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


Abstract

Spatial diversity of landscapes results in spatial and temporal heterogeneity of soil physical and soil chemical parameters. These diversities of pH and Eh 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 Eh. The increasing physiological activity of higher plants caused specific Eh. It leads to higher spatial differences of redox conditions between April and August. The most reductive conditions were measured in sedgy patches, while higher Eh prevail in horsetail and nettle dominated ecotopes. DOC concentrations have also shown similar pattern as the Eh. More reductive conditions have been correlated with higher DOC content. Under Eh<25 mV there is a direct correlation between the amount of dissolved iron and the redox conditions. The differences of Eh 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

1 Geographical Research Institute, Hungarian Academy of Sciences H-1112 Budapest, Budaörsi út 45. E-mail: szalai@mta.ka.hu (Corresponding author: SZALAI, Zoltán.)
2 Institute for Geochemical Research, Hungarian Academy of Sciences, H-1112 Budapest, Budaörsi út 45.
3 Faculty of Sciences, Eötvös Loránd University, H-1117 Budapest, Pázmány Péter sétány 1/A.
Introduction


The most important soil chemical factors for the solubility are the chemical reaction and the redox conditions (Impellitteri, 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 (Ponnampерума, 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 electron acceptors (Ponnampерума, F.N. 1972).

The status of saturation correlates with the abundance/absence of O₂ and with Eₚₚ. The published threshold Eₚₚ 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 Eₚₚ 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 ofoxic habitat around the rhizolplan 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 Völgyéség 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
$E_H$ 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 $E_{H_{0r}}$ value, which depends on temperature ($E_{H_{0r}} = -1.3903 \times T + 585.29$; $R^2 = 0.9985$; $T =$ 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 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, $\lambda = 400$–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
Table 1. Spatial distribution of main landscape forming factors

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

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

Statistical analysis was carried out using SPSS 14.0. Normality of data series were tested by Shapiro-Wilk test. For the relationship analyses Spearman’s correlation coefficients were used because the data did not have normal distribution.
### Table 2. Physical parameters of solid phase

<table>
<thead>
<tr>
<th></th>
<th>Crx0</th>
<th>Crx1</th>
<th>Crx2</th>
<th>Equ2</th>
<th>Urt3</th>
<th>Aln4</th>
<th>aB1</th>
<th>aB2</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>10</td>
<td>7</td>
<td>7</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>6.4</td>
<td>5.6</td>
<td>6.7</td>
<td>6.5</td>
<td>6.1</td>
<td>5.9</td>
<td>6.1</td>
<td>6.9</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>88.7</td>
<td>83.8</td>
<td>85.1</td>
<td>85.4</td>
<td>80.1</td>
<td>80.6</td>
<td>84.4</td>
<td>84.9</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>4.9</td>
<td>10.7</td>
<td>8.2</td>
<td>8.1</td>
<td>13.8</td>
<td>13.5</td>
<td>9.5</td>
<td>8.2</td>
</tr>
<tr>
<td>$pH_{\text{water}}$</td>
<td>7.99</td>
<td>7.95</td>
<td>7.82</td>
<td>7.81</td>
<td>7.79</td>
<td>7.76</td>
<td>7.91</td>
<td>7.82</td>
</tr>
<tr>
<td>$pH_{\text{KCl}}$</td>
<td>7.85</td>
<td>7.79</td>
<td>7.72</td>
<td>7.70</td>
<td>7.74</td>
<td>7.73</td>
<td>7.76</td>
<td>7.72</td>
</tr>
<tr>
<td>CaCO$_3$ (%)</td>
<td>13.7</td>
<td>8.7</td>
<td>3.3</td>
<td>3.3</td>
<td>3.3</td>
<td>3.3</td>
<td>7.2</td>
<td>3.3</td>
</tr>
<tr>
<td>TOC (mg/kg)</td>
<td>30899</td>
<td>23393</td>
<td>25049</td>
<td>24551</td>
<td>25602</td>
<td>26415</td>
<td>24934</td>
<td>24159</td>
</tr>
<tr>
<td>TNb (mg/kg)</td>
<td>2575</td>
<td>1949</td>
<td>2087</td>
<td>2046</td>
<td>2133</td>
<td>2201</td>
<td>2078</td>
<td>2013</td>
</tr>
<tr>
<td>Total iron (mg/kg)</td>
<td>31100</td>
<td>35500</td>
<td>37010</td>
<td>36870</td>
<td>24230</td>
<td>23820</td>
<td>41340</td>
<td>45950</td>
</tr>
<tr>
<td>cc HNO$_3$-H$_2$O$_2$ extractable iron (mg/kg)</td>
<td>21000</td>
<td>20780</td>
<td>16800</td>
<td>13290</td>
<td>12710</td>
<td>11850</td>
<td>25950</td>
<td>38950</td>
</tr>
<tr>
<td>Lakanen-Eviö extractable iron (mg/kg)</td>
<td>410</td>
<td>1582</td>
<td>580</td>
<td>889</td>
<td>909</td>
<td>840</td>
<td>4511</td>
<td>4832</td>
</tr>
</tbody>
</table>

N = sample size

Environmental parameters

Most of the main soil parameters are quasi-homogeneous (Table 2). The textural composition of the fine earth fraction is increasing in the valley bottom and it is increasing towards the slopes. The mineral composition of the fine earth fraction slopes and appears as a characteristic micro-landscape (Table 3). The different micro-climatic parameters (precipitation, 99 mm, mean air temperature above surface at 2 m, 12°C, mean wind velocity above surface, 8.8 m per second, 1828 h, number of sunshine hours, 254) and the boundary between Crx1 and Crx2 patches (aB) and by AAS. The total iron content of soils was the highest at the boundary between Crx1 and Crx2 patches (aB). The XRF measurement did not detect iron. The XRF measurement did not detect iron. The XRF measurement did not detect iron. The XRF measurement did not detect iron.

