

Dynamics of organic carbon and dissolved iron in relation to landscape diversity

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Abstract

Spatial diversity of landscapes results in spatial and temporal heterogeneity of soil physical and soil chemical parameters. These diversities of pH and E_H may cause spatial and temporal differences of dissolved macro- and microelements between ecotopes. The present paper focuses on the relationship between vegetation induced landscape patterns and the spatial and temporal diversities of soil physical and chemical parameters. We supposed that the higher plants induced soil chemical differences generate concentration gradients between ecotopes. This study primarily deals with organic carbon and iron turnover in a headwater wetland.

The study area is divided into six distinct patches (ecotopes). Measurements have been taken in the core parts of ecotopes (patches) and along their boundaries. There have been measured individual seasonal dynamics of pH and of E_H . The increasing physiological activity of higher plants caused specific E_H . It leads to higher spatial differences of redox conditions between April and August. The most reductive conditions were measured in sedge patches, while higher E_H prevail in horsetail and nettle dominated ecotopes. DOC concentrations have also shown similar pattern as the E_H . More reductive conditions have been correlated with higher DOC content. Under $E_H < 25$ mV there is a direct correlation between the amount of dissolved iron and the redox conditions. The differences of E_H may induce concentration gradients between ecotopes and a potential for horizontal DOC and dissolved iron turnover. Quantification of these turnovers by diffusion is nearly beyond possibility due to the labyrinth effect. Although we could not determine the extent of diffusion, thus to estimate the intensity of elements movement along concentration gradients between two spatial units, we introduced a new indicator called “boundary permanence index (BI)”. Results of 300 days long measurement suggest that the intensity of horizontal turnover mainly depends on the shape of the spatial units (length of boundaries) and on the dissimilarities between dominant herbaceous plants.

Keywords: landscape diversity, wetland, iron, dissolved organic carbon, redox conditions, ecotope

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Introduction

Comprehensive knowledge about global macro-element cycles have been published since late 60's on the basis of ecosystem studies (WHITAKER, R.H. 1975; ODUM, E. *et al.* 2004). These publications have essential influence on the scope and the methodology of emerging geo-ecology. The field-scale studies on nutrient cycling became one of the most important sub-discipline of geo-ecology (LESER, H. 1976). These disciplines have been active in Hungary until recently (SZALAI, Z. 1998; SZABÓ, M.–MOLNÁR, E. 2001; FARSANG, A.–M. TÓTH, T. 2003; BARTA, K. *et al.* 2006, ANTON, A. *et al.* 2008, SZABÓ, Gy. *et al.* 2008, SZABÓ, Sz. *et al.* 2008). Other sub-discipline of geo- or landscape ecology rather focused on analysis of landscape structure (FORMAN R.T.T. 1995, LÓCZY D. 2003, CSORBA P. *et al.* 2004, SZABÓ, M *et al.* 2008, KERTÉSZ, Á. 2009). This wing mostly deals with the relationship between landscape diversity and landscape stability (KEVEINÉ BÁRÁNY, I. 2003; CSONTOS, P.–TAMÁS, J. 2007; KERTÉSZ, Á. 2008). The diversity of ecotopes has an influence on the heterogeneity of soil physical and soil chemical parameters too (MOISMANN, TH. 1984; SZALAI, Z. 2008).

The most important soil chemical factors for the solubility are the chemical reaction and the redox conditions (IMPELLITERITTI, C.A. 2005; GENIN R. J-M. 2006; SZABÓ, Sz.–SZABÓ, Gy. 2006). The pH mostly enhances solubility in acidic range: solubility of Al(III) increases below pH 5.5, solubility of Fe(III) increases below pH 3.5 and solubility of Ti(II) increases below pH 3.0. The solubility of some minerals also may increase towards higher pH, as e.g. quartz (BOHN, H. *et al.* 1979).

Oscillation of redox conditions can be even more important factor for solubility. Reductive conditions increase solubility of several major and trace elements, such as iron, aluminium, arsenic, copper, etc. (CALLIE, N. *et al.* 2003). Redox potential in wetland soils is affected by saturation (PONNAMPERUMA, F.N. 1972), by quality of higher plants (WIESSNER, A. *et al.* 2005; DUSEK J. *et al.* 2008; SZALAI, Z. 2008), by activity of microorganisms (EGGLETON, J.–THOMAS, K.V. 2004; NIKOLAUSZ M. *et al.* 2008) and by presence of electronacceptors (PONNAMPERUMA, F.N. 1972).

The status of saturation correlates with the abundance/absence of O₂ and with E_H. The published threshold E_H values for activity of denitrifying bacteria vary between +400 mV (ROWELL, D.L. 1981) and +231 mV (RIVETT, M.O. *et al.* 2008). The published threshold E_H for Fe(III) reduction is also alter in wide range between +100 mV (DUSEK, J. *et al.* 2008) and -130 mV (GUO, T. *et al.* 1997; RIVETT, M.O. *et al.* 2008).

The major and trace metal reduction is strongly affected by microbial activity (GAMBRELL, R.P. 1994; KOMLOS, J. *et al.* 2007; ASCAR, L. 2008; NEBAUER S.C. *et al.* 2008). WEISS *et al.* (2005) reported that Fe(III) plaques are more rapidly reduced in rhizosphere than in non-rhizosphere. They found that

the iron oxidation and reduction is primarily driven by Fe(II)-oxidizing and Fe(III)-reducing bacteria.

The soil aeration status also depends on the dominant species of higher plants, due to the oxygen release through their aerenchyma. The range of oxic habitat around the rhizosphere depends on the physiological status of plants (LAMBERS, H. *et al.* 1998), and the activity of microbial communities, while the aeration status of the whole soil also depends on the structure and density of roots. The various lab-scale and field scale studies applied by different higher plants have reported distinct dynamics of E_H (NAGAI T. *et al.* 2007; BATTY, L.C.–YOUNGER, P.L. 2008; DUSEK, J. *et al.* 2008, NIKOLAUSZ, M. *et al.* 2008).

Since field scale and batch scale studies reported various redox dynamics in relation with different kinds of environmental conditions (e.g. dominant higher plants, microbial communities), they may appear as spatial and temporal heterogeneities of dissolved organic carbon and dissolved iron as well.

The present paper focuses on (a) the spatial pattern and seasonal dynamics of redox potential dissolved organic carbon and dissolved iron in the upper 15 cm of soils, on (b) the origin of these differences and on (c) the relationship between landscape heterogeneity and the amount of concentration gradients of DOC and of dissolved iron.

