Evaluation of Functional Properties of Various Types of Vegetation Cover Using Remotely Sensed Data Analysis

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Abstract: The dissipation of solar energy and consequently the formation of the hydrological cycle are largely dependent on the structural and optical characteristics of the land surface. In our study, we selected seven units with different types of vegetation in the Mlýnský and Horský catchments (South-Eastern part of the Šumava Mountains, Czech Republic) for the assessment of the differences in their functioning expressed through the surface temperature, humidity, and energy dissipation. For our analyses, we used Landsat 5 TM satellite data from June 25th, 2008. The results showed that the microclimatic characteristics and energy fluxes varied in different units according to their vegetation characteristics. A cluster analysis of the mean values was used to divide the vegetation units into groups according to their functional characteristics. The mown meadows were characterised by the highest surface temperature and sensible heat flux and the lowest humidity and latent heat flux. On the contrary, the lowest surface temperature and sensible heat flux and the highest humidity and latent heat flux were found in the forest. Our results showed that the climatic and energetic features of the land surface are related to the type of vegetation. We state that the spatial distribution of different vegetation units and the amount of biomass are crucial variables influencing the functioning of the landscape.

Keywords: vegetation cover; energy fluxes; surface temperature; wetness index; Normalised Difference Vegetation Index (NDVI); albedo; Landsat TM

The vegetation cover plays an important role in the energy balance on the Earth surface. Through evapotranspiration, the vegetation actively dissipates a significant part of the incoming solar energy into latent heat (Pokorný *et al.* 2007). This is particularly important in creating the water cycle (Ripl 2003).

The capacity of the surface for solar energy dissipation through latent heat depends on a number of factors. The most important for the functioning of the cultural landscape is its management which, through economic interventions such as mowing, grazing, deforestation etc., affects the vegetation cover, hydrology and, consequently, the distribution of solar energy. These changes may cause disturbance in the matter discharge from river basins (Procházka *et al.* 2008), micro and meso-climatic changes (e.g. Gordon *et al.* 2005; Makarieva *et al.* 2006; Sivakumar 2007), as well as changes in biodiversity. Consequences as great as inflow (rain)-outflow changes in some river basins have been suggested (for example, Piao *et al.* 2007; Wattenbach *et al.* 2007).

Our study is part of an extensive long-term research, which has focused on the relations between hydrology of small stream catchments and the

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Table 1. Name, location, area and basic description of vegetation composition of seven vegetation units used in the analyses

Vegetation unit	Location	Area(km^2)	Area (%)	Vegetation composition
Mowed meadows	Horský	0.160	7.8	mowed communities of *Arrhenatherion*, *Polygono-Trisetion*, *Calthenion*.
	Mlýnský	0.399	18.7	
Pastures	Horský	0.015	0.7	grazed communities of *Cynosurion*, *Arrhenatherion* and *Calthion*
	Mlýnský	0.902	42.4	
Wetlands	Horský	0.130	6.3	varied herbal and shrubby communities; *Calthenion*, *Filipendulenion*, *Molinion*, *Salicion cinereae* and *Sphagnum*
	Mlýnský	0.054	2.6	
Ruderal and degraded vegetation	Horský	0.116	5.6	degraded and sprouted meadows and pastures and ruderal vegetation
	Mlýnský	0.241	11.3	
Xerophytic communities	Horský	0.034	1.6	communities of ecotones, forest edges and low shrubby vegetation
	Mlýnský	0.003	0.1	
Carex brizoides communities	Horský	0.082	4.0	mono-dominant or degraded communities of *Carex brizoides*
	Mlýnský	0.005	0.2	
Forest	Horský	1.526	74.0	spruce and beech forests and other woody communities
	Mlýnský	0.459	21.6	

economic and agricultural activities within them. Our previous publications were focused on chemical characteristics of the water discharged from the areas studied (Procházka *et al.* 2001, 2006, 2008), and temporal and spatial distribution of the surface temperature in different stands (Hais *et al.* 2006; Brom & Pokorný 2009). The aim of the present study was to evaluate the surface temperatures in detail, humidity, amount of vegetation, albedo, and the energy fluxes in different vegetation units of two mountain catchments using remote sensing.

