Black alder (*Alnus glutinosa* (L.) Gaertner) and its bank-protective effect on the banks of water flows quantified by method BSTEM

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Abstract

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The present article reviews the significance of Black alder (*Alnus glutinosa* (L.) Gaertner) in the riparian stands of torrent Hučava (Protected Landscape Area Poľana) in connection with bank stability of water flows and resistance of the banks of the bed against the erosion. Riparian stands are nature nearest reinforcement of the banks of water flows with accent of nature and landscape protection and biodiversity. Riparian vegetation increases the bank stability and erosion resistance of the banks of water flows. In the geomorphological unit Poľana (Central Slovakia) were investigated and compared 22 of experimental sections and profiles of torrent Hučava. On these experimental sections was analyzed the stability and erosion resistance of the banks on the both sides of the bed in connection with different density of stems of Black alder. The factor of stability Fs of the banks of water flow was calculated according to Bank Stability and Toe Erosion Model (BSTEM). The results indicated close correlation between the density of the stems of Black alder and factor of stabilty Fs (correlation coefficient is I_{yx} = 0.964 for the right banks and I_{yx} = 0.952 for the left banks). The calculated results of Fs are in accordance with existing erosion damages of the banks which were determined in terrain. The analysis confirms the influence of alder stands to stability and erosion resistance of the banks of water flows. The results were validated by statistical testing.

Key words

bank stability, Black alder, riparian stands

Introduction

Riparian stands (RS) are continuous, aggregated forest stands or their parts, groups, belts of trees, shrubs, grass and herbaceous vegetation. RS grow on the banks of water flows and water reservoirs and in the near of these localities (Valtýni, 1981). Some authors use the term riparian vegetation (Wynn, 2004; Wynn and Mostaghimi, 2006). The bank protection through the vegetation is the nature nearest way of reinforcement of the banks of water flows with accent of nature and landscape protection and biodiversity. RS increase the stability of the banks and anti-erosion resistance and they are the most significant elements of natural protection on the banks of water flows. In connection with the presence or absence of RS are these processes of erosion significantly limited (reduced or increased). Grešková and Lehotský (2007) suggest that the riparian stands through their root system reinforce the banks of water flows and protect the banks against the erosion and negative effects of streaming water. Valtýni (1981) defines the soil-protection function of RS as a reinforcement of the banks by root systems also as of inhibition of soil-erosion and of disturbances on the banks of water flows and reservoirs. Novák et al. (1986) analyze the influence of trees on the banks of water flows in connection with their location on the banks of water flows and their bank-protection function. Valtýni (1974), Šlezingr and Úradníček (2009) deal with the using of several species of woody plants in various ecological conditions. The importance of riparian vegetation with the accent on the soil-protection function confirm Simon et al. (2009). The authors suggest that the soil-loss of stream banks can be up 90% of total cubature of eroded material in the watershed per year. Rosgen (2002) suggests that in some cases the soil-loss caused by erosion of the banks of water flows can be up 80% of total eroded material in watershed per year. Pollen et al. (2004) suggest that this share can be more than 50% of total eroded material in watershed per year. Simon et al. (2011) confirm that by erosion of the banks is damaged averagely 52% of the banks of water flows. According to Beeson and Doyle (1995), Huang and Nanson (1997), Hession et al. (2003), Allmendinger et al. (2005) etc. are analyzed the issues of influence of riparian stands on the widening of the beds of water flows by erosion. The influence of root systems of riparian stands of water flows on stability of the banks and their soil protection function analyze Abernethy and Rutherfurd (2000), Micheli and Kirchner (2002), Simon and Collison (2002), Easson and Yarbrough (2002), Pollen et al. (2004) etc. These authors confirm the positive influence of the roots of the vegetation on stability of the banks and indicate that the stability of the bank is in correlation with indicators of density of vegetation inclusive number of stems and standing biomass per unit area. Black alder is representative tree of riparian stands on the banks of water flows, which grows in optimal condition to a height of 20–30 m. Lukáčik and Bugala (2009) mention that the typical vertical extension of Black alder in the Slovak Republic is 700–750 m a.s.l., somewhere also higher. Area of expansion of the initial alder stands is declining due to anthropogenic activities. In the lowlands due to negative changes of water flows and in the mountainous areas due to conversion on the agricultural lands (Bugala and Pitner, 2010). The biological balance of this environment was disturbed with various negative consequences and attendant phenomenons (for example increasing erosion of the banks of water flows). Black alder is very important amelioration tree with various positive properties (improves soil structure and the quality; has a positive impact on the additional properties such as cohesion of soil with the roots and mechanical reinforcement of banks of water flows etc.). Mentioned properties and other (frost resistance, resistant to moisture of soil and flooding etc.) confirm the importance for the reinforcement of the banks of water flows. Novák et al. (1986) confirm that the stands of Black alder are more resisting to damages and they are resistant to 15–20 days flooding in the vegetation period and to 20–30 days flooding in unvegetation period without damages. In the toe of the banks of water flows have the ability to grow up to the bottom (Novák et al., 1986). Black alder can mitigate the bottom-erosion, too. The subsurface root system reinforcements the gravel layers of the bottom (Kremer, 1995).