Materials and methods

Site description

The study area is situated in Völgység region (Tolna County, Hungary), in a headwater valley extending in north to south direction (*Figure 1*). The total area of headwater wetland is less than 3,000 m². The wetland is a functional unit. Six vegetation induced individual spatial units were defined (*Figure 2*). Five of studied patches are dominated by only one herbaceous plant species: sedge (*Carex remota*, *Carex vulpina*(?) and *Carex riparia* – three individual patches), horsetail (*Equisetum arvense*), common nettle under common maple (*Urtica dioica* and *Acer campestre*). The sixth wetland ecotope does not have dominant herbaceous plant. Most of the landscape forming factors (meso-climate, soil, soil moisture) are homogeneous (*Table 1*). The studied wetland is bordered by mesophilous meadow and oak forest and it does not have outflow in most of the year. 3–10 points were used for soil sampling and for control measurements (depending on the area) and 3–5 points were used for sampling at boundaries of patches. The samples were collected from and field measurements carried out in the upper 10–15 cm horizon. All the wetland ecotopes were characterized as *mollic gleysol siltic calcaric*. The topsoil is densely penetrated by roots. The root density drastically decreases with depth and becomes negligible at 35–50 cm.

Temperature, pH, redox and PAR field measurements

One point was monitored continuously in each wetland ecotope and in each boundary. Temporary control measurements were carried out at the sampling points using handy TESTO230 pH and E_H meter. Each point of measurement included 3 measuring holes ($d = 0.9$ cm, depth = 15 cm) for the E_H and pH probes and for sampling. The permanent holes for sampling were closed by plastic sticks. The measured parameters were recorded by data collectors. The parameters were measured each day between February 15 and December 12, 2005. Since pH, E_H , and PAR units are highly variable, means of three observations per day (12:50; 13:00, 13:10) were used. Soil solution samples were transferred into falcon type PE tubes. Soil solution samples for iron measurement were conserved using cc. nitric acid. Testo Type 04 pH electrodes (with thermometer) were applied for pH measurement. The pH calibration was carried out before installation, and it was repeated at the end of the year. Applied probes were tested in laboratory using pH 7.00 and pH 10.00 buffer solutions at 25 °C. 20 pcs of Type 04 probes have recorded 24.9 °C and 2 pcs of probes measured 24.8 °C in comparison with the reference thermometer (TESTO 01: 25.0°C). Before calibrations Type 04 probes recorded pH 6.92–7.01 at pH 7.00 and pH 9.87–10.05 at pH 10.00, whereas after calibration the range of measured values were pH 6.98–7.04 and pH 9.98–10.03 for pH 7 and pH 10 buffer solutions respectively. The applied pH probes allowed continuous thermal correction.

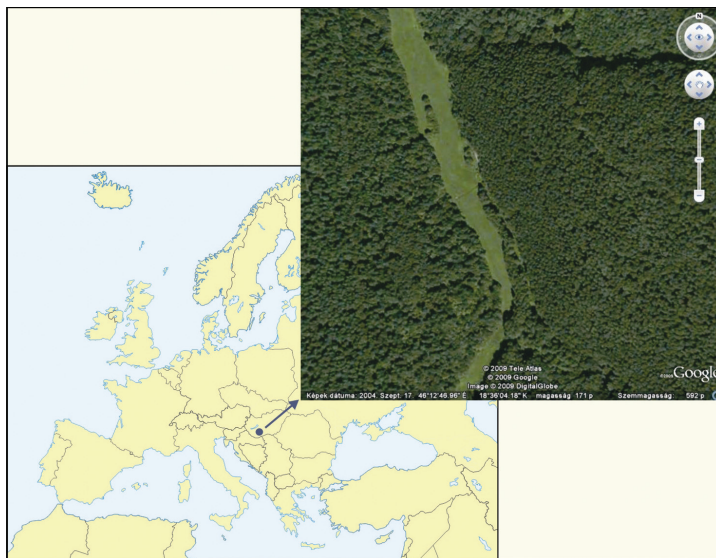


Fig. 1. The study area

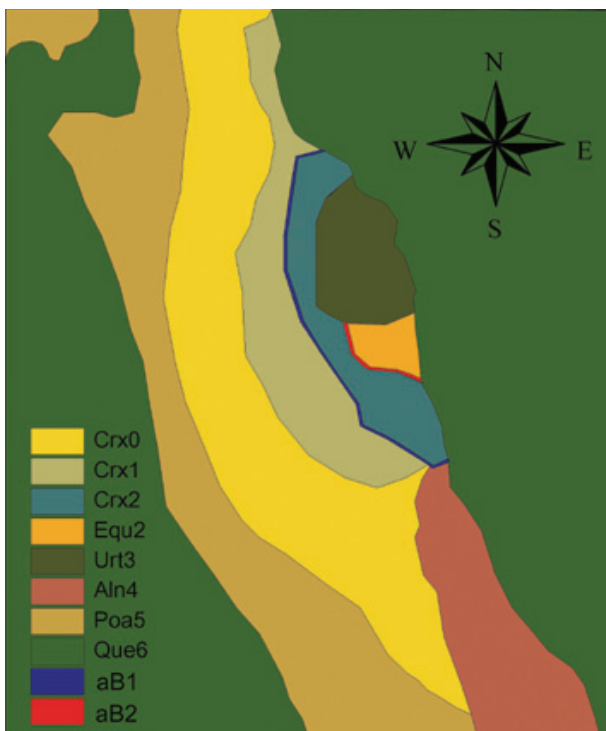


Fig. 2. Distribution of the studied ecotopes

of +352–+365 mV. To characterize redox status of the soils three threshold values were used. E_H values below +300 mV, +230 mV and +100 mV indicate activity of denitrifying bacteria, reduction of Mn^{4+} ions and reduction of Fe^{3+} ions, respectively.

Photo-synthetically active radiation (PAR, $\lambda = 400\text{--}700$ nm) was determined by Skye 200 quantum interceptor. PAR measurements in the open ecotopes were carried out upon the ground surface and on the surface of vegetation, and they were performed upon the ground surface and on the surface of herbaceous vegetation in the shaded (woody) ecotopes.

