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ORIGINAL RESEARCH ARTICLE

The main costs of natural disasters in the Forest District of Węgierska Górka

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Abstract. The aim of the study was to determine the impact of increased forest management due to natural disasters on particular core unit costs. We analysed the direct costs for the Forest District of Węgierska Górka in the years 2004–2010 based on information from the State Forests lnformation System (SFIS) database compared with selected forest districts within the Regional Directorate of State Forests in Cracow (RDSF). The forest districts were divided into two groups with two and six forest districts and confidence intervals around the mean were determined and the significance of linear regressions of the considered characteristics was tested. Additionally, the growth rate (decrease) of the unit cost was calculated. Our studies showed that natural disasters affect only certain unit costs regardless of the intensity of the forest management. The increase in unit costs resulted in economic losses in forest management. A full long-term analysis of the economic impact of natural disasters should be done, taking into account the cost of reforestation of destroyed areas which may become apparent only some years later.

Key words: natural disasters, the core activity of Forest District, unit costs, the synthetic index of costs

1. Introduction

Natural disasters in forests usually result in increased forest management activities and simultaneous increase in costs acquired and decline in profits from timber sales. However, economic effects of natural disasters cannot be fully forecasted and their level and economic significance could not be evaluated due to diversity of random events, their intensity, spatial distribution, time span and also elements surrounding forest economy. At the same time, it should be mentioned that natural disasters are an integral part of forest management and their economic analysis should be implemented on a wide scale in order to minimize negative effects in the future.

Negative circumstances related to natural disasters in the Beskid Mountains forests, which included hurricanes in 2004 and 2007 as well as damages from European spruce bark beetle (*Ips typographus*), resulted in larger volumes being harvested than those accepted in the forest management plan of 2004–2013 for the Forest District of Węgierska Górka. Planned harvest of the large-diameter timber for that period was equal to 1 032 680 m^3 net, while at the end of 2009 volumes harvested already reached the level of 1 163 933 m^3. At the same time, the largest volume harvested was reached in 2007, which was equal to 278 thousand m^3 corresponding to harvest three times higher than annual average. As a result of sanitary thinnings, the average volume per hectare decreased from 354 (in 2006) to 132 m^3/ha (in 2009) and the average stand age decreased from 73 (2006) to 47 years (Annex to forest management plan, 2009).

The literature on related topics presents the opinion that natural disasters result in larger extent of forest management activities with simultaneous increase in unit

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costs (Kaliszewski 2009; Kuc 2011; Szabla 2011). However, the level of those costs is affected by many factors related to forest management, which are hard to identify. Foreign authors present similar arguments (Bláha 2002; Baur et al. 2003; Svensson et al. 2011). Still, not enough attention is paid to the economic effects of natural disasters and especially their long-term analysis.

The goal of the current work was to evaluate the impact of wider forest management activities after natural disaster in the Forest District of Węgierska Górka on the development of selected unit costs of basic forest management activities in 2004–2010.

2. Research methods

Analysis of unit prices of basic forest management activities

The research included eight types of costs related to basic forest management activities in the Forest District of Węgierska Górka, which had the highest share of total costs or, respectively, from 93% (2004) to 97% (2007). The analysis covered the direct costs acquired during the financial years of 2004–2010. The data were obtained from the State Forests Information System (SILP).

The following unit costs were included:

– Costs of forest protection (PLN/ha) – the quotient of total forest protection costs to the area of forest district. All costs presented under the bookkeeping record 'Protection of forest from damage-causing elements', which included limiting the number of forest pests and fungi as well as protection from animal damage (Banasik et al. 2010).

– Costs of forest infrastructure maintenance (PLN/ha) – quotient of total infrastructure maintenance costs to the area of forest district. The costs from the bookkeeping record 'Maintenance of forest roads' were used and included mainly forest roads and water melioration objects (Banasik et al. 2010).

– Costs of forest amelioration (PLN/ha) – quotient of forest amelioration in total to the area covered by melioration during given year. Those costs were registered within the bookkeeping record 'Silvicultural activities' and included cleaning of harvest areas and supplementary melioration activities (Banasik et al. 2010).

– Costs of regeneration and afforestation together with costs of stand conversion (PLN/ha) – quotient of the above total to the area covered by those activities during the given year. The above costs were registered within the bookkeeping record 'Silvicultural activities' and included costs of soil preparation, cost of seedlings and planting, as well as costs related to conversion of tree stands affected by damage causing elements (Banasik et al. 2010).

– Costs of supplementary planting (PLN/ha) – quotient of total supplementary planting costs to the area covered by them in the given year. Those costs were registered under the bookkeeping record 'Silvicultural activities' and included cost of seedlings and activities necessary for their planting at the areas where in previous years regeneration or afforestation has been implemented (Banasik et al. 2010).

– Costs of stand tending (PLN/ha) – quotient of total stand tending costs to the area covered by tending in given year. Those costs were registered under the bookkeeping record 'Silvicultural activities', which included among others soil tending and pre-commercial thinning (Banasik et al. 2010).

– Costs of tree felling and bucking (PLN/m^3) – quotient of total tree felling and bucking costs to the volume of harvested timber in given year. Those costs are included in the bookkeeping record 'Timber logging' (Banasik et al. 2010).

– Costs of timber skidding (PLN/m^3) – quotient of total skidding costs to the volume of harvested timber in given year. Those costs are registered under the bookkeeping record 'Timber logging' (Banasik et al. 2010).