Material and methods

The characteristics of the experimental torrent and watershed Hučava

The research was conducted on the torrent Hučava. The experimental watershed Hučava is situated in the center of the geomorphological unit Poľana, subunits Detvianske predhorie and Vysoká Poľana. The watershed Hučava belongs to the watershed of river Slatina and general watershed of river Hron. Torrent Hučava has the hydrologic number of 4-23-03-070 in the Slovak Rebublic. The coefficient of torrent activity of the watershed is $K_b = 0.330$. The closing flow profile is situated near the locality Hrochoťský mlyn at the stream gauge station (523 m above sea level). This closing flow profile has the river log 0.000 km. The torrent Hučava rises at height of 1,285 m a.s.l., between the locations Dudáš and Na mesiac. Total lenght of torrent Hučava (from the riverhead to the closed flow profile) is 14.28 km. The highest point of the watershed is peak Poľana (1,458 m a.s.l.). The lowest point of the watershed is the bottom of closed flow profile (523 m a.s.l.). The absolute difference of altitude the torrent Hučava is 762 m and the absolute difference of altitude the watershed Hučava is 935 m. The mean longitudinal gradient of torrent Hučava is 5.33%. The mean above sea level of the watershed is 922 m. The mean slope of the banks of the watershed is 32.3%. The mean gradient of the thalweg is 6.21%. The forest coverage of the watershed is 82.4%. The average annual precipitation amount in the watershed is 937 mm, average annual evaporation is 409 mm and average annual temperature in the watershed is 4.65 °C.

Methods

On the straight stretch of torrent Hučava were established experimental sections (ES) with lenght of 20 m in different distances from the closed flow profile of the watershed.

Selection of ES was performed taking into account of the conditions along the length of the torrent Hučava. Approximately in the middle of ES were estabilished experimental flow profiles (EP). The orientation of the banks of experimental water flow was designated along a stream (right, left). The selection of ES was taking into account to different number of tree stems of Black alder on the banks of water flow. Through the levelling were measured the geometric characteristics of EP: B (m) – witdh of the flow profile inside the banks, width of the bottom b (m), median depth of the flow profile H (m). Accordig to cross sections of EP were determined partial wetted perimeters O_1 and O_2 and the slopes of the both banks. Through the leveling were determined the values of lungitudinal gradients i (%) on the ES. Input data about EP were determined for BSTEM – Bank Stability and Toe Erosion Model (Simon et al., 2009). Model BSTEM was analyzed in detail in separate paper (Jakubisová, 2011). In terrain were evaluated all of stems of Black alder and were plotted in a situation in scale 1 : 100. Numbers of Black alder stems were determined for all of experimental banks (EB). The areas of EB were calculated as the product of the sides of rectangle with the sides L_{ES} (L_{ES} – lenght of experimental section – 20 m) and Y_{ES} (Y_{ES} – width of the experimental bank from the toe of the bottom to the point of the riparian edge). According to the BSTEM – Bank Stability and Toe Erosion Model was calculated factor of stability Fs for all of the right (22) and all of the left (22) banks of ES (EB), the total number of evaluated banks is of 44. The computed results by BSTEM were compared with recent erosion of the experimental banks in terrain. The effect of root systems to the stability of the banks of water flow was calculated with using of Rip-Root-Reinforcement model (Pollen-Bankhead and Simon, 2009) including the value of the additional cohesion – c_r. The authors deal in this work with the determination of the additional cohesion for various trees, shrubs and plants. The calculated values of Fs – factor of stability of the bank is valuated in three levels: if Fs > 1.3 – the bank is stable, if Fs is from 1.0 to 1.3 – the bank is conditionally stable, if Fs < 1.0 – the bank is unstable. Basic geometric characteristics of the EP are listed in Tables 1a, 1b. The input characteristics for the analyses are listed in Tables 2a, 2b.

