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The effectivity of anti-flood technology indicated by vegetation in a hydrologically managed forest

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Abstract. In the Tatra Mts., approximately 5,000 water-holding dykes of different types were set up in the territory of 87 hectars, covering wind disaster area including burnt forest. During 2007-2009 a comprehensive vegetation investigation of inundation zones of 255 water-holding dikes took place. Ten vegetation types arising in the dike inundation zones were identified. For every plant community covering inundation zone, was calculated weighed mean of Ellenberg´ s indicator plant´ s values for environmental characteristics - light, temperature, continentality, moisture, acidity, nitrogen. The research was focused to in floristical composition of investigated dikes during 2007-2009. Using ordination methods, the relationships between environmental characteristics and vegetation types, types of dykes or supplementary environmental variables recorded in the field, like slope or increase in number of species in 2007-2009 were searched. Some widespread vegetation types show positive tendencies to moisture, e. g. vegetation types Horsmat (*Epilobium*), another nitrogen content, e. g. Red Raspberry (*Rubus idaeus*). With respect to the moisture, the triangular or semicircular dykes proved more efficient than the contour ones. Natural regeneration in the dike inundation zones related to environmental characteristics or vegetation types were analysed. The hygrophilous vegetation type Horsmat (*Epilobium*) achieved the highest increase in species diversity.

Key words: water-holding dikes, Ellenberg´ s indicator plant´ s values, ordination analysis

Introduction

On November 19, 2004, the northern down-slope wind (locally named Bora) laid down in the Tatra Mountains 12,000 ha of forest, about 2.3 mil m^3 of wood in volume. Wind gusts reached the speed over 230 km/h. Consequently, a large wildfire hit the windfall area at July 31, 2005, and 250 ha was completely burnt. Since the major part of solar energy used by the biota is spent on transpiration (i.e. evaporation of water through leaf stomata during photosynthesis), it can be expected that namely transpiration should be the key process of forest moisture pump (Makarieva *et al.* 2009). After forest destruction events, the lacking overstory reduced evaporation. Permeable moraine substratum enabled fast water outflow, the vadose zone expanded, the soil saturation became insufficient. Only minor part of dikes are constructed on impermeable flysch substratum.

In order to restore the damaged forest ecosystems in the Tatra National Park, the NGO (Non Governmental Organization) "People and Water" together with partners submitted a concrete project titled „The Water Forest". The Project is based on integrated restoration of water resources at the area as a pilot model for the destroied forest ecosystems restoration (Kravčík *et al.* 2006). In 2005-2008, the NGO built-up in the Tatra Mountains more than 5,000 water-holding dikes covering the area of 87 ha, including blowdowns areas and burnt forest. The dikes were constructed from local material – the debris wood, soil, stones.

In this paper, we examine the successional pathways in inundation zones of selected dikes. The research is focused to changes in environmental characteristics indicated by floristical composition of investigated dikes during 2007 - 2009. The results presented here refer to a very early stage of study. Nevertheless, new insights into water managed habitat dynamics are gained.

Material and Methods

Study sites and data sampling

In 2007 started the long term vegetation investigation of hydrologically managed sites. The investigation is focused to inundation zones of selected dikes. Basicaly, following types of dikes were analysed: Contour-line dikes, Terraces, Semi-circular dikes, Triangular dikes, Eye terraces, Cassette structures, Beaver´ s dikes. Inundation zones vary in size 1 - 25 m^2, depending on terrain configuration and on the type of dike. There were analysed 255 innundation zones of different types in 2007 - 2009. Since we had catched the beginning successional stage after the blowdown and after fire events (and after the dikes were established), we think the data sets should be taken in a year intervals, at least in the initial period, i.e. the first 5 - 10 years. Sampling was conducted in accordance with the principles of Zürich-Montpellier school (Braun-Blanquet 1921, 1928, 1964) and modified nine-degree abundance scale (Barkman *et al.* 1964) was used. Thus, the whole dataset for the present contains of 3 x 255 relevés. The dikes are fixed by WGS 84 coordinates, device eTrex Vista.

Data analysis

The main source of primary botanical dataset are results of divisive, polythetic methods of classification (Hennekens 1996a, b) of 255 phytocoenological relevés taken in 2007 and repeatedly in 2008 and 2009 following standard procedures of the Zürich-Montpellier School (Braun-Blanquet 1964, Westhoff and van den Maarel 1978).