MATERIAL AND METHODS

Study site

The study site is situated in the south-eastern part of the Bohemian Forest in the Šumava Biosphere Reserve (Czech Republic) and belongs to the south-eastern promontory of the Trojmezná ridge called Svatotomášské pohoří (Czudek 1972). The geology of the studied area is made up mostly of granite with acidic brown soils (cambisol). The selected catchments of the Mlýnský and Horský streams are characterised by different types of land cover. The Mlýnský catchment consists of semi-intensive drained pastures (alliance *Cynosurion*), mowed meadows (alliance *Arrhenatherion*), and degraded and ruderal vegetation. The Horský catchment consists of wetlands (herbal and shrubby communities of alliance *Calthion*), spruce forest, and mowed meadows (alliance *Arrhenatherion*). For more details on the vegetation and primary production see Hakrová (2003) and Procházka *et al.* (2001). The altitude of the catchments under study ranges from 784 to 1026 m with an average annual rainfall between 950 and 1050 mm and mean annual air temperature 5°C. The catchments have similar areas (Mlýnský 2.128 km^2, Horský 2.063 km^2) and expositions (SW, NE). The distance between the observed catchments is approximately 1 km.

Data description

For the analyses of the functional features, we used remotely sensed data. The data were obtained by processing Landsat 5 TM scene which was acquired on June 25, 2007, 9:38 GMT. The spatial resolution of the Landsat satellite system is 30 m for VIS, NIR, and SWIR spectral bands, and 120 m for the thermal band. For further processing, the pixels of the thermal band were

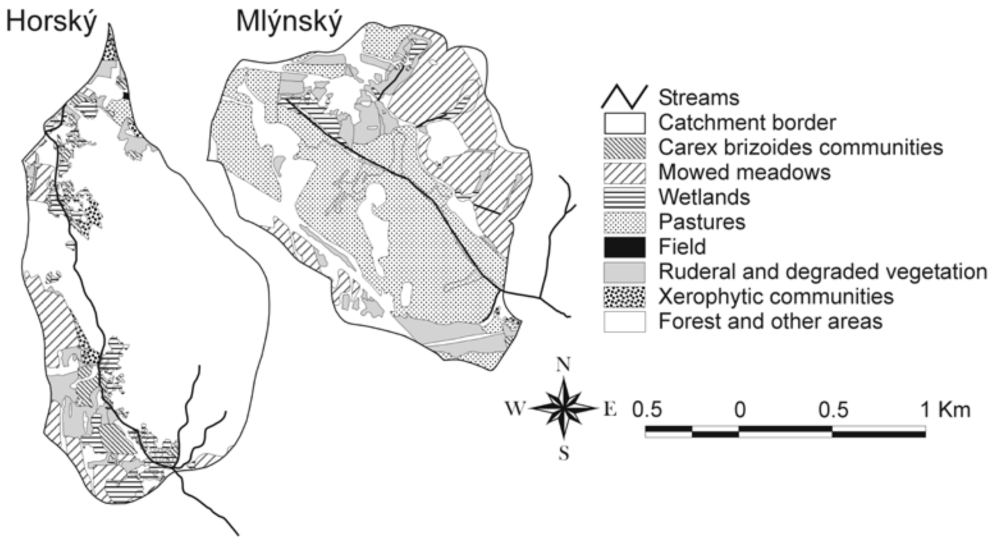

Figure 1. Spatial distribution of the vegetation units in the Horský and Mlýnský catchments

resampled into 30 m pixels. The satellite data were rectified into a S-JTSK coordinate system. The data were then resampled by applying the nearest neighbour method to preserve the original radiometric values for subsequent data processing. The data were corrected radiometrically using the ATCOR2 module (Geomatica Algorithm Reference 2003).

In view of the vegetation structure and land use, we selected seven vegetation units. The description of these units is given in Table 1. Figure 1 shows the spatial distribution of the units.