Table la. Geometric characteristics of experimental flow profiles

No. EP	Sp [km²]	DFCP [km]	a.s.l. [m]	B [m]	H [m]
1	41.158	0.015	523	10.3	1.15
2	39.048	1.425	554	9.9	1.15
3	38.153	2.020	568	9.7	1.10
4	37.582	2.532	575	9.0	1.00
5	37.307	2.820	582	8.8	1.10
6	36.651	3.310	602	8.7	1.00
7	36.085	3.755	620	8.7	1.05
8	35.304	4.210	625	8.7	1.10
9	34.575	4.600	640	8.5	1.00
10	32.901	5.060	656	8.6	1.05
11	32.207	5.340	662	8.2	1.00
12	31.763	5.745	670	8.0	0.95
13	30.534	6.155	681	7.9	1.00
14	29.100	6.645	695	8.0	0.95
15	27.033	7.100	711	7.8	0.90
16	26.801	7.490	728	7.6	0.90
17	24.552	7.865	740	7.1	0.95
18	23.765	8.235	755	6.8	0.90
19	20.469	8.715	765	6.6	0.85
20	19.431	9.160	775	6.0	0.80
21	12.633	9.620	785	5.2	0.75
22	9.713	10.100	810	3.9	0.65

Table lb. Geometric characteristics of experimental flow profiles

No. EP	S_{pp} [m²]	O_1 [m]	O_2 [m]	O [m]	R [m]	Q_k [$m^3 s^{-1}$]
1	9.2	6.8	4.3	11.1	0.829	17.30
2	8.9	6.7	4.1	10.8	0.824	16.90
3	8.5	6.7	3.7	10.4	0.817	16.41
4	7.8	6.6	3.6	10.2	0.765	16.51
5	7.5	6.3	3.8	10.1	0.743	16.26
6	7.3	6.2	3.5	9.7	0.732	15.66
7	7.0	6.1	3.9	10.0	0.700	15.32
8	6.8	5.6	3.8	9.4	0.723	14.72
9	6.8	5.6	3.9	9.5	0.716	15.33
10	6.7	5.5	3.5	9.0	0.744	15.16
11	6.5	5.3	3.7	9.0	0.722	14.22
12	5.8	5.2	3.5	8.7	0.667	12.19
13	5.7	5.1	3.7	8.8	0.648	11.78
14	5.8	5.3	3.6	8.9	0.652	11.65
15	5.3	5.1	3.2	8.3	0.639	11.17
16	5.1	4.8	3.6	8.4	0.607	10.35
17	4.8	4.6	3.3	7.9	0.623	10.62
18	4.3	4.6	2.9	7.5	0.573	10.13
19	4.1	4.5	2.7	7.2	0.569	9.38
20	3.4	4.2	2.1	6.3	0.540	8.25
21	3.0	3.5	2.1	5.6	0.536	7.06
22	1.9	2.9	1.8	4.7	0.404	3.59

Explanatory notes to Tables 1a, 1b
No. EP, serial number of experimental profile; S_p, watershed area; DFCP, distance from closed profile; B, width of the flow profile inside the banks; H, hight of the flow profile; S_{pp}, flow profile area; O_1, O_2, O, partial and total wetted perimeter; R, hydraulic radius; Q_k, bankfull discharge.