For statistical analysis, the CANOCO 4.5 for Windows package (Ter Braak and Šmilauer 2002) was used. For ordination analysis we used percentage species data without transformation. For ecological interpretation of major gradients, weighted Ellenberg´s indicator plant´s values (Ellenberg *et al.* 1992) were plotted on an ordination diagram as environmental variables (L - light, T - temperature, C - continentality, M - moisture, A - acidity, N - nitrogen).

To explain the relation between environmental variables and vegetation types, we used ordinations constrained by explanatory variables. The length of the first gradient was >3.1, thus we used unimodal canonical correspondence analysis (CCA).

For natural regeneration, the Fisher linear discriminant analysis (or canonical variate analysis, CVA) was used. We have checked the Hill´s scalling with focus on inter-species distances, using CCA. Since the species variables belong partly to more units, fuzzy coding was used.

To analyse the changes in values of environmental variables in 2007 – 2009 we had only single data set of variable, so we used the linear method of ordination (principal component analysis, the PCA).

A single data set we had disposable to analyse ordination of dike types along gradient of environmental variables, we used unimodal detrended correspondence analysis (DCA).

The statistical significance of the explanatory (environmental) variables in canonical methods were determined by Monte Carlo permutation test, the variables were tested jointly (overall test).

Results

The following vegetation types of inundation zones of dikes were identified (Table 1): Great Willow-herb (*Chamaerion angustifolium*), White Wood-rush (*Luzula luzuloides*), Common Hair Grass (*Avenella flexuosa*), Fleecy Reedgrass (*Calamagrostis villosa*), European Red Raspberry (*Rubus idaeus*), Red-berried Elder (*Sambucus racemosa*), Tomenosa Sedge (*Carex tomenosa*), Horsmat (*Epilobium*), Bog Rush (*Juncus*), Rough Small-reed (*Calamagrostis arundinacea*) and Red Sorrel type (*Acetosella vulgaris*) disappeared in 2009.

The number of dikes analysed	**61**	**57**	**15**	**65**	**4**	**7**	**10**	**5**	**23**	**8**
Increase in number of species in 2007 - 2009	**2.5**	**1.3**	**1.1**	**1.7**	**0.75**	**2.3**	**1.7**	**4.6**	**2.3**	**1.4**
Slope in °	**8.0**	**9.1**	**6.3**	**3.4**	**13.0**	**12.6**	**3.6**	**9.6**	**2.3**	**6.2**
Column No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Chamaerion angustifolium	**100 ^{61}**	100 ^{26}	93 ^{24}	95 ^{20}	100 ^{30}	100 ^{27}	100 ^{18}	0	70 ^{12}	100 ^{22}
Luzula luzuloides	85 ^{18}	**100 ^{46}**	93 ^{14}	83 ^{13}	100 ^{16}	29 ^{4}	100 ^{27}	20 ^{1}	61 ^{12}	100 ^{16}
Avenella flexuosa	47 ^{13}	77 ^{16}	**100 ^{62}**	49 ^{19}	0	0	80 ^{14}	0	35 ^{8}	50 ^{18}
Calamagrostis villosa	78 ^{27}	61 ^{18}	47 ^{15}	**100 ^{74}**	50 ^{18}	100 ^{26}	90 ^{23}	40 ^{7}	74 ^{17}	75 ^{18}
Rubus idaeus	85 ^{15}	81 ^{10}	80 ^{8}	77 ^{12}	**100 ^{66}**	85 ^{25}	90 ^{9}	40 ^{5}	65 ^{6}	63 ^{16}
Sambucus racemosa	62 ^{13}	32 ^{4}	20 ^{6}	34 ^{10}	75 ^{11}	**100 ^{71}**	30 ^{6}	0	17 ^{2}	63 ^{7}
Carex tomentosa	43 ^{17}	78 ^{22}	60 ^{13}	43 ^{10}	50 ^{3}	0	**100 ^{49}**	20 ^{1}	39 ^{9}	50 ^{11}
Epilobium obscurum	3 ^{1}	2 ^{2}	0	2 ^{1}	25 ^{10}	0	0	**100 ^{16}**	13 ^{1}	13 ^{2}
Epilobium montanum	25 ^{3}	3 ^{1}	0	15 ^{6}	0	57 ^{15}	0	**20 ^{5}**	30 ^{2}	13 ^{15}
Cardamine opicii	0	0	0	0	0	0	0	**60 ^{22}**	0	0
Juncus effusus	12 ^{8}	19 ^{13}	20 ^{7}	25 ^{10}	50 ^{5}	0	20 ^{10}	40 ^{10}	**96 ^{41}**	0
Juncus conglomeratus	2 ^{5}	3 ^{12}	0	3 ^{7}	0	0	20 ^{5}	0	**30 ^{20}**	0
Juncus articulatus	2 ^{10}	0	0	3 ^{10}	0	0	0	20 ^{4}	**43 ^{14}**	0
Juncus tenuis	0	0	0		0	0	0	0	**9 ^{15}**	0
Calamagrostis arundinacea	15 ^{9}	25 ^{12}	60 ^{19}	37 ^{11}	75 ^{12}	43 ^{19}	30 ^{10}	0	13 ^{15}	**100 ^{46}**

