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THE INFLUENCE OF EXTREME WEATHER PHENOMENA ON THE MANAGEMENT OF HARDWOOD TREES

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Abstract

The extreme meteorological phenomena, from the date of 17 09 2017, caused a series of destructions especially in the deciduous stands within the Sudrigiu Forest District, Bihor Forest Department stands, in the western part of the country. As a result, a number of stands of species from the deciduous group were affected in the Văratec Forest Management Unit (FMU) VII, with reported windfalls and wind breaks, on compact surfaces of approximately 929 hectares. The volume of the affected trees, which was inventoried as accidental products, is about 94,000 m^3. The appearance of these by-products seriously disrupted the management of the stands in the affected forest units, causing a series of major disruptions in the valorization process of the main and secondary wood products, with major implications on the regeneration process of the deciduous stands, which was in progress, at that moment. Although substantial amounts of money were recorded during the valorization of accidental wood products, a relatively high percentage of the wood was depreciated and was not recovered at a level corresponding to the main wood products.

Key words: *extreme meteorological phenomena, deciduous stands, accidental products, natural regeneration, secondary wood products.*

INTRODUCTION

The concept of sustainable forest management was developed in the 1990s, emphasizing the equal consideration of ecological, economic, and socio-economic ecosystem functions. However, contemporary society is presenting novel and intricate demands on forests, such as those related to climate change, renewable energy, and biodiversity conservation, which may not always align seamlessly. Policy instruments addressing these societal needs and transforming them into legally binding regulations have extensive implications for forest management, challenging the conventional, non-binding structure of international forest policy (Prins et al., 2023).

Within the forestry strategies, the establishment of some sustainable management criteria to be applied to obtain the expected effect and a series of indicators to reveal the sustainability of the management were foreseen. These indicators can be divided into two large categories (https://www.qdidactic.com/):

- *Quantitative indicators*: the percentage of afforestation, forest area/inhabitant, the volume of standing wood, possibility, accessibility, the amount of wood released on the market, the number of accessory products offered to the industry, turnover, capacity to receive of the public, etc.
- *Qualitative indicators*: the health and vitality of forest ecosystems, the quality of the factors improved by the forest eco protection, the weight/ratio of intensive treatments, the origin and provenance of stands, the incidence of damaging factors, the fertility of the forest soil, biodiversity indicators (the presence of secular virgin, natural and semi-natural forests, the proportion/rate of mixed stands, the volume of dead wood in the forest, the share/ratio of natural regeneration, the proportion/rate of indigenous and introduced exotic species, rare or endangered species), conservation of forest genetic resources, etc.

Carefully analyzing the two categories of indicators of sustainable management, the differentiation of the two concepts of *conservation* (expressed mainly through qualitative indicators) and *development* (expressed through quantitative indicators), concepts nuanced by the principle of sustainable evolution can be noticed (https://www.qdidactic.com/bani-cariera/).

The intensification of the effects of climate change urgently requires addressing the determinants of this phenomenon, particularly greenhouse gas emissions. Forests provide an efficient solution due to their capacity to store and reduce carbon emissions. In Romania, achieving a balance between forest exploitation and environmental conservation and protection is imperative, considering the significant economic contribution of forestry and wood-based industries to the country's GDP (approximately 5%) and employment for about 300 thousand people, representing 6% of the active workforce (Chivulescu et al., 2024).

The effects of climate change are felt more and more throughout the planet, having an impact on the natural environment, the global and regional economy, but also on people's social life. Among the most obvious effects are listed: the increase in the frequency of droughts and floods, the intensification of extreme weather phenomena, the melting of mountain glaciers and ice caps, the rise of the Planetary Ocean level, etc. Rising global temperatures have contributed to an increase in the frequency and intensity of extreme weather phenomena such as heat waves, thunderstorms, tornadoes, hurricanes, droughts, torrential rains, hail, etc. (Măhăra, 2006).

Extreme weather phenomena can have a major impact on people, both in the short term, through the large number of victims and property damage, and in the medium or long term, through the effect on land degradation and the reduction of its productive potential, through the destruction of natural habitats (Grecu, 2016). Extreme weather phenomena have negative effects in the field of agriculture, forestry, land improvements, water management, environmental protection, etc.