Lab measurement

Soil pH (pH_{dw} , pH_{KCl}) was also measured in laboratory following the “International A method” (Buzás, I. 1988) using Jenway 3510 pH meter. Soil organic carbon (TOC) and dissolved organic carbon (DOC) were measured by NDIR-chemiluminescent analyser (Tekmar Dohrmann Apollo 9000N). Textural properties of soils were determined with laser diffraction analyser (Fritsch

E_H conditions were recorded by Testo Type 06 calomel electrodes. Since the E_H is one of the most variable parameter the mean of three measurements (12:50, 13:00, 13:10) were used. The recorded data were corrected relative to the normal hydrogen electrode by adding E_{Hcor} value, which depends on temperature ($E_{Hcor} = -1.3903 \times T + 585.29$; $R^2 = 0.9985$; T = temperature (K); on the basis of the manufacturer’s correction data). Redox probes were tested before installation in laboratory using Ag/AgCl redox standard solution (+358 mV) at 25°C. Applied probes recorded values in a range

Table 1. Spatial distribution of main landscape forming factors

	Crx0	Crx1	Crx2	Equ2	Urt3	Aln4	aB1	aB2
Area (sqm)	1360	525	276	69	242	484	27	8
Perimeter (m)	271	177	122	37	63	112	125	34
Length (m)	-	-	-	-	-	-	62	16
Dominant herbaceous species	Sedge <i>C. remota</i>	Sedge <i>C. vulpina</i> (?)	Sedge <i>C. riparia</i>	Horsetail <i>E. arvense</i>	Nettle <i>U. dioica</i>	none	Sedge	Sedge /horsetail
Dominant tree species	none	none	none	none	<i>Acer campestre</i>	<i>Alnus glutinosa</i>	none	none
Number of sampling points and of the control measurements	10	7	7	3	5	5	5	3

Crx0, Crx1, Crx2, Equ2, Urt3, Aln4 = studied ecotopes; aB1 = boundary between Crx1 and Crx2 ecotopes; aB2 = boundary between Crx2 and Equ2 ecotopes

Analysette Microtech A22). Mineralogical properties of soils were determined by X-Ray diffraction analyser (Philips PW1710). Total iron content of soils was measured by X-Ray Fluorescence Spectrometer (Atomika Extra IIA and Philips PW1410).

Total bounded iron was determined on the basis of HNO₃-H₂O₂ digestion method: 1g soil was digested in 3 ml 2M HNO₃ and 5 ml 30% H₂O₂. The samples were then heated to 85°C, and maintained at this temperature for 6 hours with intermittent agitation. Later 3 ml aliquots of 30% H₂O₂ (adjusted to pH 2.0 by HNO₃) were added and the samples were heated again to 85°C for 12 hour with intermittent agitation. After cooling 5 ml 3,2 M NH₄OAC and 20% HNO₃ (v/v) were added and followed by dilution to a final volume of 20 ml with DI water. The tubes were continuously agitated for half an hour.

The available iron content of soils was extracted following Lakanen-Erviö method (Hungarian Standard-MSZ21470-2). The extractions were measured by fl-AAS. The conserved water samples were measured using VIS spectrophotometer (Merck SQ118) and gf-AAS (Zeiss AS30).

Statistical methods

Statistical analysis was carried out using SPSS 14.0. Normality of data series were tested by Shapiro-Wilk test. For the relationship analyses Spearman correlation coefficients were used, because the data did not have normal distribution.

Table 2. Physical parameters of solid phase

	Crx0	Crx1	Crx2	Equ2	Urt3	Aln4	aB1	aB2
N	10	7	7	3	5	5	5	3
Sand (%)	6.4	5.6	6.7	6.5	6.1	5.9	6.1	6.9
Silt (%)	88.7	83.8	85.1	85.4	80.1	80.6	84.4	84.9
Clay (%)	4.9	10.7	8.2	8.1	13.8	13.5	9.5	8.2
pH _{dwater}	7.99	7.95	7.82	7.81	7.79	7.76	7.91	7.82
pH _{KCl}	7.85	7.79	7.72	7.70	7.74	7.73	7.76	7.72
CaCO ₃ (%)	13.7	8.7	3.3	3.3	3.3	3.3	7.2	3.3
TOC (mg/kg)	30899	23393	25049	24551	25602	26415	24934	24159
TN _b (mg/kg)	2575	1949	2087	2046	2133	2201	2078	2013
Total iron (mg/kg)	31100	35500	37010	36870	24230	23820	41340	45950
cc. HNO ₃ -H ₂ O ₂ extractable iron (mg/kg)	21000	20780	16800	13290	12710	11850	25950	38950
Lakanen-Erviö extractable iron (mg/kg)	410	1582	580	889	909	840	4511	4832

N = sample size

Results

Environmental parameters

Most of the main soil parameters are quasi homogeneous (Table 2). The texture is loam, the CaCO₃ content is 3.3% in the valley bottom and it is increasing towards the slopes. The mineral composition of the fine earth fraction is also homogeneous (Figure 3). Primary silicate minerals (quartz, plagioclases, K-feldspars, amphibole), primary and secondary phyllo-silicates (mica, illite, chlorite), calcite and dolomite are the main minerals. The XRD measurement did not detect iron minerals, however 2.4–4.6% of iron was detected by XRF and by AAS. The total iron content of soils was the highest at the boundary between Crx1 and Crx2 patches (aB1) and the boundary between Crx2 and Equ2 patches (aB2). The cc HNO₃-H₂O₂ extractable iron and Lakanen-Erviö extractable iron concentrations were also higher in these boundaries than in the core part of the patches. This kind of distribution was not observed in the organic carbon content of the solid phase (TOC).