Table 2a. Characteristics to calculation of Factors of safety of experimental banks of the bed

No. EP	Y_{RB} [m]	S_{RB} [m²]	BA_R [No.]	BA_R/m^2 [No.]	Fs_{RB}
1	2.3	46	20	0.43	8.71
2	2.1	42	14	0.33	5.57
3	2.0	40	18	0.45	8.33
4	1.8	36	8	0.22	4.55
5	1.9	38	12	0.32	5.03
6	1.7	34	12	0.35	7.60
7	1.9	38	7	0.18	3.37
8	2.0	40	15	0.38	6.17
9	1.9	38	14	0.37	7.40
10	1.8	36	9	0.25	3.26
11	1.8	36	7	0.19	4.30
12	1.8	36	10	0.28	5.04
13	1.8	36	4	0.11	1.20
14	1.8	36	12	0.33	6.30
15	1.5	30	3	0.10	1.27
16	1.6	32	5	0.16	2.11
17	1.6	32	9	0.28	3.88
18	1.3	26	6	0.23	3.48
19	1.3	26	7	0.27	4.50
20	1.0	20	2	0.10	0.91
21	1.0	20	1	0.05	0.63
22	0.9	18	1	0.06	0.51

Table 2b. Characteristics to calculation of Factors of safety of experimental banks of the bed

No. EP	Y_{LB} [m]	S_{LB} [m²]	BA_L [No.]	BA_L/m^2 [No.]	Fs_{LB}
1	2.0	40	11	0.28	6.27
2	2.0	40	8	0.20	3.03
3	1.7	40	7	0.21	3.10
4	1.8	36	15	0.42	9.30
5	1.9	39	10	0.26	5.94
6	1.8	36	6	0.17	1.90
7	2.0	40	12	0.30	6.11
8	1.8	36	14	0.39	9.07
9	2.0	40	4	0.10	1.01
10	1.7	34	10	0.29	4.90
11	1.9	38	9	0.24	3.66
12	1.7	34	8	0.24	3.17
13	1.9	38	7	0.18	2.42
14	1.8	36	9	0.25	4.10
15	1.7	34	9	0.26	4.25
16	2.0	40	8	0.20	3.82
17	1.7	34	3	0.09	1.22
18	1.6	32	7	0.22	2.91
19	1.4	28	4	0.14	1.30
20	1.1	22	1	0.05	0.90
21	1.1	22	1	0.05	0.68
22	0.9	18	1	0.06	0.77

Explanatory notes to Table 2a, 2b
No. EP, serial number of experimental flow profile; RB, right bank of the experimental flow profile; LB, left bank of the experimental flow profile; Y_{RB}, width of the right bank of the bed; S_{RB}, area of the right bank of experimental flow profile; BA_R, number of Black alder on the area of rigth bank; BA_R/m^2, number of Black alder per m², on the right experimental bank; Fs_{RB}, factor of safety of the right experimental bank; Y_{LB}, width of the leftt bank of the bed; S_{LB}, area of the left bank of experimental flow profile; BA_L, number of Black Alder on the area of left bank; BA_L/m^2, number of Black Alder per m² on the left experimental bank; Fs_{LB}, factor of safety of the left experimental bank.

Results and discussion

The theoretical analysis confirms the close correlation between the number of stems of Black alder per m² (No. BA_R m^{-2}, No. BA_L m^{-2}) and factor of stability (Fs_{RB}, Fs_{LB}) for right and left banks. The results and statistical testing are listed in Table 3.

From the research is remarkable that between the density of Black alder on the bank of ES and the Factor of stability – Fs of the bank exists close correlation dependence. Analyse of the dependencies between density of stems of Black alder and values of Fs on the experimental banks proves that the calculated values of density of stems of Black alder per m² on the right experimental bank are in the interval from 0.05 (EP 21) to 0.45 (EP 3). The values of Factor of stability Fs_{RB} are in the interval from 0.51 (EP 21) – unstable bank to 8.71 (EP 1) – stable bank. From the results of dependence Fs_{RB} = f (No. BA_R m^{-2}) was derived (Fig. 1) the following equation:

$$Fs_{RB} = -0.7954 + 20.5183 \,.\, (\text{No. } BA_R \; m^{-2}) \qquad (1)$$

The calculated correlation coefficient for this dependence is $I_{yx} = 0.964$ and determination coefficient is $I_{yx}2 = 0.930$.

The calculated values of density stems of Black alder per m² on the left experimental bank are in the interval from 0.05 (EP 20, EP 21) to 0.42 (EP 4). The values of factor of stability Fs_{LB} are the interval from 0.68 (EP 21) – unstable bank to 9.30 (EP 4) – stable bank. From the results of dependence Fs_{LB} = f (No. BA_L/m^2) was derived (Fig. 2) the following equation:

$$Fs_{LB} = -1.3109 + 23.6240 \,.\, (\text{No. } BA_L/m^2) \qquad (2)$$

The calculated correlation coefficient for this dependence is $I_{yx} = 0.952$ and determination coefficient is $I_{yx^2} = 0.906$.