Calculation of the synthetic cost indicator

Evaluation and classification of each forest district was implemented using the synthetic cost indicator (*SWK*), which orders various objects (forest districts) according to the level of researched characteristics (unit costs) describing a study even in given years (2004–2010). Synthetic cost indicator was calculated using the following equation, as it was suggested among others by Nowak (1990):

$$SWK_i = k^{-1} \cdot \sum_{k=1}^{k} z_{ij}; \quad (i = 1,\ldots,N) \tag{1}$$

where z_{ij} – is the normalised value of the j characteristic within the i unit, k – the number of diagnostic characteristics and N – the number of forest districts.

Normalisation of researched characteristics (all observed diagnostic characteristics were treated as incentives) was done using equation (2), as suggested among others by Nowak (1990):

$$z_{ik} = \frac{x_{ij}}{\max_i \{x_{ik}\}}; \quad \max_i \{x_{ik}\} > 0 \tag{2}$$

where x_{ij} is the exit value of the j characteristic within the i unit.

The synthetic value can vary within the interval [0, 1]. The closer the *SWK* value was approaching to one, the higher were analysed the costs of basic silvicultural activities and the more unfavourable was economic situation for the studied characteristics. Final classification of forest districts was based on *SWK* values, on the arithmetic mean (*SWK* mean) and on the standard deviation SD (*SWK*) of the synthetic attribute in given years. Based on the above information, four classes were identified:
– 1st class (low costs) when:
SWK<mean *SWK*–*SD* (*SWK*).
– 2nd class (lower average costs) when:
mean *SWK*–*SD* (*SWK*) ≤ *SWK*<mean *SWK*.
– 3rd class (higher average costs) when:
mean *SWK* ≤ *SWK*<mean *SWK* + *SD* (*SWK*).
– 4th class (high costs) when:
SWK ≥ mean *SWK* + *SD* (*SWK*).

Statistical analysis

Economic consequences of natural disasters in the Forest District of Węgierska Górka were studied in relation to forest districts located in the Kraków Regional Directorate: Krościenko, Limanowa, Łosie, Myślenice, Nawojowa, Nowy Targ, Piwniczna and Stary Sącz. The listed forest districts are mainly located in the Beskid Sądecki and Gorce Mountains and are similar to the Węgierska Górka forest district in their geographic, natural and economic conditions. At the same time, those forest districts differed in their volume of harvested timber during the 2004–2010 period. Harvesting volume could have an influence on the level of evaluated economic parameters, so accuracy of grouping of forest districts was also evaluated. Two sets of forest districts similar in their harvested timber volumes were established based on the hierarchical cluster analysis using a method of single-linkage clustering (Florek et al. 1951) and the Euclidean distance as a measure of distance between observations. Those sets were as follows: (1) Krościenko, Limanowa, Stary Sącz, Nawojowa, Piwniczna and Łosie (the set of six forest districts) and (2) Myślenice and Nowy Targ (the set of two forest districts).

Statistical analysis of selected unit costs of the basic silvicultural activities was consequent to the adopted grouping of compared units. The 95% confidence interval for the means in given years was adopted for the set of six forest districts. Whereas means only were calculated for the set of two forest districts due to the small sample size. The significance of linear trends of the studied characteristics in both sets of forest districts was established using the F-test. The analysis was implemented using the statistical package STATISTICA 10.0 (StatSoft 2011).

The rate of growth (decline) was calculated for eight analysed unit costs of the basic silvicultural activities in the Forest District of Węgierska Górka and for the two adapted sets of forest districts located in the Kraków Regional Directorate.

3. Results

Unit costs of forest protection in the Forest District of Węgierska Górka significantly differed from the mean unit costs of the six forest districts set in the Kraków Regional Directorate and were from 42.81 PLN/ha (2010) to even 263.89 PLN/ha (2008) higher (Fig. 1). Unit costs of the Forest District of Węgierska Górka were also higher from 12.94 PLN/ha (2010) to 224.42 PLN/ha (2008) than mean unit costs calculated for the set of two forest districts. Natural disasters resulted in evident increase of analysed costs in the Forest District of Węgierska Górka to their highest level equal to 283.83 PLN/ha (2008). In the following years, there was sharp drop in costs to the level of 72.59 PLN/ha (2010), which could be explained by the recession of causing agents. The mean costs of the six forest districts set as well as two forest districts set showed statistically significant (in both cases $p < 0.05$) linear growing trend (Fig. 1).

Unit costs of forest infrastructure maintenance in the Forest District of Węgierska Górka were higher than mean costs calculated for the set of six forest districts from 52.95 PLN/ha (2004) to 265.27 PLN/ha (2010). Those costs were also from 12.94 PLN/ha (2010) to 224.42 PLN/ha (2008) higher than mean costs calculated for the set of two forest districts with the exception of the year 2005 (when costs were 79.61 PLN/ha lower). Unit costs of forest infrastructure maintenance in the Forest District of Węgierska Górka were constantly growing during the analysed period from 123.37 PLN/ha (2004) to 377.87 PLN/ha (2010) with the statistically significant linear growing trend ($p < 0.05$) (Fig. 2).