The main meso-climatic parameters (precipitation 909 mm/y; mean air temperature above surface at 2 m: 12°C; mean wind velocity: 8.8 m s⁻²; annual amount of sunshine hours: 1828 h; number of cloudy days: 254 days; overcast: 114 days; duration of snow cover: 34 days) were modified by microrelief and vegetation pattern and appeared as a characteristic microclimate of ecotope (Table 3). The differences in incident radiation (Figure 4)

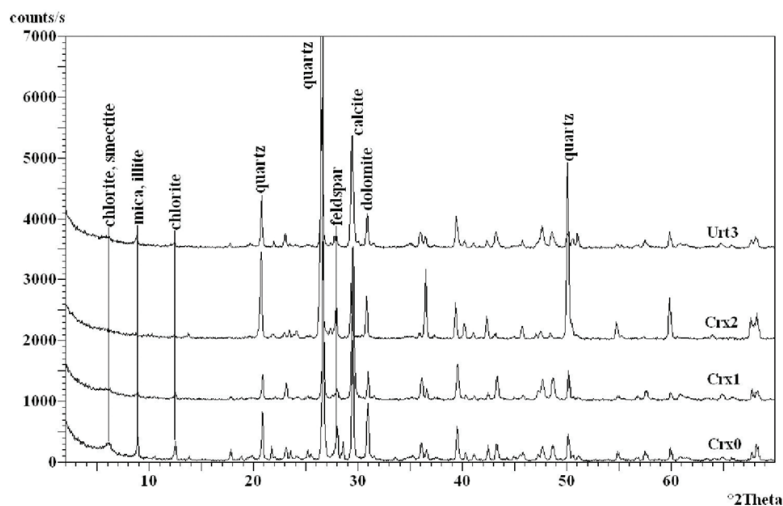


Fig. 3. The mineral composition fine earth fraction. Crx0, Crx1, Crx2, Urt3 = ecotopes

Table 3. Duration of anaerobic conditions, spatial differences in the incident solar radiation and yearly average of porewater temperature in the studied ecotopes

	Crx0	Crx1	Crx2	Equ2	Urt3	Aln4	aB1	aB2
Duration of saturated conditions (days)	156	300	300	300	142	136	300	300
Duration of unsaturated conditions (days)	14	0	0	0	158	164	0	0
Max. amount of PAR (umol m ⁻² s)	1756	1756	1756	1528	1247	712	1756	1756
Yearly average of porewater temperature (°C)	15.8	12.1	11.9	12.1	11.9	11.9	13.9	12.0

PAR = photosynthetically active radiation

and in the duration of saturated conditions appear in the diurnal and seasonal fluctuation of porewater temperature (Figure 5).

The pH of porewater was always lower and showed higher diversity between spatial units than the measurements carried out in the laboratory did for pH_{dw} and pH_{KCl} of soils (Figure 6). The higher porewater pH values were usually measured during the winter season, while lower ones were observed during the vegetation period. The seasonal fluctuations of pH in core part of wetland patches did not reach the pH unit and it was higher in the studied boundaries. Although high seasonal fluctuations were observed towards the acidic conditions in the boundaries, the observed lowest values were not acidic enough to increase solubility of Fe(OH)₃.

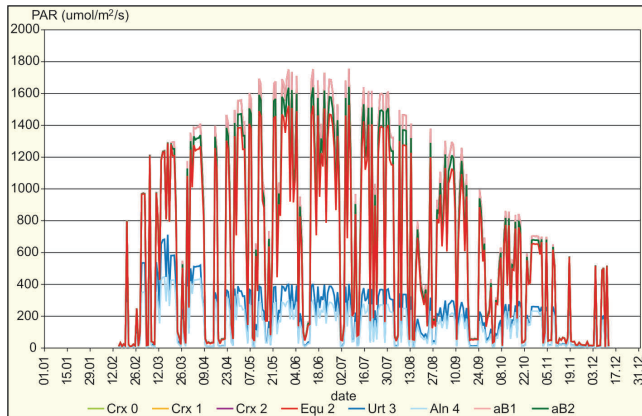


Fig. 4. Seasonal fluctuation of photosynthetically active radiation at the surface of herbaceous vegetation

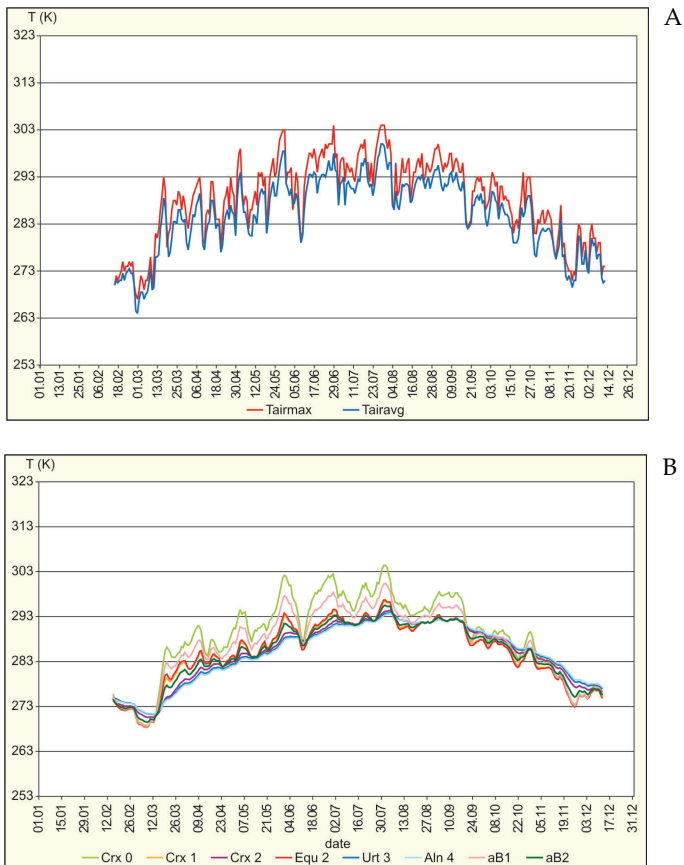


Fig. 5. Seasonal fluctuation of (A) air and (B) porewater temperature

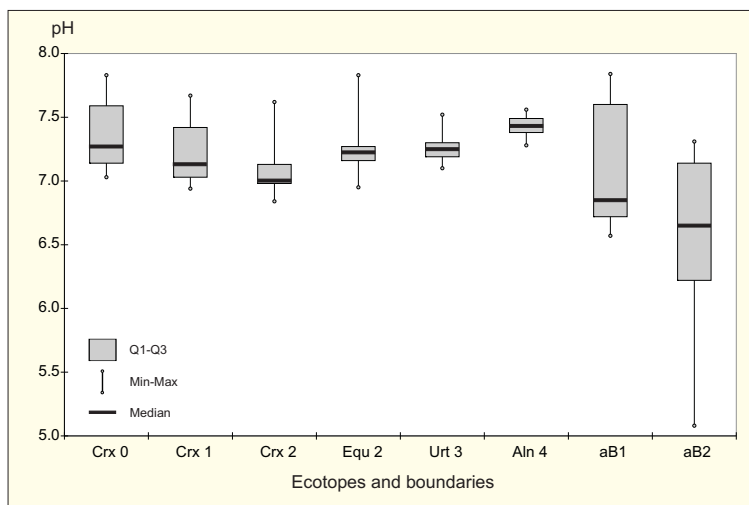


Fig. 6. Fluctuation of porewater acidity in the studied wetland ecotopes. Q1–Q3 = inter quartile; Min–Max = range; Median; N = 2400