In recent decades, the intensification of extreme weather phenomena has also been observed in Romania, including in the western part of the country (Cristea, 2004; Șerban, 2010; Tudose et al., 2016), where our study area is located. The intensification of storms is also due to local relief conditions, there. The positioning of the Apuseni Mountains range from north to south causes the masses of moist, oceanic air, coming from Western Europe, to suddenly cross the mountains, which intensifies the storms on the western side of the Apuseni Mountains (where our study area is also located) (Șerban, 2010).

Climate change and environmental pollution are increasingly affecting forest ecosystems (Šimonovičová et al., 2019). Extreme weather phenomena, especially storms, represent a threat to forest ecosystems through the windthrows they generate. This aspect is increasingly studied by many researchers (Ruel, 2020; Giannetti et al., 2021; Konôpka et al., 2021; Ritter et al., 2022; Bozzini et al., 2023; etc.). Many studies focus on the issue of the resistance of stands types to windthrows (Nolet & Béland, 2017; Rukh et al., 2020; Krišāns et al., 2020). Other studies analyze the forest area affected by windthrows and the severity of the damage (Goff et al., 2021; Zhang et al., 2021) or the impact of post-disturbance management on forest stands, presenting various forest regeneration models (Ruel, 2020; Konôpka et al., 2021; Costa et al., 2021).

The storms affected large areas of forest in Romania as well. Such was the severe storm of September 17, 2017, which affected several countries in central and south-eastern Europe, especially Serbia and Romania. Due to the large area of the damage swath (at least 500 km long) and strong wind gusts (up to 40 m/s), it was considered similar to a derecho (Sipos et al., 2021).

In the west of the country, the storm caused windthrows on an area of more than 700 ha of forest only within the Sudrigiu Forest District, Bihor County Forest Administration (Sicoe et al., 2023). As a result, these extreme weather phenomena have significantly affected the management of the forest district. In this context, a percentage of the timber volume that was scheduled to be harvested during the 2017-2024 period according to the management plan was affected, and the remaining portion was not harvested (Crainic et al., 2023).

In the current context of global changes and interconnection, forest management needs to present a continuous evolution adapted to contemporary challenges. Consequently, one of the main challenges in forest management is represented by the sustainability of forest resources and the need to preserve the biological diversity of forests (Dinca & Zhiyanski, 2023). Consequently, sustainable forest management

offers long-term benefits, both economically and ecologically (Crişan et al., 2024).
The objectives of the case study refer to the analysis and study of the influence of extreme weather phenomena on forest management within management unit VII Văratec. As a result, the affected stands and the resulting incidental timber products will be identified, evaluated, and analyzed.

MATERIALS AND METHODS

The case study was carried out in the stands affected by extreme weather events within the management unit (PU) VII Văratec, managed by the Sudrigiu Forest District, within the Bihor County Forest Administration. The period during which the research and studies were conducted is from September 2017 to the present. Part of the research activities were carried out in the framework of a research project coordinated by specialists from the Department of Forestry and Forest Engineering, Faculty of Environmental Protection, University of Oradea, in collaboration with the forestry staff of the Sudrigiu Forest District, Bihor County Forest Administration.
In this context, affected stands have been surveyed and analysed, where regeneration works and cultural operations (care felling) are planned, according to the forest management plan in force (Crainic et al., 2023).
The research methods used are: bibliographic documentation, route observation, stationary observation, experimentation, full inventory, comparison, analysis, simulation and digital image recording (Crainic et al., 2022).
For the assessment of the affected stands, a complete inventory of the affected trees was carried out. These are represented by broken trees (partially and fully) and uprooted and fallen trees (Figure 1). The situation of natural regeneration in the stands that are currently being felled for regeneration under the stand and included in the forest management plan was also analysed. As a result, the areas where natural or mixed forest vegetation is needed in these stands have been identified, assessed, and analysed.
Following the complete inventories of all affected trees in the studied stands, the data were processed with the specialized software FOND and SUMAL, within the Sudrigiu Forest District, Forest Fund Department, thus obtaining the volume of wood related to trees blown down and broken by the wind.