Unit costs of tree felling and bucking in the Forest District of Węgierska Górka were from 0.39 PLN/m^3 (2010) to 5.16 PLN/m^3 (2008) higher or, respectively, 1.6% and 21.4% than similar costs calculated for the set of six forest districts (Fig. 3). The analysed costs of the Forest District of Węgierska Górka were also from 0.05 (2005) to 3.91 PLN/m^3 (2007) or, respectively, 0.2% and 17.1% higher than similar costs received for the set of two forest districts with the exception of the year 2010

(when costs were higher 1.67 PLN/m^3 or 6.6%). The analysed unit costs in the Forest District of Węgierska Górka increased by 11.2% in 2005 and 22.4% in 2007 (Table 2) as a consequence of natural disaster damages removal. During the last years, there was a significant drop in costs compared with the year 2008, when the costs decreased to the level of 25.15 PLN/m^3 (2010). During the study period statistically significant linear growing trends were

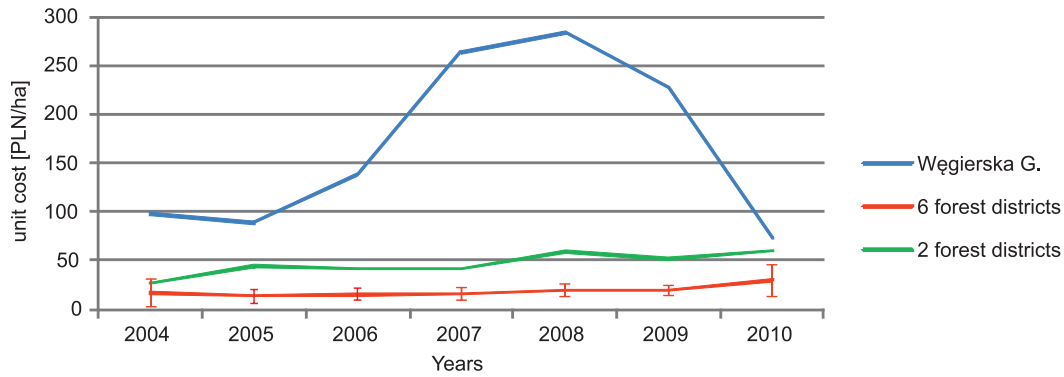

Figure 1. Current unit cost of forest protection (PLN/ha) in the Forest District of Węgierska Górka and selected forest districts in the years 2004–2010 (note: Figures from 2 to 8 show a further average of the confidence intervals for the six forest districts and the average for the two forest districts)

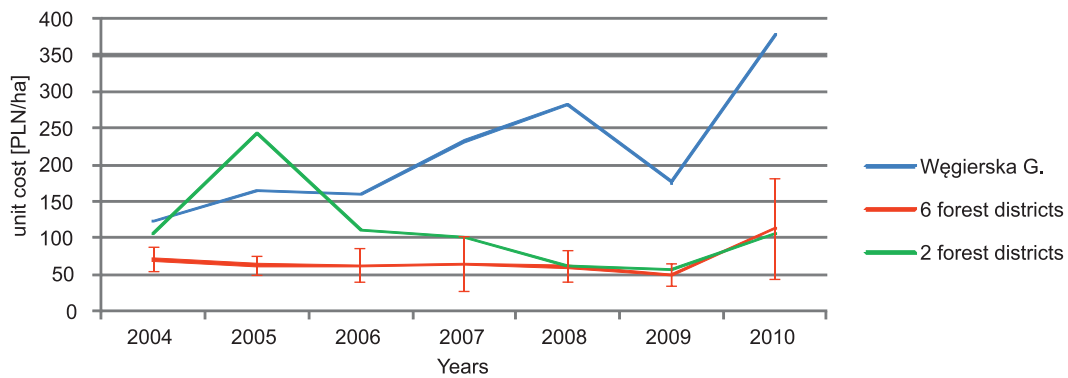

Figure 2. Current unit cost of maintaining of forest infrastructure (PLN/ha) in the Forest District of Węgierska Górka and selected forest districts in the years 2004–2010

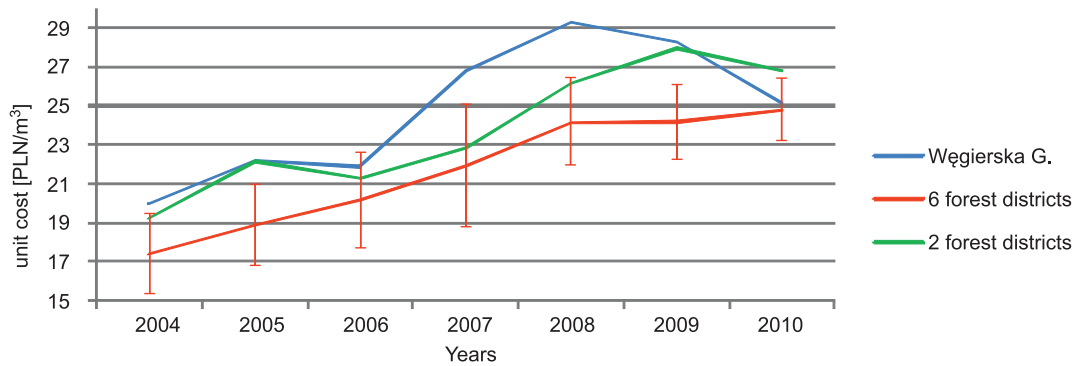

Figure 3. Current unit cost of timber felling and bucking (PLN/m^3) in the Forest District of Węgierska Górka and selected forest districts in the years 2004–2010

noted for the Forest District of Węgierska Górka ($p < 0.05$) and the two analysed sets of forest districts (set of six $p < 0.001$; set of two $p < 0.01$) (Fig. 3).

Unit costs of timber skidding in the Forest District of Węgierska Górka were from 0.38 PLN/m^3 (2005) to 5.56 PLN/m^3 (2010) or, respectively, 1.3% and 12.2% lower than mean costs calculated for the set of six forest districts with the exception of the year 2004 (the costs were 2.57 PLN/m^3 or 9.9% higher) (Fig. 4). However, the Węgierska Górka costs were from 0.63 PLN/m^3 (2006) to 6.28 PLN/m^3 (2004) or, respectively, 2% and 28% higher than mean unit costs calculated for the set of two forest districts with the exception of the year 2005 (costs were 1.1 PLN/m^3 or 3.7% lower). Unit costs of timber skidding in the Forest District of Węgierska Górka gradually increased from 28.65 to 40.08 PLN/m^3, showing a statistically significant linear trend ($p < 0.001$), which was similar to the compared sets of forest districts (set of six $p < 0.001$; set of two $p < 0.01$). The rate of growth was also similar in all sets of forest districts (Table 2).