Table 1. Identified vegetation types, synoptic table (frequency and median cover, both in %). Columns: 1. *Chamerion angustifolium*, 2. *Luzula luzuloides*, 3. *Avenella flexuosa*, 4. *Calamagrostis villosa*, 5. *Rubus idaeus*, 6. *Sambucus racemosa*, 7. *Carex tomentosa*, 8. *Epilobium*, 9. *Juncus*, 10. *Calamagrostis arundinacea*.

Vegetation type Great Willow-herb (Chamaerion angustifolium)

Vegetation type *Chamaerion angustifolium* is very common vegetation type, colonized sunlit habitats with high nitrogen supply or habitats where the soil surface had been disturbed by fire. Slope 8.0° in average.

Vegetation type White Wood-rush (Luzula luzuloides)

This is a rather common vegetation type. Occupies sunlit, more acid, relatively dry habitats with moderate nitrogen supply. Slope 9.1° in average.

Vegetation type Hair Grass (Avenella flexuosa)

This rather common vegetation type is developed on acid soils with low nitrogen content, prefers sunlit habitats. Slope 6.3° in average.

Vegetation type Fleecy Reedgrass (Calamagrostis villosa)

This frequent type of heliophilous vegetation occupies nearly plain habitats, more humic, acid soils with low nitrogen content. Slope 3.4° in average.

Vegetation type Red Raspberry (Rubus idaeus)
R
ather rare vegetation type *Rubus idaeus* requires sunlit habitats with comparatively high nitrogen supply, the leading species is tolerant against moisture and acidity. Slope 13.0° in average. The vegetation type *Rubus idaeus* has not been recorded in 2007, the vegetation type was converted mainly from vegetation type *Chamaerion angustifolium*, but from *Sambucus racemosa* and *Juncus*.

Vegetation type Red-berried Elder (Sambucus racemosa)

Rather rare and ecologicaly determinated heliophilous vegetation type *Sambucus racemosa* occupies steep slopes rich in nitrogen. Slope 12.6° in average.

Vegetation type Tomenosa Sedge (Carex tomenosa)

This rather common heliophilous vegetation type is developed on nearly plain habitats with neutral soils and poor nitrogen content. Slope 3.6° in average.

Vegetation type Horsmat (Epilobium-Cardamine)

The leading species of this rare vegetation type are more species of the genera Horsmat (*Epilobium*). These species colonize hygromophic to hydromorphic habitats of neutral pH with low nitrogen supply. Slope 9.6° in average.

Vegetation type Bog Rush (Juncus)

The leading species of this rather common vegetation type are more species of the genera Bog Rush (*Juncus*). This vegetation type is tolerant against slight shadow, occupies hydromophic, nearly plane habitats of neutral pH with low nitrogen supply. Slope 2.3° in average.

Vegetation type Rough Small-reed (Calamagrostis arundinacea)

This very rare vegetation type colonize sunlit, relatively dry, more acid habitats with moderate nitrogen supply. Slope 6.2° in average.

Note:
Vegetation type Red Sorrel (Acetosella vulgaris)

This very rare vegetation type invaded dry, mild, acid, sunlit, nearly plane habitats, poor in nitrogen. Slope 2.5° in average. Because of increased wetness due to dikes construction, within three years this vegetation type completely disappeared.

Discussion

Vegetation types *Rubus idaeus*, *Sambucus racemosa* and *Chamaerion angustifolium* are aligned along axis corresponding with the nitrogen gradient.