Figure 1. Stand affected by extreme weather events in stand 104 A

The stand damage index i_{as}, according to the total volume of affected wood for each stand, was determined with the formula:

$$i_{as} = \frac{V_{extracted}}{V_{stand}} \quad (1)$$

where:
- i_{as} is the stand damage index;
- $V_{extracted}$ represent the volume of affected trees that has been inventoried and will be extracted;
- V_{stand} is the total volume of the stand at the time of the inventory of affected trees, which represents the volume of the stand when the V_{fm} forest management came into force, i.e. in 2014, plus four annual increases (until 2017) i_{va}, when the inventory is carried out (Crainic et al., 2023).
As a result,

$$V_{stand} = V_{fm} + 4i_{va} \quad (2)$$

The stand damage index was then used to determine the average degree of damage to the production unit. It was also used to determine the affected areas on which forest vegetation would need to be installed. The stand damage index is applied to the stand area, which is mentioned in the forest management plan, and the following formula is used to obtain the affected area:

$$S_{affected} = S_{fm} \cdot i_{as} \quad (3)$$

where:
- $S_{affected}$ is the area affected;
- S_{fm} represent the area of the plot in the forest management.

The determination of the affected areas, according to the algorithm presented, was carried out in the EXCEL spreadsheet calculation program. After determining the affected areas, the areas on which the regeneration process was carried out, and the areas on which the installation of forest vegetation was necessary, were determined on the basis of field data. These data were recorded in specially prepared sheets, through direct observations in the field and qualitative and quantitative evaluations, analysing in parallel the forest management plan and the forest map. These elements are used for the preparation of the future management plan for the period 2024-2033.

RESULTS AND DISCUSSIONS

The volume of wood that has been determined to be harvested in the period 2014-2023, according to the forest management plan, in the Sudrigiu Forest District is 57855 m^3 (Table 1). From the analysis of the data in Table 1, the opportunity for the management unit VII Văratec for the period 2014-2023 is 35761 m^3, i.e. 62% of the total opportunity of the forest district for the period mentioned.
Up to September 17, 2017, within the P.U. VII Văratec, a volume of approximately 13853 m^3 has been harvested (exploited), which represents 38.7% of the total possibility of the production unit. The volume exploited from S.U.P. A by applying regeneration cuts represents 97%, and the difference of 3% was exploited from S.U.P. M by applying conservation cuts (Figure 2).

Table 1. The possibility for the period 2014-2023, related to Sudrigiu Forest District

Management unit No.	Management unit Designation	S.U.P.	Possibility (m^3)
II	Aleu	A	4100
		M	4496
IV	Chișcău	A	8010
		M	5488
VII	Văratec	A	35401
		M	360
		K	0
Total Sudrigiu Forest District			**57855**

The volume of affected trees was calculated on the basis of their inventories, and classified according to the type of wood products obtained.

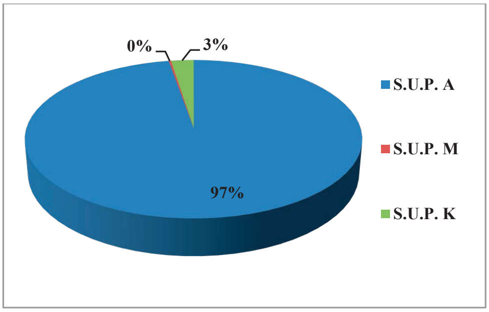

Figure 2. Volume of timber harvested up to September 17, 2017, from P.U. VII Văratec

Volume of Incidental Overlapping Products
Affected trees that have been inventoried in stands that are included in the ten-year primary product plan constitute incidental overlapping wood products. These are assimilated as main wood products (which are harvested during regeneration of stands) and are pre-counted from the possibility of main products (Crainic, 2023; Crainic, 2017) (Figure 3).

Figure 3. Incidental wood products I in the stand of plot 110

The stands in plots 35C and 107 are included in the ten-year forest management plan in regeneration urgency I, with a consistency index $k \leq 0.3$. As a result, the natural regeneration process in these stands is relatively advanced, with the area occupied by natural regeneration being about 70% of the plot area.
The analysis of the results in Table 2 shows that the volume affected in the two strands is 1152 m^3 and the total area affected is 8.58 ha.

Table 2. Evidence of overlapping adventitious products in stands included in regeneration urgency I

Plot	V_{amenaj} (m^3/u.a.)	S_{amenaj} (ha)	V(m^3/u.a.)		i_{as}
			V_{actual}	V_{extras}	
35C	540	7.29	577.908	95	0.16
107	2356	15.30	2453.920	1057	0.43
Total	**2896**	**22.59**	**3031.828**	**1152**	**0.38**

The stands in the plots shown in Table 3 are included in the ten-year main product plan - regeneration, in urgency II, and the consistency index k has values in the range 0.4-0.7. The process of natural regeneration is actively dynamic, with natural regeneration installed on about 50% of their area. Analysing the results presented in Table 3 it can be seen that the volume of affected trees in the seven stands is 2962 m^3 and the affected area is 11.09 ha.