3.2. Seasonal fluctuation E_H

The redox status of the soils is depended on the duration of inundation (DUSEK, J. *et al.* 2008). Half of wetland ecotopes were inundated for the whole year and half of them were unsaturated for 144–164 days. Anaerobic conditions appeared in all wetland ecotopes. The value and the length of reductive conditions were not only depending on the saturated conditions, it also correlated with the herbaceous vegetation. The shortest anaerobic conditions were observed in Crx0, Urt3 and Aln4 ecotopes. The time of anaerobic environment varied between 38 and 85 days in the (other) spatial units, except for Equ2 where the duration of anaerobic conditions was lasting longer than five months. The E_H value was never below +231 mV in these spatial units. Although the duration of saturated conditions were equal in Equ2, and Crx1 ecotopes, the duration of anaerobic condition was shorter by 64 days in Equ2 than in Crx1 ecotopes. Besides E_H was lower in the sedgy (Crx1) ecotope than in the horsetail (Equ2) ecotope. The time of saturated conditions were also 300 days long in Crx2 ecotope and in its aB boundaries, but the number of the reductive days was higher by 60 days. Moreover, E_H was below +100 mV in the aB boundaries (Figure 7).

The E_H values started to decrease in the middle of March, then slightly increased again from July and August (Figure 8). While the amount and variability of redox conditions are partly depended on the the time of saturated

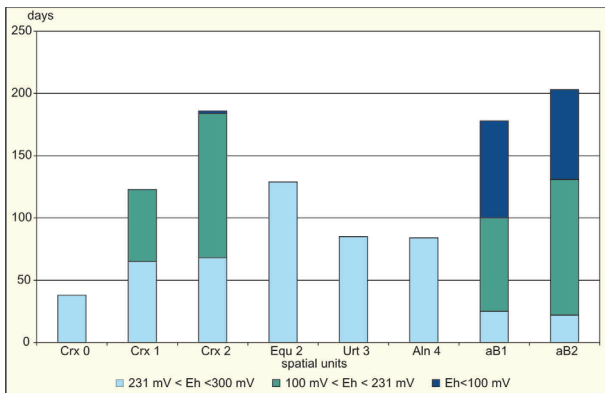


Fig. 7. Duration of anaerobic conditions in the studied wetland ecotopes

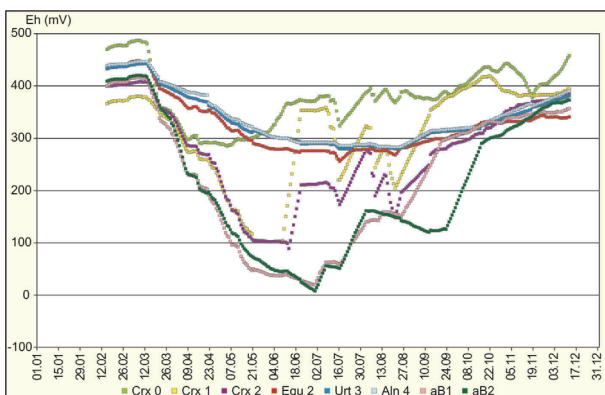
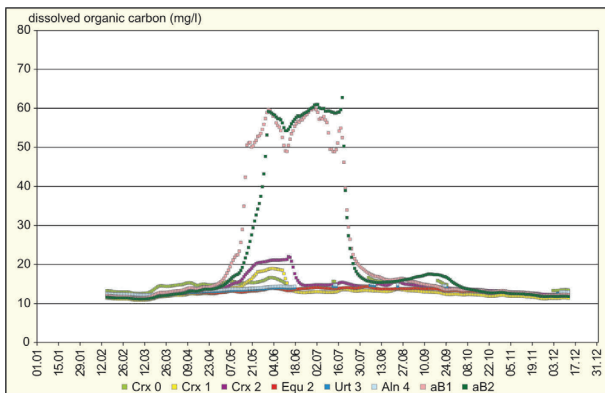


Fig. 8. Seasonal fluctuation of E_H in the studied wetland ecotopes (each box marks a mean of three measurements: 12:50, 13:00, 13:10)



conditions, the seasonal dynamics of redox potential is only determined by the vegetation. The oscillation of redox status was not as intensive as DUSEK *et al.* (2008) have published. This can be explained by the different timing of measurements. NIKOLAUSZ *et al.* (2008) and our team (SZALAI, Z. *et al.* 2009) also observed high diurnal variation of $E_{H'}$ in contrast with the midday measurements where similar values were shown.

Relation of redox condition to DOC and to dissolved iron

The DOC concentration of soil solution varied between 12–18 mg/l in the majority (80%) of measurements (Figure 9). These values fit to the batch scale results (CALLIE, N. *et al.* 2003) and two-three times higher than most of the aquifers (RIVETT, M.O. *et al.* 2007). The range of DOC concentration (80% of measurements) is smaller than 5 mg/l in each core part of ecotopes.

Fig. 9. Seasonal variation of dissolved organic carbon in the studied wetland ecotopes

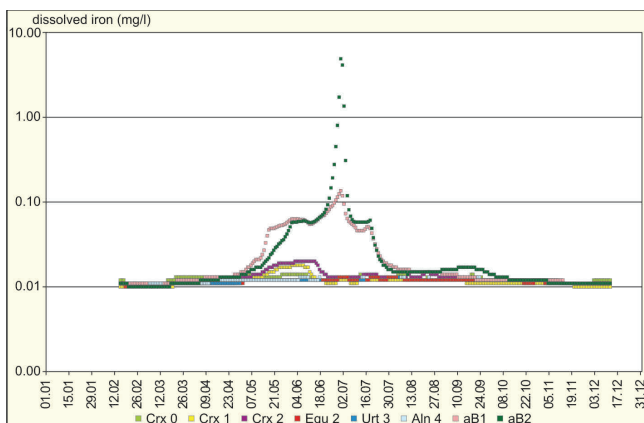


Fig. 10. Seasonal variation of dissolved iron in the studied wetland ecotopes

Variation of dissolved organic carbon has almost reached 50 mg/l in aB boundaries. The winter values of DOC are usually close to 11–12 mg/l, however concentrations reached 15 mg/l by the middle of June (Figure 10). The decreasing E_H always indicates increasing DOC content. The highest concentrations of DOC coincided with the lowest E_H .