For the satellite data processing, we used additional meteorological data from an automatic meteorological station situated in the Mlýnský stream catchment (from 9:45 GMT+1) – air temperature (21.08°C), relative air humidity (67%), and incoming global radiation (813 W/m^2).

Meteorological conditions prior to the data collection are important for evaluating the results. Table 2 shows the mean values of the air temperature, relative humidity of the air, sums of incoming global radiation, total net radiation, and daily precipitations of five days before the data acquisition.

Temperature, humidity and Normalised Difference Vegetation Index (NDVI)

Thermal characteristics were obtained from Landsat 5 TM thermal band in the spectral range from 10.42 to 12.5 μm. The surface temperature was computed using the THERMAL Idrisi 15 Andes module (Clark Labs 2006). To get the real surface temperature, we used the surface emissivity (ε) which was computed as follows (Van de Griend & Owe 1993):

$$\varepsilon = 1.0094 + 0.047\ln(\text{NDVI}) \quad (1)$$

NDVI describes the relative amount of green biomass. It was computed using the following formula:

Table 2. Basic variables of meteorological conditions five days prior to satellite data collection (June 25, 2007, 9:38 GMT+1); mean values were computed from the data collected in 15-minutes interval

Date	Mean air temperature (°C)	Mean relative humidity (%)	Global radiation (kWh)	Net radiation (kWh)	Precipitation (mm)
June 20, 2007	20.4	64.0	–	3.8	0.8
June 21, 2007	18.6	76.2	–	2.9	4.4
June 22, 2007	15.6	78.5	4.5	2.2	3.4
June 23, 2007	13.7	77.4	4.9	2.6	0.0
June 24, 2007	15.0	71.5	7.4	4.4	2.8

$$\mathrm{NDVI} = \frac{\mathrm{band4} - \mathrm{band3}}{\mathrm{band4} + \mathrm{band3}} \quad (2)$$

We used the Tasseled Cap wetness index for assessing the surface moisture. This was computed using the TASSCAP Idrisi Andes Module. For more details see Lillesand *et al.* (2004).

Radiation balance

The radiation balance of the surface was calculated from the radiation balance equation:

$$Rn = Rs_{\downarrow}\,(1 - \alpha) + Rl_{\downarrow} - Rl_{\uparrow} \quad (3)$$

where:
Rn – net radiation (W/m^2)
$Rs_{\downarrow}$ – incoming short wave radiation (global radiation; W/m^2) measured at the surface using a pyranometer (see data description)
α – albedo (rel.)
Rl – long wave radiation

The arrows indicate the direction of the energy flux. Albedo (α) was acquired from spectral reflectances (unitless) using the conversion formula (Liang *et al.* 2002)

$$\alpha = 0.365\alpha_1 + 0.130\alpha_3 + 0.373\alpha_4 + 0.085\alpha_5 + 0.072\alpha_7 - 0.0018 \quad (4)$$

Spectral reflectances were computed for Landsat 5TM spectral bands (Chander & Markham 2003):

$$\alpha_i = \frac{\pi \times L_{\lambda} \times d^2}{\mathrm{ESUN}_{\lambda} \times \cos\theta} \quad (5)$$

where:
L_{λ} – spectral radiance
d – earth-sun distance in astronomical units
ESUN_{λ} – mean solar extraatmospheric irradiance (W/m^2/μm)
θ – solar zenith angle (°)
i – indicates the spectral channel of the satellite

The spectral radiance was computed using the RADIANCE Idrisi 15 Andes module (Clark Labs 2006).

The calculation of the long wave radiation was based on Stefan-Boltzman law. The downward long wave radiation was calculated for clear sky conditions using the formula (Brutsaert 1982)

$$Rl_{\downarrow} = 1.24\left(\frac{e_a}{(T_a + 273.16)}\right)^{\frac{1}{7}} \sigma (T_a + 273.16)^4 \quad (6)$$

where:
e_a – water vapour pressure (hPa)
T_a – air temperature at 2 m (°C) above the ground
σ – Stefan-Boltzman constant (W/m^2/K^4)

The upward long wave radiation was computed using the equation

$$Rl_{\uparrow} = \varepsilon\sigma\,(T_s + 273.16)^4 \quad (7)$$

where:
T_s – surface temperature (°C)