Table 3. Evidence of overlapping by-products in stands included in regeneration emergency II

Plot	V_{amenaj} (m^3/u.a.)	S_{amenaj} (ha)	V(m^3/u.a.)		i_{as}
			V_{actual}	V_{extras}	
97B	1961	6.74	2036.488	155	0.08
99B	105	0.4	109.160	167	1.53
102B	4524	17.07	4776.636	1819	0.38
108A	1028	5.17	1087.972	44	0.04
108B	195	0.84	206.424	46	0.22
113C	8105	28.95	8498.720	365	0.04
114C	2678	14.79	2896.892	366	0.13
Total	**18596**	**73.96**	**19612.292**	**2962**	**0.15**

The stands in the plots shown in Table 4 are included in the ten-year plan of main products, in the third urgency, and their consistency index k varies between 0.7 and 0.8. In these plots, the natural regeneration process has been triggered, due to abundant fructification in recent years. The volume of affected trees in the six stands analysed is 3573 m^3, the affected area being 9.43 ha.

Table 4. Evidence of overlapping by-products in stands included in regeneration emergency III

Plot	V_{amenaj} (m^3/u.a.)	S_{amenaj} (ha)	V(m^3/u.a.)		i_{as}
			V_{actual}	V_{extras}	
100B	266	1.00	278.800	104	0.37
110	10537	30.72	11053.10	1954	0.18
114B	201	0.80	213.160	10	0.05
115B	2677	7.52	2824.390	273	0.10
121B	5154	14.94	5416.940	1022	0.19
312A	6476	17.55	6714.68	210	0.03
Total	**25311**	**72.53**	**26501.070**	**3573**	**0.13**

The volume of accidental wood products over the stands included in the ten-year regeneration plan, in the three emergencies, is 7687 m^3. This represents 21.50% of the volume of wood that has been set to be recovered in the period 2014-2023. Broken down by emergency, the volume of affected stands included in emergency III represents 46% of the assessed volume, that included in emergency II represents 39%. The volume of affected stands included in Emergency I represents 15% of the assessed volume, as they are in the final stage of application of regeneration felling below the tree stand (Figure 4).

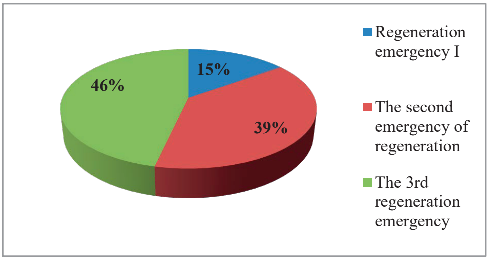

Figure 4. Volume of overlapping accidental products by regeneration urgencies

Volume of Incidental Products

In accordance with the technical rules in force for the national forestry fund, wood products resulting from damage to stands caused by extreme weather events, insect attacks, fires, etc. constitute incidental wood products (Figure 5).

Figure 5. Incidental wood products I in the stand of plot 111

If the age of the affected stands is more than half of the harvestable age (of the production cycle), the resulting incidental wood products are called incidental I products, and are assimilated as main products (Crainic, 2023).
As a result, these wood products are pre-counted from the ten-year possibility of main products, which has been established according to the forest management plan in force.

Volume of Incidental Products I

The affected stands shown in the plots in Table 5 are more than half the age of exploitability.

Accordingly, the timber products assessed in these are considered incidental timber products I and are therefore pre-counted from the possibility of main products (Figure 6).