The unit costs of forest amelioration in the Forest District of Węgierska Górka were several times higher (from 3121.32 PLN/ha in 2007 to 8300.15 PLN/ha in 2005) than costs of the six forest districts sets (Fig. 5). In the same years, they were also higher (from 2786.04 to 7793.08 PLN/ha) than mean unit costs of the two forest districts sets. In other two studied years, the Forest District of Węgierska Górka costs were similar to the compared sets of forest districts. In the Forest District of Węgierska Górka forest, amelioration costs were subjected to periodic fluctuations (Table 2). Only for the set of six forest districts, the statistical analysis showed statistically significant ($p < 0.01$) growing trend (Fig. 5).

Unit costs of regeneration and afforestation together with stand conversion in the Forest District of Węgierska Górka were somewhat higher from 26.16 PLN/ha (2007) to 1302.68 PLN/ha (2004) or, respectively, 0.5 and 46.7% than mean unit costs of the six forest districts set with the exception of the year 2006 (costs were 420.85 PLN/ha or 8.2% lower (Fig. 6). At the same time, the anal-

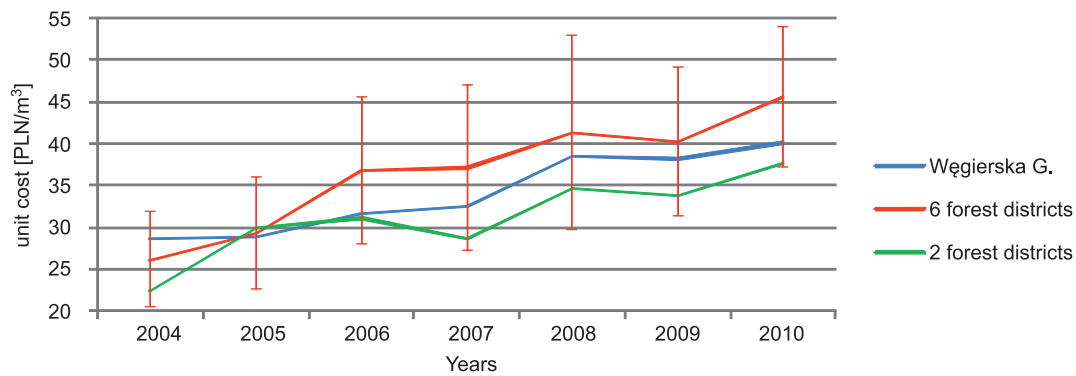

Figure 4. Current unit cost of timber skidding (PLN/m^3) in the Forest District of Węgierska Górka and selected forest districts in the years 2004–2010

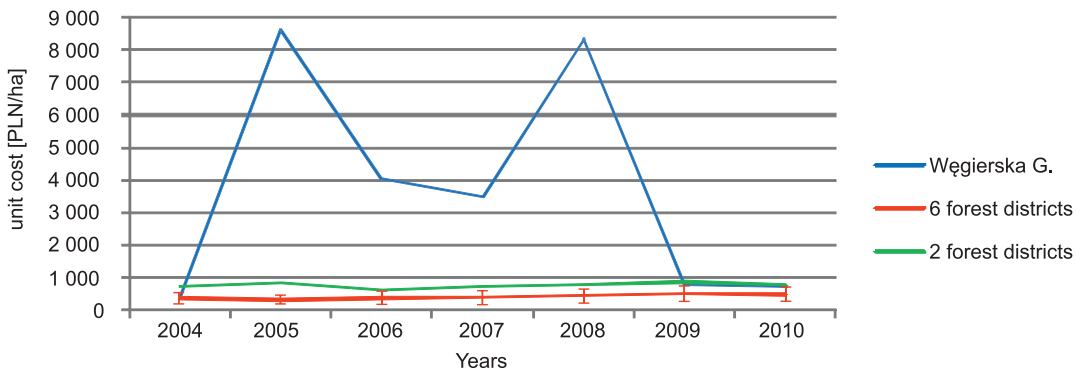

Figure 5. Current unit cost of agrotechnical melioration (PLN/ha) in the Forest District of Węgierska Górka and selected forest districts in the years 2004–2010

Table 1. The increase (decrease) rate of the core unit costs in the Forest District of Węgierska Górka and selected forest districts in the years 2004–2010