The water vapour pressure of the air was computed from the measured air temperature and relative humidity of the air at 2 m above the surface

$$e_a = \frac{e_s \cdot Rh}{100} \quad (8)$$

where the saturation water vapour pressure (e_s, kPa) was computed using the equation (Buck 1981):

$$e_s = 0.61121 \cdot \exp\left(\frac{17.502 \cdot T_a}{240.97 + T_a}\right) \quad (9)$$

Heat balance and energy fluxes

The energy fluxes were estimated from the energy balance equation

$$Rn = G + H + LE \quad (10)$$

where:
G – ground heat flux (W/m^2)
H – sensible heat flux (W/m^2)
LE – latent heat flux (W/m^2)

The ground heat flux was computed using the equation (Moran *et al.* 1989):

$$G = Rn\,(0.583 \exp(-2.13\,\mathrm{NDVI})) \quad (11)$$

For the estimation of the latent heat flux, we used the Crop Water Stress Index (CWSI) calculation developed by Jackson *et al.* (1981)

$$CWSI = 1 - \frac{LE}{LE_p} \quad (12)$$

where:
LE_p – potential latent heat flux

Thus, the latent heat flux can be calculated using

$$LE = (1 - \text{CWSI})\, LE_p \qquad (13)$$

As Idso *et al.* (1981) showed, CWSI can be computed using three temperatures only.

$$CWSI = \frac{T_{s,\min} - T_s}{T_{s,\min} - T_{s,\max}} \qquad (14)$$

where:

T_s – land surface temperature (°C)

$T_{s,\min}$, $T_{s,\max}$ – temperatures (°C) of the full transpiring, well watered canopy, and non transpiring canopy, respectively

To obtain $T_{s,\min}$ and $T_{s,\max}$, we used the means of 1% of the lowest and 1% of the highest values of the surface temperature from the histogram of our area, respectively. We proceeded from the assumption that in the area of our interest both non transpiring and well watered sites were present.

For the potential latent heat flux calculation (LE_p), we used Priestley and Taylor formula (Priestley & Taylor 1972):

$$LE_p = 1.26 \cdot \frac{\Delta}{\Delta + \gamma}(Rn - G) \qquad (15)$$

The slope of the saturated vapour pressure-temperature relation (Δ, kPa/°C) was modelled using polynomial regression. We found a narrow nonlinear correlation between Δ and the surface temperature based on the meteorological data ($r^2 = 0.99$, $P < 0.001$). We used the regression model:

$$\Delta = 0.0531 + 0.0027T_s + 0.23608 \times 10^{-4}T_s^2 + 0.37373 \times 10^{-5}T_s^3 \qquad (16)$$

The sensible heat flux was computed from the energy balance equation:

$$H = Rn - G - LE \qquad (17)$$

The Bowen ratio (β; unitless) was expressed as a ratio between the sensible and latent heat fluxes (Bowen 1926):

$$\beta = \frac{H}{LE} \qquad (18)$$

Statistical analysis

We used descriptive statistics for the description of the parameters studied. The normality of the characteristics studied was tested using Kolmogorov-Smirnov test. The parameters did not show normal distribution.

We used the non-parametric Kruskal-Wallis test to compare the climatic characteristics and energy fluxes of the vegetation units. Because we had varying numbers of data for different types of vegetation units, we selected one hundred values from each vegetation type using random selection for each parameter. The xerophytic communities were not included in this test due to insufficient data.

For analysing the similarity between the vegetation units, we used the cluster analysis (CLU). The distances between the groups were evaluated according to the mean values of the parameters studied. Because the groups correlated on the cardinal scale, the Pearson correlation coefficient and the test for similar linkage between groups were used as a measure of similarity between the groups.

The relations between the parameters studied were statistically tested using correlation analysis.

We used Statistica 7.1 software system (StatSoft, Inc. 2005) for all analyses.

RESULTS

The mean values of the monitored characteristics which describe the differences between the individual vegetation units are compared in Table 3.