Table 5. Evidence of incidental products I in affected stands

Plot	V_{amenaj} (m^3/u.a.)	S_{amenaj} (ha)	V(m^3/u.a.)		i_{as}
			V_{actual}	V_{extras}	
34B	1270	3.64	1367.552	137	0.10
34C	1124	3.03	1182.176	64	0.05
35A	5235	13.12	5639.096	1254	0.22
35B	750	2.93	810.944	45	0.06
52	882	3.34	951.472	381	0.40
72B	7586	23.56	7896.992	2477	0.31
73B	5075	15.52	5273.656	715	0.14
73C	340	3.24	409.984	13	0.03
94A	5954	22.3	6498.120	1763	0.27
94B	221	0.64	230.984	111	0.48
94C	307	0.89	320.884	145	0.45
95A	6220	16.95	6592.900	2621	0.40
96A	1541	4.27	1640.064	896	0.55
98B	11935	32.61	12417.628	2328	0.19
99A	8160	22.54	8664.896	2654	0.31
100A	7659	22.46	8081.248	1601	0.20
101A	12863	30.92	13506.136	4105	0.30
101B	342	1.23	358.236	137	0.38
102A	3919	9.42	4114.936	1281	0.31
102C	2456	5.47	2585.092	1130	0.44
103A	8861	26.14	9572.008	2806	0.29
104A	11314	35.58	12139.456	5247	0.43
105A	8601	23.63	9215.380	863	0.09
109B	6408	18.79	6911.572	2750	0.40
111	10627	28.19	11258.456	4351	0.39
112A	5316	17.84	5729.888	774	0.14
112B	234	0.55	261.720	220	0.84
113D	579	1.36	637.208	346	0.54
114A	5265	16.35	5709.720	1615	0.28
116A	6330	15.63	6611.340	753	0.11
117A	9654	27.9	10290.120	3058	0.30
118B	3457	12.48	4026.088	1588	0.39
119B	1025	2.14	1146.552	923	0.81
119C	12344	39.82	13427.104	828	0.06
120A	9229	24.81	9814.516	136	0.01
122B	10089	27.49	10979.676	2865	0.26
123A	4602	15.04	5023.120	294	0.06
124A	19567	50.3	21035.760	1573	0.07
124B	746	1.75	834.200	26	0.03
125A	2037	5.46	2279.424	660	0.29
125B	6599	17.74	7017.664	234	0.03
126A	2702	7.34	2857.608	146	0.05
126B	3430	9.42	3641.008	216	0.06
126C	1149	3.29	1234.540	103	0.08
140B	5463	18.21	5725.224	147	0.03
141	5796	18	6055.200	307	0.05
312B	171	0.75	195.000	6	0.03
326	10015	39.9	11148.160	942	0.08
327	12021	42.03	13382.772	2237	0.17
328	3551	15.24	3983.816	421	0.11
329A	9409	32.9	10474.960	202	0.02
329C	519	1.38	562.056	11	0.02
330A	521	2.7	595.520	4	0.01
330B	464	0.97	515.992	18	0.03
330C	9818	36.91	11028.648	19	0.002
331	7713	36.73	8917,744	16	0.002
Total	**299465**	**912.84**	**322782.216**	**60563**	**0.19**

Figure 6. Incidental wood products I, in the stand of plot 105 A

From the analysis of the records presented in Table 5, the volume of affected trees inventoried in the 56 stands is 60,563 m^3 and the actual area affected is 173.44 hectares.
The average degree of damage of these stands is i_{as} = 19% of the total volume at the time of the extreme weather events.
The accidental products I (Figure 6) were recovered in several stages, depending on how they were identified, inventoried, and assessed.

Volume of Incidental Products II
If the age of the affected stands is less than half of the harvestable age, the resulting incidental wood products are called incidental products II and are not assimilated as main products (Crainic, 2023). The affected stands in the plots shown in Table 6 are less than half of the harvestable age.

Table 6. Record of affected stands in plots from which incidental products are harvested II

Plot	V_{amenaj} (m^3/u.a.)	S_{amenaj} (ha)	V(m^3/u.a.)		i_{as}
			V_{actual}	V_{extras}	
34 A	3075	12.71	3507.14	192	0.05
72 A	808	5.18	990.34	50	0.05
98 A	1847	8.63	2285.40	112	0.05
329 B	942	2.54	1064.94	89	0.08
Total	**6672**	**29.06**	**7847.82**	**442**	**0.06**

As a result, the wood products inventoried and evaluated in these stands are considered incidental wood products II (Figures 7 and 8).
The volume of incidental wood products II assessed in the affected stands is 442 m^3 and the actual area affected is 1.74 ha (Table 6).
According to the diagram in Figure 9, it can be seen that the volume of incidental product I has the highest share of 88%, overlapping incidental products account for 11% of the assessed volume and incidental product II has only 1%. Although spruce stands are vulnerable to the destabilizing actions of prevailing winds, in this study, deciduous stands were considerably damaged.

