mts., since its effects will modify the structure of some of the last primary forests found in the European Union [68,77]. Instead, this area should be cherished for its biodiversity, richness of ecological information, and the ecosystem services it provides. We believe that these forest functions, unique to the European continent, are a priority over timber utilization in this region. Therefore, we suggest large-scale nature reserves under strict protection are urgently established in the Făgăraș landscape.

Author Contributions: Conceptualization, M.S., M.M. and A.P.S. conceived the study design, ideas and organized the data collection. A.P.S., M.M. collected the data. A.P.S., P.J., O.V., V.Č. performed the data analysis. A.P.S. led the writing of the manuscript with significant input from I.C.P., M.M. and M.S. All authors contributed critically to the study and gave final approval for publication. All authors have read and agreed to the published version of the manuscript.

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Appendix A

Table A1. Main Stand Characteristics of the Sampled Plots.

Plots	Mean Elevation	Mean Slope	Mean Tree Density	DBH	Mean Height	Mean Basal Area	MEAN Age	Max Age
	m.a.s.l.	°	N·ha^{-1}	cm	m	m^2·ha^{-1}	years	years
P1	1269	34.6	420	42.5	26.3	68.6	126	160
P20	1519	36.1	720	30.9	22.4	62.1	118	177
P23	1506	36.4	450	43.7	25.6	70.9	161	283
P91	1426	32.3	760	32.3	23.1	66.6	185	216
P94	1369	37.5	1320	21.2	18.2	50.5	90	120
P123	1417	38.2	230	38.4	18.5	31.6	131	220
P139	1457	43.2	450	38.8	26.4	61.5	142	219
P148	1361	38.8	360	35.4	23.4	42.5	167	319
P194	1316	38.1	430	37.0	22.5	54.0	168	218
P232	1498	35.6	750	28.4	21.5	50.4	154	343
P256	1307	40.5	520	36.6	23.8	61.1	131	305
P262	1499	37.5	830	28.6	20.7	59.8	99	115

Appendix B

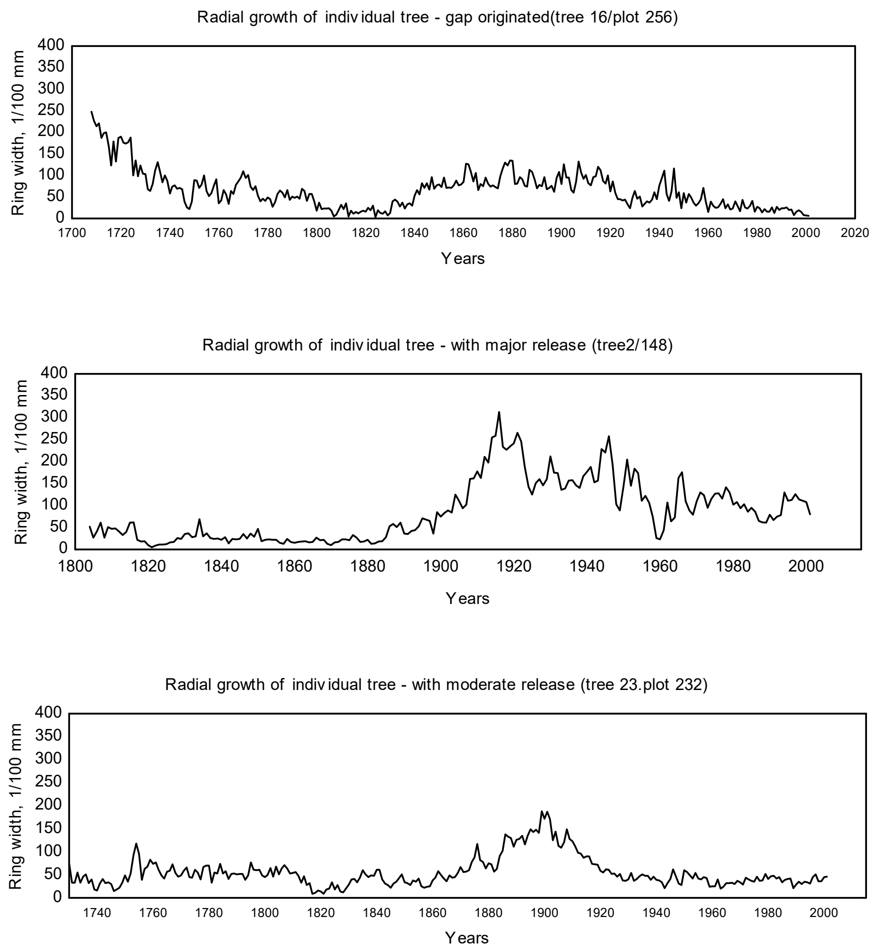

Figure A1. Radial Growth of Individual Trees: (**a**) Gap Originated, (**b**) Showing Major Release, (**c**) Showing Moderate Release.

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