Vegetation types *Luzula luzuloides*, *Carex tomentosa* and *Avenella flexuosa* occupy more acid habitats moderate in nitrogen supply. These vegetation types are aligned along axis corresponding with the temperature gradient, but differing in slope. The vegetation type *Chamaerion angustifolium* prefers habitats where surface litter was completely consumed by intense fire. Burning, even if it is light intensity, can increase total nitrogen (Ryu et al. 2009). After nitrogen consumption, *Chamaerion* is often replaced by *Luzula luzuloides*.

The vegetation type *Rubus idaeus* has not been recorded in 2007, this felled-area species recorded main development in 2008, supported by high nitrogen content in soil. Bryophytes occur where the soil surface had been disturbed and fresh soil became exposed.

The hygrophilous vegetation type Horsmat (*Epilobium*) achieved the highest increase in species diversity.

The everage value of moisure index of all checked dikes in 2007 was 5,823, while in 2009 5,928, i.e. increase of 0.105 degree of Ellenberg´ s scale. While Fig. 1 shows ordination of environmental variables and vegetation types in 2009 (CCA), Fig. 2 pictures the dynamics - changes in environmental variables in relation to vegetation types in 2007-2009 (PCA). All the vegetation types recorded increase in moisture. The most significant increase in moisture we have recorded at the vegetation type *Epilobium* (Fig. 2, Table 2). Moisture variable close correlates with acidity and light. In time dimesion, moisture negatively correlates with nitrogen, the reason is evident, an increasing moisture and vegetation growth caused the nitrogen consumption (Fig. 2). Except for vegetation type *Epilobium*, the decrease in nitrogen values is everywhere significant. Nitrogen supply was gradually consumed by vegetation, resulting in 2008 - 2009 by expansion of less nitrophilous species, mainly *Luzula luzuloides*.

Some vegetation types showed shift to less acid area, especially nitrophilous, e.g. vegetation type *Rubus idaeus*.

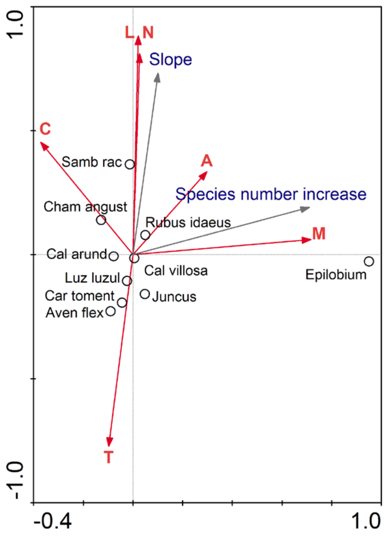

Fig. 1. Canonical correspondence analysis (CCA), ordination of environmental variables and vegetation types in 2009. Source data: species variables - synoptic table 2009; environmental variables - weighted Ellenberg´ s indicator plant´ s values. Environmental variables: **L** - light, **T** - temperature, **C** - continentality, **M** - moisture, **A** - acidity, **N** - nitrogen. Species number increase in 2007 - 2009 and slope were plotted in the ordination diagram as supplementary variables (nitrogen p=0.04, F=1.67; light p=0.13, F=1.57).

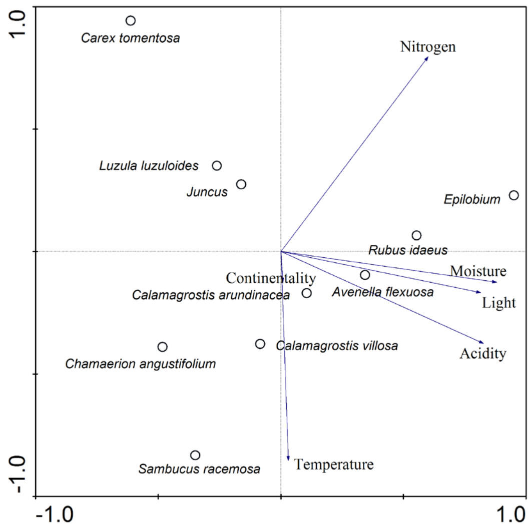

Fig. 2. Principal component analysis (PCA). Change in values of environmental variables in 2007 - 2009. Eigenvalues: 1st axis 0.510, 2nd axis 0.288, 3rd axis 0.144. Source data: Changes in environmental variables in 2007 - 2009 (Table 2).