Specification	Years						
	2004	2005	2006	2007	2008	2009	2010
Forest protection							
Węgierska Górka	-	-9.19	55.65	90.45	7.70	-19.95	-68.05
6 forest districts	-	-17.66	11.41	4.72	24.53	-2.51	53.18
2 forest districts	-	67.17	-7.59	1.95	41.18	-13.28	15.78
Maintaining forest infrastructure							
Węgierska Górka	-	33.06	-2.46	44.97	21.79	-37.67	114.43
6 forest districts	-	-10.91	-2.45	5.56	-5.85	-19.21	129.09
2 forest districts	-	131.07	-54.68	-9.14	-37.69	-9.49	88.64
Timber felling and bucking							
Węgierska Górka	-	11.16	-1.44	22.35	9.41	-3.59	-10.94
6 forest districts	-	8.61	6.74	8.83	9.95	0.17	2.44
2 forest districts	-	15.17	-3.90	7.39	14.48	6.78	-4.03
Timber skidding							
Węgierska Górka	-	0.70	9.84	2.75	18.09	-0.60	4.87
6 forest districts	-	12.07	26.05	0.83	11.31	-2.73	13.49
2 forest districts	-	33.83	3.72	-7.97	21.16	-2.40	11.29
Agrotechnical melioration							
Węgierska Górka	-	2086.68	-52.98	-13.63	137.76	-90.56	-8.76
6 forest districts	-	-10.76	13.62	3.94	14.93	15.52	-5.44
2 forest districts	-	15.88	-24.94	14.95	11.64	9.75	-11.68
Regeneration, afforestation and stand by conversion							
Węgierska Górka	-	5.16	9.66	8.23	5.47	28.28	-10.77
6 forest districts	-	47.40	25.00	-1.13	-6.63	32.83	-5.56
2 forest districts	-	16.06	-0.69	8.65	29.29	5.70	13.56
Filling and completing seeding							
Węgierska Górka	-	22.43	-7.71	7.51	36.05	1.79	19.48
6 forest districts	-	23.14	0.88	2.52	19.18	-2.12	6.74
2 forest districts	-	0.89	16.42	-10.01	13.58	11.54	13.30
Stand treatment							
Węgierska Górka	-	7.15	7.35	2.88	31.81	2.46	-1.45
6 forest districts	-	6.46	7.01	6.17	13.05	1.84	0.38
2 forest districts	-	15.02	1.49	3.41	14.82	4.23	0.77

6 forest districts: Krościenko, Limanowa, Stary Sącz, Nawojowa, Piwniczna, Łosie

2 forest districts: Myślenice, Nowy Targ

Source: Own study based on reports from SFIS database

ysed costs of the Forest District of Węgierska Górka were from 169.19 PLN/ha (2004) to 116.24 PLN/ha (2010) or, respectively, 3.9 and 25.5% lower than mean costs of the two forest districts set. The discussed unit costs of the Forest District of Węgierska Górka showed statistically significant ($p < 0.01$) growing trend, which was similar to the compared sets of forest districts (set of six $p < 0.01$; set of two $p < 0.001$; Fig. 6).

Unit costs of supplementary planting in the Forest District of Węgierska Górka were from 534.76 PLN/ha (2009) to 1402.66 PLN/ha (2006) or, respectively, 8.4 and 26.4% lower than similar costs calculated for the set of six forest districts with the exception of the year 2010 (costs were 169.19 PLN/ha or 2.5% higher; Fig. 7). When compared with the set of two forest districts, the Węgierska Górka costs were from 173.38 PLN/ha (2010)

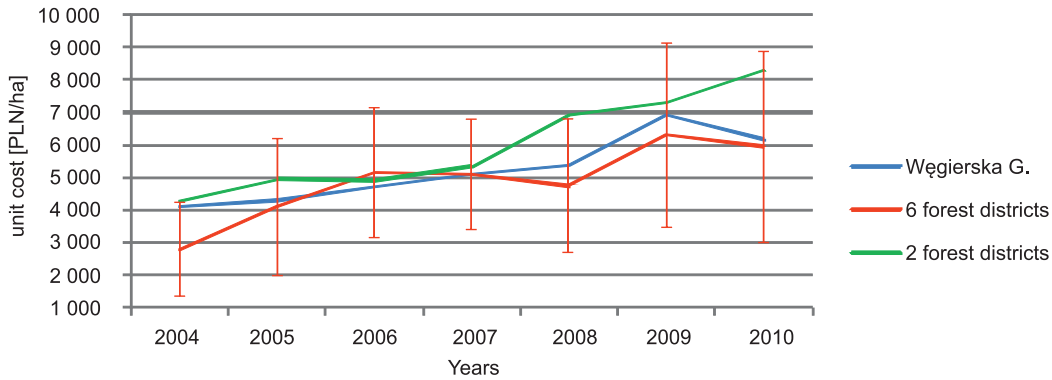

Figure 6. Current unit cost of regeneration, afforestation and stand conversion (PLN/ha) in the Forest District of Węgierska Górka and selected forest districts in the years 2004–2010

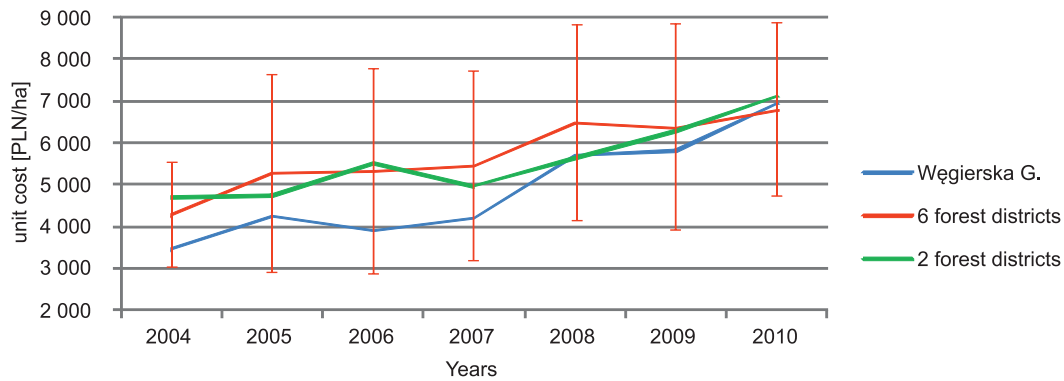

Figure 7. Current unit cost of filling and completing seeding (PLN/ha) in the Forest District of Węgierska Górka and selected forest districts in the years 2004–2010