The reduction of Fe^{3+} to Fe^{2+} increased the amount of dissolved iron in the porewater. Although the publications reported threshold values for microbial iron reduction between +100mV (KOROM, S.F. 1992) and -130mV (GUO, T. *et al.* 1997), the observed dissolved iron content increased from 10 $\mu\text{g/l}$ to 20 $\mu\text{g/l}$ below +231 mV. The concentration of dissolved iron was much higher in the aB boundaries. The concentration patterns of DOC and dissolved iron were similar until E_H reached +25 mV and then the concentrations of DOC remained constant, while the amount of dissolved iron has reached the 4890 $\mu\text{g/l}$. This extreme high concentration of dissolved iron was only observed in the aB boundaries for 12 days (Figure 10).

Discussion

Interrelationships between porewater temperature, PAR, pH, E_H , DOC and dissolved iron

We supposed that higher plants have direct and indirect effects on soil E_H and pH. The direct influence is the O_2 translocation to the rhizosphere through the aerenchyma and the root excretion of organic acids. The indirect effect can be the shading, which has influence on soil temperature. Both of them are influenced by the incident radiation. In contrast to our initial conception, our results support the PAR has only indirect influence on E_H and pH. It significantly correlates with porewater temperature, but it does not correlate with E_H and pH (Table 4). Although we did not studied physiological activities of higher plants, it can be explained with the delay of root excretion to maximum

Table 4. Table of Spearman's correlation

Spearman's rho		PAR	T _{porewater}	pH	E _H	DOC	dIron
PAR	Corr. coeff.	1.000*	-0.386*	-0.407*	-0.365*	0.379*	0.404*
	N	2408	2408	2408	2408	1927	1926
T _{porewater}	Corr. coeff.		1.000*	-0.466*	-0.609*	0.806*	0.815*
	N		2408	2408	2408	1927	1926
pH	Corr. coeff.			1.000*	0.666*	-0.588*	-0.652*
	N			2408	2408	1927	1926
E _H	Corr. coeff.				1.000*	-0.840*	-0.897*
	N				2408	1927	1926
DOC	Corr. coeff.					1.000*	0.988*
	N					1927	1925
dIron	Corr. coeff.						1.000*
	N						1926

PAR = photosynthetically active radiation, T_{porewater} = porewater temperature, DOC = dissolved organic carbon, dIron = dissolved iron, N = sample size; *Correlation is significant at the 0.01 level (2-tailed)

intensity of PAR. There is significantly no correlation between soil temperature and pH, there is weak relationship between DOC and pH. The soil temperature correlates primarily with DOC and E_H. The higher porewater temperature usually results higher DOC and lower E_H. The correlation is strong between E_H and dissolved iron and between E_H and DOC, the amount of dissolved iron is determined by the DOC in the +300–+25 mV range.

Estimation of potential intensity of horizontal turnover between wetland ecotopes

The studied wetland ecotopes are divided into two groups on the basis of the time period of saturated conditions. The Crx1, Crx2 and Equ2 ecotopes were continuously saturated, while Crx1, Urt3 and Aln4 ecotopes were unsaturated for five months. The time of anaerobic condition was not directly depending on this parameter, since E_H below +300 mV was more persistent in Urt3 than in Crx1. Similar distribution of E_H was observed in the other group, as well. The anaerobic condition was more intensive and more persistent in Crx2 than in Equ2.

Our results support the view that the spatial distribution of soil physical and chemical parameters directly affected by vegetation pattern of the surface. The spatial heterogeneousness is not constant, it is negligible during wintertime and can be significant between April and August. The diversity of soil physical properties (e.g. porewater temperature) and of soil chemical parameters (e.g. redox) has resulted in concentration gradients of DOC and of dissolved iron between wetland ecotopes.

The DOC (and iron) turnover can appear as diffusion (and convection). The temporary existing concentration gradients can be the momentum of diffusion, while the differences of evapotranspiration of ecotopes may affect convection. Heterogeneity of ecotopes affects both of these processes. The landscape diversity can be measured by several indices (FORMAN, R.T.T, 1995). The turnovers by diffusion are primarily influenced by the length of the boundaries in the study area (m/m²).

The quantification of diffusion was not possible owing to the labyrinth effect. Although we did not quantify the DOC and iron turnover by diffusion, we tried to estimate the intensity of these processes. The potential intensity of horizontal turnover depends on the length of boundary of two studied ecotopes, on the duration and rate of the concentration gradient. We suppose to introduce a “boundary index” (BI) to estimate this process:

$$BI_{ij} = \frac{B_{ij} - \text{Min}(B_1..B_n)}{\text{Max}(B_1..B_n) - \text{Min}(B_1..B_n)}$$

where,

$$B_{ij} = |l \cdot t \cdot c|$$

l is the length of boundary between i and j ecotopes (m); t is the duration of concentration gradient between i and j ecotopes; c is the mean of concentration gradient ($\mu\text{g/l}$ or $\mu\text{mol/l}$) i and j ecotopes, n is the number of boundaries.

The value of BI varies between 0 and 1, and it allows to compare the potential intensities of diffusion of different kinds of elements and molecules.

Functional landscape units can be characterized by “landscape boundary index”, which also varies between 0 and 1.

Table 5. Potential horizontal DOC and dissolved iron turnover on the basis of Landscape Boundary Index

	Crx0-Crx1	Equ2-Urt3	Crx2-Urt3	Crx0-Aln4
	Dissolved organic carbon			
Concentration gradient ($\mu\text{mol l}^{-1}$)	-192	-26	641	328
Duration (days)	24	2	37	30
Direction	to Crx0	to Equ2	to Urt	to Aln4
B ($\mu\text{mol m d l}^{-1}$)	427 622	541	611 899	383 760
Boundary index	0.699	0	1.000	0.627
Landscape boundary index	0.581			
	Dissolved iron			
Concentration gradient ($\mu\text{mol l}^{-1}$)	-0.062	0	0.138	0.085
Duration (days)	21	0	31	21
Direction	to Crx0	n.d.	to Urt3	to Aln4
B ($\mu\text{mol m d l}^{-1}$)	121	0	110	70
Boundary index	1.000	0	0.914	0.576
Landscape boundary index	0.622			

Our results support that the diffusion driven DOC horizontal turnover is potentially less intensive than dissolved iron turnover. The highest potential turnovers were calculated between Crx2 and Urt3 ecotopes (Table 5). This potential is primarily caused by the length of boundary. On the basis of our results, we suppose that the decreasing compactness (FORMAN, R.T.T. 2001) of ecotopes increases the horizontal turnover within a wetland.