The highest mean surface temperature and the lowest humidity (characterised by the wetness index) were found on the mowed meadows (24.0°C and –49.2, respectively). The lowest mean surface temperature was found in the forests (19.4°C).

NDVI, as a measure of the amount of biomass and vegetation cover quality, was the lowest on the mowed meadows because they had been recently harvested, and the highest in the *Carex brizoides* communities. Albedo, computed from the spectral reflectance, was the lowest in the forest communities (11.0%) and the highest in the *Carex brizoides* communities (17.1%).

Net radiation, an important factor in the assessment of the surface energy balance, was the lowest on the pastures (599.6 W/m^2) and the highest in the forest areas (663.6 W/m^2). The highest ground heat flux was found on the mowed meadows (88.8 W/m^2) and the lowest in the *Carex brizoides* communities (55.8 W/m^2).

We found the highest sensible and the lowest latent heat fluxes on the mowed meadows (235.6 and 281.5 W/m^2, respectively). The opposite ex-

Table 3. Surface temperature (T_s), wetness index (WI), Normalised Difference Vegetation Index (NDVI), albedo (α), net radiation (*Rn*), ground heat flux (*H*), latent heat flux (*LE*) and Bowen ratio (β) determined from the satellite data for the vegetation units, the whole catchments, and for the non-forested areas only

Unit	*N* (–)	T_s (°C)	WI (–)	NDVI (–)	α (%)	*Rn* (W/m²)	*G* (W/m²)	*H* (W/m²)	*LE* (W/m²)	β (–)
Mowed meadows	622	24.0	–42.9	0.68	15.2	605.9	88.8	235.6	281.5	0.84
Pastures	1007	22.1	–13.7	0.84	17.0	599.6	59.4	205.8	334.5	0.62
Wetlands	216	20.7	–10.8	0.86	16.3	613.0	57.6	180.3	375.2	0.48
Ruderal and degraded vegetation	385	21.2	–9.5	0.86	16.4	609.6	58.2	189.6	361.7	0.52
Xerophytic communities	38	19.6	–12.5	0.83	12.9	647.1	65.6	165.0	416.5	0.40
Carex brizoides communities	102	20.2	–6.9	0.87	17.1	609.5	55.8	169.0	384.7	0.44
Forest	2287	19.4	–9.7	0.84	11.0	663.6	66.7	165.4	431.5	0.38
Horský – non forested areas	603	21.2	–21.0	0.79	16.4	611.1	70.0	184.8	356.3	0.52
Mlýnský – non forested areas	1769	22.6	–19.8	0.80	16.3	603.3	65.5	213.8	324.0	0.66
Horský – whole catchment	2290	19.5	–12.3	0.82	11.8	657.1	68.6	163.6	425.0	0.38
Mlýnský – whole catchment	2369	22.2	–17.6	0.81	15.6	611.4	64.9	208.2	338.4	0.62

N – number of pixels; in the case of the surface temperature the number of used pixels is four times lower

treme values, i.e. the lowest sensible and the highest latent heat fluxes, were recorded in the forests and xerophytic communities (forest: 165.4 and 431.5 W/m²; xerophytic: 165.0 and 416.5 W/m² respectively).

An overview of the Bowen ratios showed that solar energy was converted mostly into latent heat in the forested areas (0.38) whereas on the mowed meadows the prevailing part of energy was directed into sensible heat (0.84).

To compare the characteristics of our vegetation units, we used the Kruskal-Wallis non-parametric test. The results showed that, apart from the xerophytic communities affected by insufficient number of data, all vegetation units differed significantly in all characteristics ($P < 0.001$).

To analyse the differences between the vegetation groups, we developed a similarity analysis based on cluster analysis of the mean values of the parameters studied. The distances between the vegetation groups expressed as Pearson coefficient r-1 are shown in Figure 2. The graph shows that the distances between different vegetation units were small. Closer relations may be observed between the forests and xerophytic communities on the one hand, and between the wetlands, ruderal and degraded communities, and *Carex brizoides* communities on the other hand. Pasture units near the latter group. The mowed meadows are most distant from other vegetation units.