Figure 7. Incidental wood products II in the stand of plot 34A

Figure 8. Incidental wood products II in the stand of plot 34A

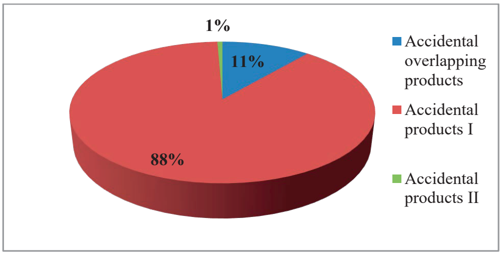

Figure 9. Percentage of valued wood products in affected stands

As a result, beech and gorun trees were uprooted and broken in a relatively high proportion (Figures 10 and 12). Spruce stands, growing in the study area outside the natural range of this species, being mostly artificial stands, were affected to a lesser extent. Most of the spruce trees were broken, at different heights, which shows that they had a console-dated rooting system (Figures 11 and 13).

The recovery of the assessed incidental products was carried out under conditions of high economic efficiency. Although most of the time these wood products are of questionable quality, in this study the value obtained is high. Beech wood was valued at an average price of 250 lei/m^3 and gorun wood at an average price of 450 lei/m^3. A percentage of 15% of the volume of incidental products was recovered on its own account, thus obtaining an average value of 300 lei/m^3.

Figure 10. Stand in plot 110, beech, affected by windthrow and windthrow breakage

Figure 11. Spruce stand, plot 125A, affected by wind breaks

The high volume of incidental I and overlying products assessed in P.U. VII Văratec has been partially precounted from the unreclaimed volume in the 10-year plan for the period 2014-2023. As a result, the difference in volume that has not been pre-computed will influence the volume of timber that will be determined to be harvested in the following decades (2024-2033, 2034-2043, etc.).

Figure 12. Stand in plot 110, beech, affected by windthrow and windthrow breakage

Figure 13. Spruce stand, plot 124B, affected by wind breaks

The proposed forest management plan for the period 2024-2033, foresees in most of the affected stands, where regeneration works are needed, only hygienic felling. The volume of wood predicted to be harvested during these interventions is relatively small, about 1 m^3/year/ha. In addition, stands that are included in regeneration emergency I, regeneration felling and specific works for the installation and management of natural regeneration are proposed in the decade 2024-2033. Given the considerable areas from which incidental products have been harvested, specific works for the re-establishment of forest vegetation are proposed in the forest management plan for the period 2025-2035. This will ensure that the principle of continuity in time and space is respected.

CONCLUSIONS

The extreme weather events of September 17, 2017 caused considerable damage to the stands in the P.U. VII Văratec, administered by the Sudrigiu Forest District.

As a result, there were windthrow and wind breakages. The incidental wood products that have been identified, assessed and recovered are located in a high proportion in deciduous stands, consisting of beech and gorun species.

The volume of incidental products I represents 88% of the total volume of incidental products assessed, in P.U. VII, during the case study. Consequently, stands older than half the age of exploitability are found to be vulnerable to the destabilising actions of prevailing winds and strong storms.

In stands that have been coppiced for regeneration, the volume of incidental overlapping products accounts for 11% of the total volume assessed. The volume of by-products II represents 1% of the assessed volume, so that stands less than half the age of exploitability have a high stability to the action of destabilising factors.

Artificial spruce stands in P.U. VII Văratec, although growing outside or at the limit of the range of this species, were affected to a relatively small extent. In this context, they were mostly affected by wind breaks.

The impact of extreme weather events on the management of P.U. VII Văratec is particularly strong. As a result, the volume of timber to be harvested will be considerably reduced in the coming decades. The silvicultural interventions that will be proposed in the management plan for the decade 2024-2033 in the affected stands will be reforestation and hygiene works.

In the stands that have been included in regeneration emergency I during 2014-2023, natural and mixed regeneration works will be completed.

Although incidental wood products have been optimally harvested, the economic efficiency of the activities to be carried out in the P.U. VII Văratec will be affected in the coming decades. As a result, part of the necessary works will be financially supported by the Sudrigiu Forest District and the Bihor County Forest Administration.

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