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REFERENCES

- ANTON, A., CSONTOS, P., TAMÁS, J. and KALAIPOS, T. 2008. Effects Pinus nigra plantations on the soils of dolomite grassland. *Cereal Research Communications* 36 (2): 715–718.
- ASCAR, L., AHUMADA, I. and RICHTER, P. 2008. Influence of redox potential (Eh) next term on the availability of arsenic species in soils and soils amended with biosolid. *Chemosphere* 72 (10): 1548–1552.
- BUZÁS, I. 1988. *Talaj- és agrokémiai vizsgálati módszerkönyv 2. (Methods of analysis for soils and agrochemistry 2.)* Budapest, Mezőgazdasági Kiadó, 243 p.
- BARTA, K., FARSANG, A., MEZŐSI, G., ERDEI, L. and CSER, V. 2006. Fitoremediációs kísérletek eltérő szennyezettségű területeken. (Fitoremediation experiments on different polluted areas.) *Talajvédelem* 28.: 144–152.28.
- BATTY, L.C. and YOUNGER, P.L. 2007. The effect of pH on plant litter decomposition and metal cycling in wetland mesocosms supplied with mine drainage. *Chemosphere* 66: 158–164.
- BOHN, H. L., MCNEAL, B.L. and O'CONNOR, G. A. 1979. *Soil Chemistry*. New York, John Wiley and Sons, 363 p.
- CALLIE, N., TIFFREAU, C., LEYVAL, C. and MOREL, J.L. 2003. Solubility of metals in an anoxic sediment during prolonged aeration. *The Science of the Total Environment* 301: 239–250.
- CSONTOS, P. and TAMÁS, J. 2007. Fás mezsgyék növényzetének vizsgálata a Balaton-felvidéken (Vegetation studies of hedges in the Balaton Riviera, Hungary.) *Acta Agronomica Óváriensis* 49. (1): 3–14.
- CSORBA, P., LÓCZY, D. and MEZŐSI, G. 2004. Recent Landscape Research in Hungary. *BELGEO, Special Issue*, 289–300.
- DUSEK, J., PICEK, T. and CIZKOVÁ, H. 2008. Redox potential dynamics in a horizontal subsurface flow constructed wetland for wastewater treatment: Diel, seasonal and spatial fluctuations. *Ecological Engineering* 34: 223–232.
- EGGLETON, J. and THOMAS, K.V. 2004. A review of factors affecting the release and bioavailability of contaminants during sediment disturbance events. *Environment International* 30: 973–980.
- FARSANG, A. and M. TÓTH, T. 2003. Spatial distribution of soil nutrient in a cultivated catchment area: estimation using basic soil parameters. In *Proceedings Book. 4th European Congress on Regional Geoscientific Cartography and Information Systems. Bologna, Italy.* Eds: ANGELELLI, A.; BARCHIESI, P.; FORNI, S.: 154–156.

- FORMAN, R.T.T. 1995. *Land mosaics. The ecology of landscapes and regions*. Cambridge, Cambridge University Press, 632 p.
- GENIN R., J.-M., RUBY, C., GÉHIN, A. and REFAIT, PH. 2006. Synthesis of green rust by oxidation of Fe(OH)₂, their products of oxidation and reduction of ferric oxyhydroxides: Eh-pH Pourbaix diagrams. *Comptes Rendus Geoscience* 338: 433–446.
- GAMBRELL, R.P. 1994. Trace and toxic metals in wetlands – a review. *Journal of Environmental Quality* 23: 883–891.
- GUO, T., DELAUNE, D. and PATRICK, W.H. 1997. Effect of Sediment redox Chemistry on Solubility/Chemically Active Forms of Selected Metals in Bottom Sediment receiving produced Water Discharge. *Spill Science and Technology Bulletin* 4 (3): 165–175
- IMPELLITERITTERI, C.A. 2005. Effects of pH and phosphate on metal distribution with emphasis on As speciation and mobilization in soils from lead smelting site. *The Science of the Total Environment* 345: 175–190.
- KERTÉSZ, Á. 2008. Tájdegradáció és elsivatagosodás. (Land degradation and desertification.) *Magyar Tudomány* 169. (6): 715–724.
- KERTÉSZ, Á. 2009. The global problem of land degradation and desertification. *Hungarian Geographical Bulletin* 58. (1): 19–31.
- KEVEI-BÁRÁNY, I. 2003. Tájszerkezet és tájváltozás vizsgálatok karsztos mintaterületen (Investigations of landscape structure and landscape change on karstic area.) *Tájökológiai lapok* 1. (2): 145–151.
- KOMLOS, J., KUKKADAPU, R. K., ZACHARA, J.M. and JAFFÉ, P.R. 2007. Biostimulation of iron reduction and subsequent oxidation of sediment containing Fe-silicates and Fe-oxides: Effect of redox cycling on Fe(III) bioreduction. *Water Research* 41: 2996–3004.
- KOROM, S.F. 1992. Natural denitrification in saturated zone. *Water Resources Research* 28. (6): 1657–1668.
- LAMBERS, H., CHAPIN, F.S. and PONS, T.L. 1998. *Plant physiological ecology*. New York, Springer Science, 591 p.
- LESER, H. 1991. *Landschaftsecologie*. Stuttgart, UTB-Ulmert, 433 p.
- LÓCZY, D. 2003. Lehetőségek a mezőgazdasági tájak mikroszerkezetének értékelésére. (Possibilities on evaluation of microstructure of agro-landscapes) *Tájökológiai Lapok* 1. (1): 33–43.
- MOISMANN, TH. 1984. *Landchaftsökologische Komplexanalyse*. Wiesbaden, Franz Steiner Verlag. Cit in: CSORBA P. Tájökológia (Landscape ecology) Kossuth Egyetemi Kiadó, Debrecen. 113 p.
- NAGAI, T., IMAI, A., MATSUSHIGE, K., YOKIO, K. and FUKUSHIMA, T. 2007. Dissolved iron and its speciation in a shallow eutrophic lake and its inflowing rivers. *Water Research* 41: 775–784.
- NEUBAUER, S.C., EMERSON, D. and MEGONIGAL, J.P. 2008. Microbial oxidation and reduction of iron in the root zone and influences on metal mobility. In *Biophysico-Chemical Processes of Heavy Metals and Metalloids in Soil Environments*. Eds: VIOLANTE, A., HUANG, P.M. and GADD, G.M. New Jersey, John Wiley & Sons, 339–371.
- NIKOLAUSZ, M., KAPPELMEYER, U., SZÉKELY, A., RUSZNYÁK, A., MÁRIALIGETI, K. and KÄSTNER, M. 2008. Diurnal redox fluctuation and microbial activity in the rhizosphere of wetland plants. *European Journal of Soil Biology* 44. (3): 324–333.
- ODUM, E., BREWER, R. and W. BARRETT, G. 2004. *Fundamentals of ecology*. 5th edition. Florence, Brooks Cole, 624 p.
- PONNAMPERUMA, F.N. 1972. The chemistry of submerged soils. *Advances in Agronomy* 24: 29–96.