We also compared separately the characteristics of the non-forested areas of the catchments to the whole catchments (Table 3). The comparison between the non-forested areas of the two catchments showed that the albedo, net radiation, ground heat flux, and latent heat flux were higher in the non-forest area of the Horský catchment whereas the temperature, wetness index, NDVI, sensible heat flux, and the Bowen ratio were higher in the Mlýnský catchment. The comparison of the whole catchments showed the following results: the surface temperature, albedo, sensible heat flux, and Bowen ratio were higher in the Mlýnský catchment, the wetness index, net radiation, and latent heat flux were higher in the Horský catchment. The mean values of NDVI and the ground heat flux were similar with both catchments.

DISCUSSION

The landscape management substantially influences the structure, composition, and function of the land surface. This may affect also the climatic conditions and energetic regime and, consequently, the hydrological and ecological processes of the landscape (e.g. Savenije 1995; Pokorný 2001;

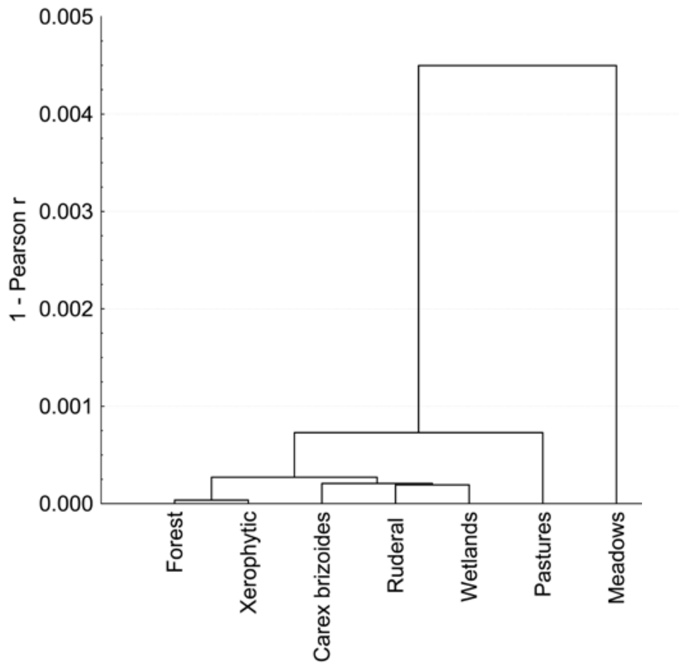

Figure 2. Graph of similarities between the studied units determined by the cluster analysis (CLU)

Ripl 2003; Gordon *et al.* 2005; Makarieva *et al.* 2006; Piao *et al.* 2007).

In this study, we attempted to evaluate the impact of the selected vegetation types on the microclimatic conditions and energy fluxes. Using remote satellite data, we analysed seven vegetation units in two small mountain catchments.

As follows from the results (see Table 3), the mowed meadow and forest vegetation units showed the most extreme values in the climatic and energetic characteristics – the forests with their lowest temperature, albedo, sensible heat flux, and Bowen ratio, and the highest net radiation and latent heat and high mean values of the wetness index being one extreme, and the mowed meadows with the highest values of the surface temperature, ground heat flux, sensible heat flux, and Bowen ratio, and the lowest values of the wetness index and latent heat flux being the other extreme.

The highest values of the net radiation and the lowest values of albedo in the forest correspond with the results of Marková *et al.* (2006). We could assume that a high input of energy is manifested in the high surface temperature and high sensible heat flux (Bala *et al.* 2007). Our results, however, showed that the mean surface temperature and sensible heat flux in forests were the lowest with all vegetation types studied. The latent heat flux was approximately 150 W/m^2 higher than in the pasture. We suppose that this was the result of many factors such as intensive evaporation of intercepted water, high transpiration, high leaf area index etc.

The statistical analyses showed that the vegetation units differed in all of the parameters studied. However, the statistical test examined all the data together and showed no apparent differences between the particular pairs of the units. This drawback was partially compensated by a similarity analysis based on cluster analysis (CLU) – Figure 2. The close relation in the features of the forests and xerophytic communities is surprising because these communities are botanically very different. This phenomenon might in fact be an artefact because the xerophytic communities create narrow strips along the forests and it is difficult to separate them from each other on the Landsat images. The area of the xerophytic communities in our catchments under study is low and therefore its impact is rather negligible in this case.