Results

The main meso-climatic parameters (precipitation, 99 mm, mean air temperature above surface at 2 m, 12°C, mean wind velocity above surface, 8.8 m per second, 1828 h, number of sunshine hours, 254) and the boundary between Crx1 and Crx2 patches (aB) by AAS. The total iron content of soils was the highest at the boundary between Crx1 and Crx2 patches (aB). The XRF measurement did not detect iron. The XRF measurement did not detect iron. The XRF measurement did not detect iron. The XRF measurement did not detect iron.
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. 3. The mineral composition fine earth fraction. Crx0, Crx1, Crx2, Urt3 = ecotopes](image)

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

<table>
<thead>
<tr>
<th></th>
<th>Crx0</th>
<th>Crx1</th>
<th>Crx2</th>
<th>Equ2</th>
<th>Urt3</th>
<th>Aln4</th>
<th>aB1</th>
<th>aB2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of saturated conditions (days)</td>
<td>156</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>142</td>
<td>136</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Duration of unsaturated conditions (days)</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>158</td>
<td>164</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Max. amount of PAR (umol m$^{-2}$ s)</td>
<td>1756</td>
<td>1756</td>
<td>1756</td>
<td>1528</td>
<td>1247</td>
<td>712</td>
<td>1756</td>
<td>1756</td>
</tr>
<tr>
<td>Yearly average of porewater temperature (°C)</td>
<td>15.8</td>
<td>12.1</td>
<td>11.9</td>
<td>12.1</td>
<td>11.9</td>
<td>11.9</td>
<td>13.9</td>
<td>12.0</td>
</tr>
</tbody>
</table>

PAR = photosynthetically active radiation
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.
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
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 $E_\text{h}$ 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. 7. Duration of anaerobic conditions in the studied wetland ecotopes**

**Fig. 8. Seasonal fluctuation of $E_\text{h}$ in the studied wetland ecotopes (each box marks a mean of three measurements: 12:50, 13:00, 13:10)**

**Fig. 9. Seasonal variation of dissolved organic carbon 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 µg/l to 20 µg/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 µg/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, $E_{ir}$, 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
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 heterogeneity 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 (μg/l or μmol/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

<table>
<thead>
<tr>
<th>Boundary Index</th>
<th>Crx0-Crx1</th>
<th>Equ2-Urt3</th>
<th>Crx2-Urt3</th>
<th>Crx0-Aln4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration gradient (μmol l⁻¹)</td>
<td>-192</td>
<td>-26</td>
<td>641</td>
<td>328</td>
</tr>
<tr>
<td>Duration (days)</td>
<td>24</td>
<td>2</td>
<td>37</td>
<td>30</td>
</tr>
<tr>
<td>Direction</td>
<td>to Crx0</td>
<td>to Equ2</td>
<td>to Urt</td>
<td>to Aln4</td>
</tr>
<tr>
<td>B (μmol m d l⁻¹)</td>
<td>427 622</td>
<td>541</td>
<td>611 899</td>
<td>383 760</td>
</tr>
<tr>
<td>Boundary index</td>
<td>0.699</td>
<td>0</td>
<td>1.000</td>
<td>0.627</td>
</tr>
</tbody>
</table>

| Landscape boundary index | 0.581 |

<table>
<thead>
<tr>
<th>Dissolved iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration gradient (μmol l⁻¹)</td>
</tr>
<tr>
<td>Duration (days)</td>
</tr>
<tr>
<td>Direction</td>
</tr>
<tr>
<td>B (μmol m d l⁻¹)</td>
</tr>
<tr>
<td>Boundary index</td>
</tr>
<tr>
<td>Landscape boundary index</td>
</tr>
</tbody>
</table>
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.

Acknowledgement: This research were supported by Hungarian Scientific Research Fund (OTKA T38122) and by Bolyai Fellowship of Hungarian Academy of Sciences.

REFERENCES


NOW AVAILABLE!

Hungary in Maps

Edited by
Kocsis, Károly and Schweitzer, Ferenc

*Geographical Research Institute Hungarian Academy of Sciences. Budapest, 212 p.*

Budapest, 2009

‘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.

In its concentration and focus, this atlas was intended to act as Hungary’s ‘business card’, as the country’s résumé, to serve as an information resource for the sophisticated general reader and to inform the international scientific community about the foremost challenges facing Hungary today, both in a European context and on a global scale. Examples of such intriguing topics are: stability and change in the ethnic and state territory, natural hazards, earthquakes, urgent flood control and water management tasks, land degradation, the state of nature conservation, international environmental conflicts, the general population decline, ageing, the increase in unemployment, the Roma population at home and the situation of Hungarian minorities abroad, new trends in urban development, controversial economic and social consequences as a result of the transition to a market economy, privatisation, the massive influx of foreign direct investment, perspectives on the exploitation of mineral resources, problems in the energy supply and electricity generation, increasing spatial concentration focused on Budapest in the field of services (e.g. in banking, retail, transport and telecommunications networks), and finally the shaping of an internationally competitive tourism industry, thus making Hungary more attractive to visit.

This project serves as a preliminary study for the new, 3rd edition of the National Atlas of Hungary, that is to be co-ordinated by the Geographical Research Institute of the Hungarian Academy of Sciences.

--------------------------------------------------------

Price: EUR 40.00
Order: Geographical Research Institute HAS Library
H-1388 Budapest, POB. 64. E-mail: magyar@sparc.core.hu