These analyses confirm that the density of stems of Black alder has weighty importance for the stability of the banks of water flows. These results were statistically tested. Statistical testing was conducted according to ŠMELKO (1991). Table 3 lists the regression equations with specific absolute and relative parameters for analyzed dependences, too. SIMON and COLLISON (2002) confirm that the mechanical effect of the trees increase the safety factor of the banks of the bed of water flow about 32%. WYNN and MOSTAGHIMI (2006) confirm that with change of vegetation from herbaceous riparian vegetation to trees was the erosion on the banks of water flows reduced up to 39%.

Table 3. Regression equations and statistical testing of analyzed dependences

Des.	Regression equation	I_{yx}	I_{yx^2}	SR	t	> = <	$t_{0.01}$ (20)
RB	$Fs_{RB} = a0 - a1 \ . \ (No.\ BA_R)$	0.964	0.930	0.059	16.34	>	2.845
	$Fs_{RB} = -0.7954 + 20.5183 \ . \ (No.\ BA_R)$						
LB	$Fs_{LB} = a0 - a1 \ . \ (No.\ BA_L)$	0.952	0.906	0.069	13.80	>	2.845
	$Fs_{LB} = -1.3109 + 23.6240 \ . \ (No.\ BA_L)$						

Explanatory notes to Table 3

RB, right bank of the flow profile; LB, left bank of the flow profile; $t_{0.01}$, critical value of Student t-distribution; I_{yx}, correlation coefficient; I_{yx^2}, determination coefficient; $SR = \sqrt{\frac{1 - I_{yx^2}}{n-2}}, t = \frac{I_{yx}}{S_R}$.

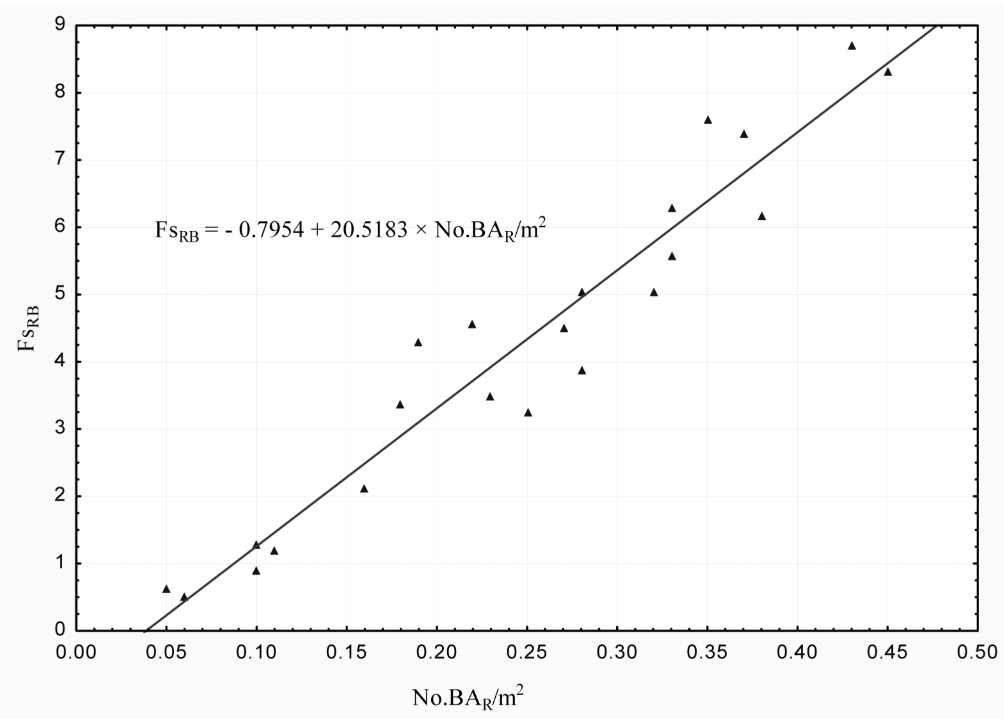

Fig. 1. Dependence between variables No. BA_R/m^2 and Fs_{RB}.