The close similarity of the wetlands, ruderal and degraded communities, and *Carex brizoides* communities (Figure 2) is probably caused by similarly high amounts of detritus and organic matter (see NDVI values) in all these vegetation units, which are not cultivated by man. The high amounts of green biomass and organic matter on the surface indicate the ability to retain large amounts of water by these vegetation types (Kirkham 2005).

The driving factors which influence the energy fluxes on the surface can be divided into two categories: natural factors, and factors affected by the management. The first group consists of factors which influence topography, i.e geographical altitude and latitude, aspect of slope, and elevation over sea, etc. (see e.g. Yoshino 1975; Geiger *et al.* 2003; Hais & Kučera 2008). We did not include these factors into our analyses as a pilot study (data not shown) had shown that under the conditions studied these factors did not significantly affect the characteristics analysed. The second group of factors affected by the landscape management is the spatial composition of vegetation and the amount of biomass in the area. The dominant units play a major role in creating the climatic conditions of an area. In our case, the energy fluxes and microclimatic conditions of the non-forested areas were predominantly determined by the mowed meadows, wetlands, ruderal and degraded communities, and by *Carex brizoides* communities altogether in the Horský catchment, and by the pastures in the Mlýnský catchment. The energy fluxes and microclimatic conditions of the total catchment area were determined mostly by the forest and by the pastures in the Horský and Mlýnský catchments, respectively (Table 1).

The amount of biomass in the study area was expressed as NDVI. We analysed the relationships between NDVI and other characteristics. The index was closely related to the ground heat flux (r^2 = 0.93, P < 0.05). This was probably because of two reasons, first, the ground heat flux was computed from NDVI, second, NDVI was in a close relation to the wetness index (r^2 = 0.63, P < 0.05). As Peters-Lidard *et al.* (1998) showed, the thermal conductivity of soil increases with increasing soil water content. The soil water content or, in our case, the moisture of the surface can be considered a factor which is indirectly influenced by the management.

Although a good relation between the amount of biomass and surface temperature has been described in literature (Jenerette *et al.* 2007; Pokorný *et al.* 2007), we found only a poor relation between NDVI and the surface temperature (r^2 = 0.27, P < 0.05). The correlations between the heat fluxes and NDVI were poor as well. This might be due to a balanced amount of biomass in the whole area. The only parts in our catchments with a considerably different amount of biomass during the remote scanning were the mowed meadows. We suppose it was this fact that made the characteristics of this unit markedly different from the other ones.

In general, the differences between the selected vegetation units were only small in the characteristics studied. Only the mowed meadows displayed greater dissimilarities. We suppose that the leveling of our results was caused by two facts. First, the vegetation was in its maximum development stage which did not show the differences potentially expressed at the time of great differences of the amount of biomass. Second, the weather which preceded the day of the remote sensing was rather rainy (Table 2) which led to a high relative air humidity and probably also to a high water content in the soil.

Anyway, our results showed that the areas with a well developed vegetation cover attenuate the surface temperature through an intensive latent heat flux. As has been suggested in the short water cycle theory (Ripl 1995, 2003; Pokorný 2001; Kravčík *et al.* 2008), the intensively evaporating vegetation retains close circulation of water and energy in the ecosystem (Brom & Pokorný 2009). A transformation of the vegetation cover may lead not only to changes in the water and energy budget of the landscape in question, but also to mineralisation and consequent leaching of nutrients and CO_2 release (Rees & Ribens 1995; Neal *et al.* 2001; Procházka *et al.* 2008). Our research has supported the importance of the role of vegetation in the solar energy dissipation and water use, and has contributed to other published results which point to the imperative need of wise management of the landscape in order to improve its functions.