- RIVETT, M.O., SMITH, J.W.N., BUSS, S.R. and MORGAN, PH. 2007. Nitrate occurrence and attenuation in the major aquifers of England and Wales. *Quarterly Journal of Engineering Geology and Hydrogeology* 40: 335–352.
- RIVETT, M.O., STEPHEN, R.B., MORGAN, PH., SMITH, J.W.N. and BEMMENT, CH.D. 2008. Nitrate attenuation in groundwater. A review of biogeochemical processes. *Water Research* 42: 4215–4232.
- ROWELL, D.L. 1981. Oxidation and reduction. In: *The chemistry of soil processes*. Eds: GREENLAND, D.J. and HAYES, M.H.B. Toronto, Wiley, 401–462.
- SZABÓ, GY., ELEK, Z. and SZABÓ, SZ. 2008. Study of heavy metals in the soil-plant system. *Cereal Research Communications* 36: 403–406.
- SZABÓ, M. and MOLNÁR, E. 2001. Monitoring of environmental properties in a wetland region of Hungary. IX. Congress of Croatian Society of Soil Science. „Land management and soil protection for future generations. Brijuni. pp: 123–124.
- SZABÓ, M., HAJDU-DARABOS, G. and SZABÓ-VERES, É. 2008. Övzátányok tájökológiai szempontú vizsgálata a Szigetközben. (Landscape ecological survey of river bars in Szigetköz. In *Tájökológiai kutatások III. (Research on Landscape ecology III.)* Eds: CSIMA, P. and DUBLINSZKI-BODA, B. Corvinus University, Budapest. 219–227.
- SZABÓ, SZ. and SZABÓ, GY. 2006. Sósavas terhelések hatásának vizsgálata a talajok kémhatására és a nehézfémek mobilizációjára Ramann-féle barna erdőtalajokon. (Effects of hydrochloric acid load to soil pH and to heavy metal mobilisation in cambisol / Ramman brown forest soil). In *Egy szakmai életút eredményei és színhelyei. Tiszteletkötet Martonné Dr. Erdős Katalin 60. születésnapjára*. Debrecen, University of Debrecen, 151–158.
- SZABÓ, SZ., ÁGOSTON, CS., BRAUN, M., KERESZTÚRI, P. and SZABÓ, GY. 2008. Cadmium and zinc uptake of rye-grass as related to soil type and different land use. *Cereal Research Communications* 36: 427–430.
- SZALAI, Z. 1998. Nyomelem-eloszlási típusok természeteshez közeli állapotú ártéri területek talajaiban és üledékeiben. (Distribution types of trace elements in sediments and soils of quasi-natural floodplains.) *Földrajzi Értesítő*. 47. (1): 19–30.
- SZALAI, Z. 2008. A kémhatás és redox viszonyok térbeli és időbeli dinamikájának hatása a felvehető nyomelem tartalomra vízhatású élőhelyeken (Effects of spatial and temporal patterns of chemical reaction and redox conditions on available trace element content in wetlands). In *IV. Kárpát-medencei Környezettudományi Konferencia előadásai*. Proceedigs of 4th Conference on Environmental Sciences. Ed: OROSZ, Z. University of Debrecen, Debrecen. 367–371.
- SZALAI, Z. JAKAB, G. and KISS, K. 2009. Növényzeti mintázatok hatása a talajok redox viszonyainak, kémhatásának és oldott nyomelem tartalmának dinamikájára és térbeli eloszlására. (Effect of vegetation pattern on the Eh, pH and dissolved trace element contents of wetland soils.) In *Abstracts of oral papers and poster presentations*. 8th Congress of Hungarian Ecologists. Szeged, Ed. KÖRMÖCZI L. University of Szeged: 205.
- WEISS, J.V., EMERSON, D. and MEGONIGAL. J.P. 2005. Rhizosphere Iron (III) Deposition and Reduction in a *Juncus effusus* L.-Dominated Wetland. *Soil Science Society of America Journal* 69: 1861–1870.
- WIESSNER, A., KAPPELMAYER, U., KUSCHK, P. and KÄSTNER, M. 2005. Influence of the redox conditions dynamics on the removal efficiency of a laboratory-scale constructed wetland. *Water Research* 39: pp. 248–256.
- WHITAKER, R.H. 1975. *Communities and Ecosystems*. 2nd edition. New York, Macmillan, 352 p.

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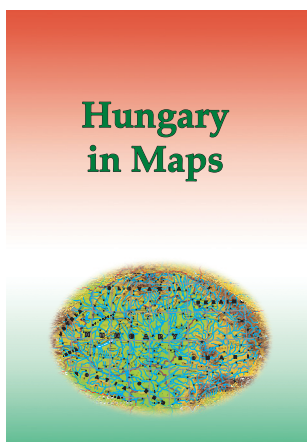
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'Hungary in Maps' is the latest volume in a series of atlases published by the Geographical Research Institute of the Hungarian Academy of Sciences. A unique publication, it combines the best features of the books and atlases that have been published in Hungary during the last decades. This work provides a clear, masterly and comprehensive overview of present-day Hungary by a distinguished team of contributors, presenting the results of research in the fields of geography, demography, economics, history, geophysics, geology, hydrology, meteorology, pedology and other earth sciences. The 172 lavish, full-colour maps and diagrams, along with 52 tables are complemented by clear, authoritative explanatory notes, revealing a fresh perspective on the anatomy of modern day Hungary. Although the emphasis is largely placed on contemporary Hungary, important sections are devoted to the historical development of the natural and human environment as well.

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