Sorbus aucuparia and *Picea abies* increased in all vegetation types. The immense natural regeneration of *Acer pseudoplatanus*, *Corylus avellana*, *Betula pubescens*, *Pinus sylvestris* is ongoing in *Luzula luzuloides* vegetation type (Fig. 3). Suitable regeneration potential provide vegetation types *Chamaerion angustifolium*, *Juncus* and *Carex tomentosa*, while in *Rubus idaeus* and *Calamagrostis arundinacea* vegetation types only few seedling of *Sorbus aucuparia* could be recorded, *Picea abies* and *Populus tremula* are an exception. *Populus tremula* gives preference to vegetation type *Juncus* (Fig. 3). We couldn´ t recorded natural regeneration in vegetation types *Sambucus racemosa* and *Epilobium*.

The high moisture values show eye terraces, beaver's dikes and cassette structures. After three year activity is shown that the triangular dikes and semicircular dikes are more efficient than contour-line dikes (Fig. 4). The terraces are narrow structures, usually constructed on the steepe slopes. With respect to the moisture indicator plant´ s value, they are less efficient.

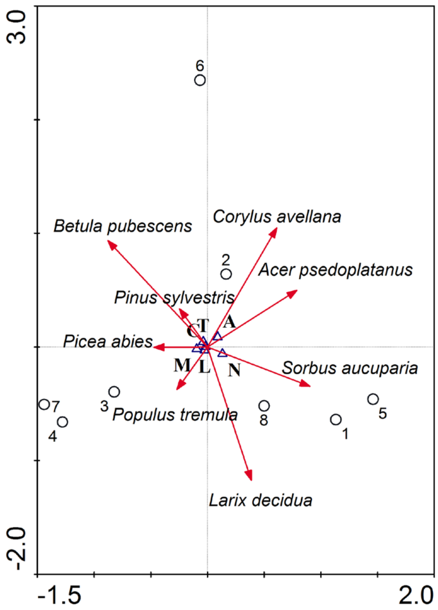

Fig. 3. Canonical variate analysis (CVA). Triplot, the seedling ordination in relation to vegetation types: 1. *Chamaerion angustifolium*, 2. *Luzula luzuloides*, 3. *Avenella flexuosa*, 4. *Calamagrostis villosa*, 5. *Rubus idaeus*, 6. *Carex tomentosa*, 7. *Juncus*, 8. *Calamagrostis arundinacea* and environmental variables: **L** - light, **T** - temperature, **C** - continentality, **M** - moisture, **A** - acidity, **N** - nitrogen.

	1	2	3	4	5	6	7	8	9	10
Light	-0.31	-0.33	-0.16	-0.13	-0.10	-0.14	-0.28	0.18	-0.37	-0.16
Temperature	-0.20	-0.31	-0.24	-0.11	-0.30	-0.01	-0.34	-0.18	-0.30	-0.13
Continentality	-0.20	-0.13	-0.06	-0.03	-0.23	-0.01	-0.10	-0.04	0.03	-0.04
Moisture	0.03	0.02	0.30	0.15	0.15	0.11	0.03	0.38	0.08	0.19
Acidity	-0.32	-0.33	-0.10	-0.28	0.05	-0.33	-0.74	-0.08	-0.26	-0.21
Nitrogen	-0.56	-0.24	-0.26	-0.43	-0.15	-0.64	-0.14	0.02	-0.23	-0.30

Table 2. Principal component analysis (PCA). Change in values of environmental variables in 2007 - 2009. Eigenvalues: 1st axis 0.510, 2nd axis 0.288, 3rd axis 0.144. Source data: Changes in environmental variables in 2007 - 2009.

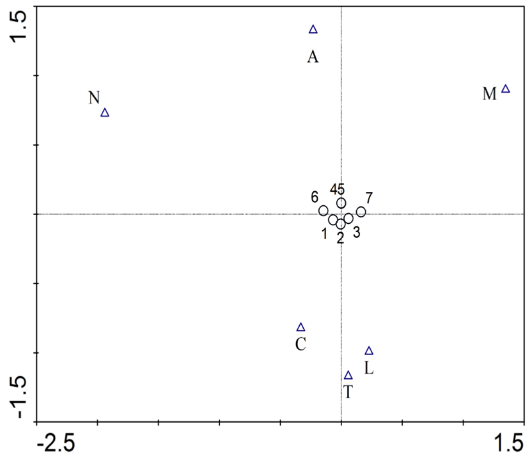

Fig. 4 Detrended correspondence analysis (DCA), ordination of dike types in 2009. 1 - contour-line dikes, 2 - triangular dikes, 3 - eye terraces, 4 - beaver's dikes, 5 - semicircular dikes, 6 - terraces, 7 - cassette structures.

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