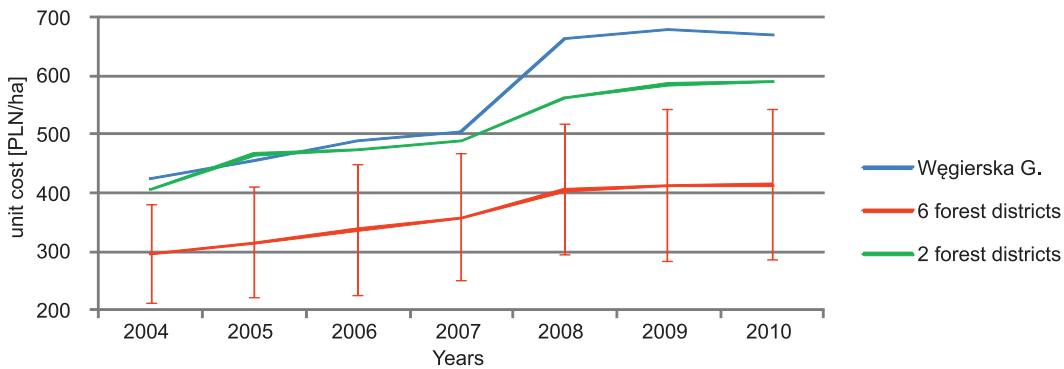

Figure 8. Current unit cost of stand treatment (PLN/ha) in the Forest District of Węgierska Górka and selected forest districts in the years 2004–2010

Table 2. The synthetic index of costs in the Forest District of Węgierska Górka and selected forest districts in the years 2004–2010

Forest district	Years							Average
	2004	2005	2006	2007	2008	2009	2010	
Krościenko	0.70	0.62	0.59	0.59	0.55	0.48	0.56	0.58
Limanowa	0.44	0.39	0.44	0.43	0.40	0.44	0.50	0.43
Łosie	0.63	0.49	0.47	0.42	0.44	0.58	0.58	0.52
Myślenice	0.70	0.67	0.55	0.56	0.53	0.65	0.71	0.62
Nawojowa	0.50	0.45	0.52	0.48	0.45	0.54	0.65	0.51
Nowy Targ	0.77	0.67	0.66	0.58	0.55	0.61	0.73	0.65
Piwniczna	0.62	0.49	0.52	0.57	0.49	0.61	0.70	0.57
Stary Sącz	0.55	0.44	0.53	0.60	0.50	0.51	0.52	0.52
Węgierska G.	0.81	0.79	0.82	0.86	0.87	0.82	0.81	0.82
Average	0.63	0.56	0.57	0.57	0.53	0.58	0.64	0.58
Standard deviation	0.12	0.13	0.12	0.13	0.14	0.11	0.11	0.11

1st class: low costs – $SWK <$ mean $SWK - SD$ (SWK)*

2nd class: mid-lower costs – mean $SWK - SD$ (SWK) $\leq SWK <$ mean SWK

3rd class: medium-higher costs – mean $SWK \leq SWK <$ mean $SWK + SD$ (SWK)

4th class: high costs – $SWK \geq SWK$ mean + SD (SWK)

*Class intervals determined based on the average and standard deviation for each year

Source: Own study based on reports from SFIS database

to 1606.22 PLN/ha (2006) or, respectively, 2.4 and 29.2% lower with the exception of 2008 (costs were 77.1 PLN/ha or 1.4% higher). The analysed costs of the Forest District of Węgierska Górka shaped similar to the costs of the comparative sets of forest districts. Statistically significant growing trend ($p < 0.01$; Fig. 7) was established for all linear relationships.

Unit costs of stand tending in the Forest District of Węgierska Górka varied from 425.36 PLN/ha (2004) to 679.83 PLN/ha (2009). Moreover, they were from 129.69 PLN/ha (2004) to 268.17 PLN/ha (2009) or, respectively, 43.9 and 65.1% higher than similar costs calculated for the set of six forest districts (Fig. 8). The Węgierska Górka costs were also from 14.01 PLN/ha (2007) to 101.65 PLN/ha (2008), which is, respectively, 2.9 and 18.1% higher than mean costs received for the set of two forest districts. The exception presented the year 2005, when costs were 10.50 PLN/ha (or 2.3%) lower. Evident jump in costs of forest tending was noted in the Forest District of Węgierska Górka in 2008 (Table 2). Statistically significant linear growing trends could be shown for the Węgierska Górka costs ($p < 0.01$) and also for two sets of compared forest districts ($p < 0.001$; Fig. 8).

The values of the synthetic cost indicator calculated for the Forest District of Węgierska Górka were significantly higher than in other analysed forest districts (Table 1). The synthetic indicator in the Forest District of Węgierska Górka was ranked as the highest cost class (IV) during the subsequent study years while taking the values from 0.79 (2005) to 0.87 (2008). It was noted that only in the first (2004) and in the last (2010) study year, the values of the synthetic indicator were approximating the parameters received for other analysed forest districts.