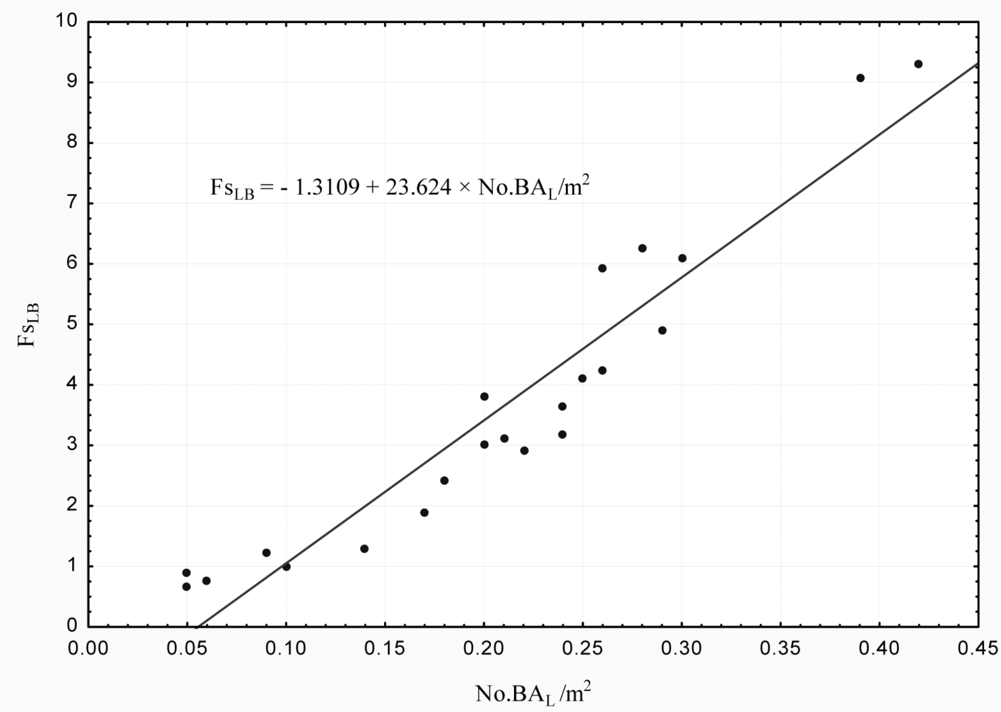

Fig. 2. Dependence between variables No.BA$_L$/m^2 and Fs$_{LB}$.

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Jelša lepkavá (*Alnus glutinosa* (L.) Gaertn.) a jej brehoochranný efekt na brehoch vodných tokov kvantifikovaný metódou BSTEM

Súhrn

Práca sa zaoberá významom jelše lepkavej (*Alnus glutinosa* (L.) Gaertn.) v brehových porastoch bystriny Hučava (CHKO Poľana) v súvislosti so zvyšovaním stability a protieróznej odolnosti brehov koryta. Vegetačné pozdĺžne spevnenia sú z hľadiska ochrany a tvorby krajiny a biodiverzity primárnym – prírode najbližším spôsobom spevňovania brehov vodných tokov. Zvyšujú ich stabilitu a odolnosť proti erózii. Na 22 pokusných úsekoch a profiloch bystriny Hučava (geomorfologický celok Poľana) bolo uskutočnené porovnanie stability a protieróznej odolnosti brehov v závislosti od hustoty kmeňov jelše lepkavej (Alnus glutinosa). Faktor stability brehu koryta Fs bol vypočítaný modelom BSTEM (Bank Stability and Toe Erosion Model). Analýza preukázala tesnú korelačnú závislosť medzi hustotou kmeňov jelše lepkavej na svahoch pokusných úsekov a faktorom stability brehu Fs (korelačný koeficient I_{yx} = 0,964 pre pravé svahy koryta a I_{yx} = 0,952 pre ľavé svahy koryta). Vypočítané výsledky faktora stability Fs korešpondujú s existujúcim poškodením brehov eróziou, ktoré bolo zistené v teréne. Analýza potvrdila význam jelšových porastov pre stabilitu a protieróznu odolnosť brehov vodných tokov. Výsledky boli potvrdené štatistickým testovaním.

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