4. Discussion and conclusions

The unit costs of forest protection in the Forest District of Węgierska Górka were several times higher than similar costs in two groups of the compared forest districts. Such a situation was caused by the increased expenses related to the limitation of forest pests populations, especially in the year 2008 (Table 3). Evident jump in those costs in the Wisła Forest District was also noted by Piszczek (2007). According to Lysik (2005), the high level of forest protection unit costs could be observed in mountainous forest districts when they have

Table 3. Costs (PLN) and share (%) incurred for the selected task of forest management core activity in the Forest District of Węgierska Górka in the years 2004–2010

Specification	Costs in the years													
	2004		2005		2006		2007		2008		2009		2010	
	(PLN)	(%)	(PLN)	(%)	(PLN)	(%)	(PLN)	(%)	(PLN)	(%)	(PLN)	(%)	(PLN)	(%)
Forest protection	912 094.77	11.04	828 296.32	8.02	1 289 242.24	9.24	2 455 298.65	10.39	2 644 274.02	10.07	2 116 611.74	10.18	676 288.47	5.61
Maintaining forest infrastructure	1 149 311.75	13.91	1 529 320.21	14.81	1 491 677.50	10.69	2 162 428.54	9.15	2 633 614.80	10.03	1 641 606.78	7.89	3 520 117.55	29.18
Timber felling and bucking	2 092 224.58	25.31	2 784 328.79	26.96	4 000 021.42	28.68	7 450 778.93	31.52	7 704 222.66	29.34	5 982 791.42	28.77	1 885 515.11	15.63
Timber skidding	2 999 050.44	36.28	3 597 552.61	34.84	5 769 610.58	41.37	9 060 985.39	38.33	10 086 791.11	38.42	8 070 615.15	38.81	2 978 792.65	24.70
Agrotechnical melioration	14 616.00	0.18	337 710.35	3.27	279 289.02	2.00	436 542.46	1.85	808 000.14	3.08	87 602.17	0.42	258 113.08	2.14
Filling and completing seeding	27 383.06	0.33	24 435.56	0.24	30 238.80	0.22	139 690.36	0.59	198 317.04	0.76	274 433.79	1.32	249 047.08	2.06
Regeneration, afforestation and stand by conversion	767 426.05	9.28	802 199.19	7.77	790 785.59	5.67	1 476 484.59	6.25	1 542 476.22	5.87	1 927 285.54	9.27	1 752 576.81	14.53
Stand treatment	303 347.74	3.67	422 850.34	4.09	296 625.80	2.13	459 456.14	1.94	638 560.27	2.43	694 067.42	3.34	741 505.51	6.15
Total	8 265 454.39	100.00	10 326 693.37	100.00	13 947 490.95	100.00	23 641 665.06	100.00	26 256 256.26	100.00	20 795 014.01	100.00	12 061 956.26	100.00

Source: Own study based on reports from SFIS database for Forest District of Węgierska Górka

large share of spruce in their stands. It is mainly related to pest control and especially the European spruce bark beetle (*Ips typographus*). In the USA, Progar et al. (2007) recorded significant increase in forest protection costs due to tasks related to limitation of forest pests with the use of repellents and removal of infected trees.

Unit costs of forest infrastructure maintenance in the Forest District of Węgierska Górka had a clear growing tendency in contrast to two other analysed forest districts. Such a situation could be explained by reconstruction of road infrastructure, which was damaged when large volumes of timber transported. According to Lysik (2005), those costs additionally increase with the large share of mountainous and lowland sites, which have difficult access and terrain characteristics. Szabla (2011) underlines that after snow tree damage there was also the need to increase expenses related to road repair due to larger intensity of timber removal. Similar opinion was presented by Piszczek (2007) describing the hurricane in the Wisła Forest District in 2004. Foreign literature also presents information about increased costs of damaged road infrastructure repair after hurricane disasters (Baur et al. 2003 and Svensson et al. 2011).

The unit costs of tree felling and bucking in the Forest District of Węgierska Górka evidently increased after the hurricane of 2004 and also in 2007–2008 due to removal of trees damaged by pests. As indicated by, among others, Prestemon et al. (2006), the delays related to timber removal from the areas affected by natural disasters result in large financial losses linked to deteriorating timber quality. The increase in the discussed costs is undoubtedly caused by time pressure and limited possibilities for using special equipment (harvesters and forwarders). Large majority of tasks was done manually with the use of chainsaws, which resulted in hike of unit costs, as suggested by Suwała (2004).

During the last years, the apparent drop of the discussed costs in the Forest District of Węgierska Górka resulted from decrease in timber removal. It was accompanied by growing competition from other forest companies causing the decrease in rates. Similar arguments were presented by Szabla (2011), discussing the example of snow damage in 2010, which affected the forests of the Katowice Regional Directorate. Also, Piszczek (2011) mentions that those costs depend on situation at domestic market. The unit costs of tree felling and bucking were heavily impacted by demand on labour. Similar conclusions were also made by Svensson et al. (2011) in the analysis of timber harvesting costs after the Gudrun hurricane in Sweden.

The unit costs of timber skidding in the Forest District of Węgierska Górka had similar growing tendencies as unit costs of compared two sets of forest districts. As suggested by Suwała (2004), the hike in those costs can occur due to increasing skidding distances or due to implementation of skidding in two stages (Suwała, 2002). Lysik (2005) mentions that hike in those costs could also occur when share of mountainous and lowland sites becomes larger. Kocel (2013) considers that ground roughness has significant effect on skidding costs. The research conducted in the Szumawa National Park in Czech Republic indicated that after forest damage by the European spruce bark beetle (*Ips typographus*), there was a significant increase in timber skidding costs due to the use of special equipment for difficult mountainous terrain (Bláha 2002). However, in the Forest District of Węgierska Górka, the increase in timber harvesting did not result in larger unit costs of timber skidding as it happened in the case of unit costs of timber felling and bucking.

The unit costs of forest amelioration in the Forest District of Węgierska Górka were several times higher than in analysed sets of forest districts. This hike in costs resulted from the need to clear the area after the hurricane and the pest damage by the European spruce bark beetle. The similar increase in costs was also noted by Kuc (2011) after the hurricane Kyrill. Piszczek (2007) indicates that larger forest amelioration costs could be observed after forest fire in the Rudy Raciborskie Forest District. According to Kaliszewski (2009), those costs depend on the intensity of slash removal and the process of slash disposal. Similar arguments are presented by Szabla (2011), who also notes that forest amelioration costs could be avoided or significantly decreased when they are covered by timber buyer. Nevertheless, the use of special equipment on mountain terrain, as suggested by Suwała (2004), results in significant growth of such costs.

The unit costs of regeneration and afforestation calculated for the Forest District of Węgierska Górka were not significantly different from the two sets of compared forest districts and followed a similar growing trend. As it was discovered, the process of stand conversion and elimination of natural disaster consequences was supported by successful natural regeneration. Moreover, as noted by Szabla (2011), low costs of regeneration and afforestation were largely affected by the limited use of mechanical equipment and also by low rates on silvicultural works agreed with forest companies. Szramka (2001) and Lysik (2005) also remark lower costs of natural regeneration in comparison with artificial in the

Table 4. The implementation of selected task of forest management core activity (ha) in the Forest District of Węgierska Górka in the years 2004–2010

Specification	The implementation of tasks in the years											
	2004 (ha)	2005 (ha)	Change y/y (%)	2006 (ha)	Change y/y(%)	2007 (ha)	Change y/y (%)	2008 (ha)	Change y/y (%)	2009 (ha)	Change y/y (%)	2010 (ha)	Change y/y (%)
Agrotechnical melioration	37.07	39.17	5.66	68.90	75.89	124.69	80.97	97.07	-22.15	111.48	14.85	360.02	220.94
Regeneration, afforestation and stand by conversion	187.50	186.37	-0.60	167.53	-10.10	289.00	72.51	286.27	-0.94	278.83	-2.60	284.16	1.91
Filling and completing seeding	7.93	5.78	-27.11	7.75	34.08	33.30	329.68	34.75	4.35	47.24	35.94	35.88	-24.05
Stand treatment	713.15	927.80	30.10	606.26	-34.65	912.78	50.56	962.41	5.44	1 020.94	6.08	1 106.83	8.41

Source: Own study based on reports from SFIS database for Forest District of Węgierska Górka

same site conditions and suggest using the potential of less expensive natural regeneration. Baur et al. (2003) also noted lower costs of natural regeneration in stands destroyed by the Lothar hurricane.

The unit costs of supplementary planting in the Forest District of Węgierska Górka were lower than unit costs calculated for the compared sets of forest districts. There was also a similar growing tendency. As noted by Lysik (2005), supplementary planting unit costs grow when the share of lowland and mountainous areas is higher. According to him, such a cost increase is caused by additional costs carried due to the need to supplement weak natural regeneration. According to Kocel (2013), supplementary planting costs are higher in the situation when the share of mountainous spruce forests and mixed mountainous forests is higher as the costs of soil preparation there are higher. In the Forest District of Węgierska Górka, there was, however, no significant increase in unit costs of supplementary planting despite the fact that more activities were implemented in that time period (Table 4). Such a situation could be explained by successful natural regeneration and also by low rates of silvicultural works implemented.

The unit costs of stand tending in Forest District of Węgierska Górka were not behaving similarly as similar costs in the compared set of six forest districts. In Węgierska Górka, there was a sudden hike in those costs in 2006 due to increase in tasks related to soil tending and weeding (Table 4). The hike in similar costs lasting through several years after the hurricane Kyrill was also noted by Kuc (2011). Identical opinion was presented by Piszczek (2007) using the example of forest fire area in the Rudy Raciborskie Forest District. In the analysis of different forest regeneration possibilities after the hurricane in the Piska Puszcza, Kaliszewski (2009) declared that tending costs depends on the density of developing forest vegetation. Similar conclusions are made by Kocel (2013), especially in the case of fertile forest sites.

The last parameter discussed is the synthetic cost indicator. The highest values of the indicator were obtained for the Forest District of Węgierska Górka, especially in years 2007–2008. Such high values of the indicator intercepted in time with the culmination of pest infection and, therefore, with higher costs of selected silvicultural activities. The high values of the synthetic cost indicator were also noted in the forest districts with high share of spruce, such as Krościenko Forest District, and also in the set of two forest districts of Nowy Targ and Myślenice. Lysik (2005) also indicates that the highest values of the synthetic cost indicator could be found in the mountainous forest districts with dominating spruce forests in contrast with forest districts with dominating fir and beech forests. According to him, it could be explained by higher costs carried by forest districts managing spruce forest stands.

The above research results allow formulation of the following conclusions:

– Natural disasters result in hike of only some of the unit costs irrespective of the volume of tasks implemented, such as tree felling and bucking, forest amelioration, forest protection, forest infrastructure maintenance and stand tending.

– Natural disasters did not cause the increase in unit costs of timber skidding, forest regeneration and afforestation, as well as stand reconstruction (calculated jointly) and supplementary planting.

– Natural disasters lead to economic losses in forest industry, which could be seen in higher unit costs of implemented silvicultural activities.

– Favourable arrangements of spatial and time conditions, beneficial forest site conditions, employment of more productive and less expensive technologies, as well as advantageous economic factors of the forest economy surrounding, are significant in mitigating negative economic effects of natural disasters in forests.

– Full analysis of economic consequences of natural disasters in forests should be implemented for longer time periods taking into account trends and periodic fluctuations since most of the costs related to reconstruction of damaged sites can become obvious only in later time periods.

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Authors' contribution

A.T.S. – study conception, literature review, data collection and analysis, drafting of manuscript.
J.U. – statistical assistance and consultations.

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