CONCLUSION

Our analyses of satellite images showed that different types of vegetation exhibit different microclimatic characteristics as a consequence of their diverse use of solar energy. In the mountain area studied, the mowed meadows with their lowest humidity showed the highest surface temperature and sensible heat flux whereas the forests with the highest abundance of moisture, in spite of their highest net radiation, had the lowest surface temperature because they dissipated higher amounts of solar energy through the latent heat flux. This indicates that the landscape management may substantially influence the local climate through changing the distribution of the vegetation types.

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References

Bala G., Caldeira K., Wickett M., Phillips T.J., Lobell D.B., Delire C., Mirin A. (2007): Combined climate and carbon-cycle effects of large-scale deforestation. Proceedings of the National Academy of Sciences of The United States of America, **104**: 6550–6555.

Bowen I.S. (1926): The ratio of heat losses by conduction and by this magnitude and the diminution of the aerodynamic evaporation from any water surface. Physical Review, **27**: 779–787.

Brom J., Pokorný J. (2009): Temperature and humidity characteristics of two willow stands, a peaty meadow and a drained pasture and their impact on landscape functioning. Boreal Environment Research, **14**: 389–403.

Brutsaert W. (1982): Evapotranspiration into the Atmosphere. Theory, History and Applications. D. Reidel Publishing Company, Dortrecht.

Buck A.L. (1981): New equations for computing vapor pressure and enhancement factor. Journal of Applied Meteorology, **20***:* 1527–1532.

Chander G., Markham B. (2003): Revised Landsat-5 TM radiometric calibration procedures and postcalibration dynamic ranges. IEEE Transactions on Geoscience and Remote Sensing, **41**: 2674–2677.

Clark Labs (2006): IDRISI 15. The Andes Edition. Clark University, Worcester.

Czudek T. (ed.) (1972): Geomorphological Classification of the Czech Socialistic Republic. Institute of Geography, Academy of Science, Brno. (in Czech)

Geiger R., Aron R.H., Todhunter P. (2003): The Climate Near the Ground. 6th Ed., Rowman & Littlefield Publishers, Inc., Lanham.

Geomatica Algorithm Reference (2003): PCI Geomatics 5.0 West Wilmot Street, Richmond Hill, Ontario, Canada, L4B 1M5.

Gordon L.J., Steffen W., Jönsson B.F., Folke C., Falkenmark M., Johannessen Å. (2005): Human modification of global water vapor flows from the land surface. Proceedings of the National Academy of Sciences of the United States of America, **102**: 7612–7617.

Hais M., Kučera T. (2008): Surface temperature change of spruce forest as a result of bark beetle attack: remote sensing and GIS approach. Europaean Journal of Forest Research, **127**: 327–336.

Hais M., Brom J., Procházka J., Pokorný J. (2006): Effect of water drainage on the forest microclimate; case study of two small catchments in the Šumava mountains. Ekológia (Bratislava), **25** (Suppl. 3): 18–26.

Hakrová P. (2003): The Research of Conditions of the Support of the Specific Diversity Grasslands. University of South Bohemia in České Budějovice, Faculty of Agriculture, České Budějovice. (in Czech)

Idso S.B., Jackson R.D., Pinter P.J., Reginato R.J., Hatfield J.L. (1981): Normalizing the stress-degree-day parameter for environmental variability. Agricultural Meteorology, **24**: 45–55.

Jackson R.D., Idso S.B., Reginato R.J., Pinter P.J. Jr. (1981): Canopy temperature as a crop water stress indicator. Water Resource Research, **17**: 1133–1138.

Jenerette G.D., Harlan S.L., Brazel A., Jones N., Larsen L., Stefanov W.L. (2007): Regional relationships between surface temperature, vegetation, and human settlement in a rapidly urbanizing ecosystem. Landscape Ecology, **22**: 353–365

Kirkham M.B. (2005): Principles of Soil Water Relations. Elsevier Academic Press, Amsterdam.

Kravčík M., Pokorný J., Kohutiar J., Kováč M., Tóth E. (2008): Water for the Recovery of the Climate. A New Water Paradigm. Typopress-Publishing House Ltd., Košice.

Liang S., Shuey C.J., Russ A.L., Fang H., Chen M., Walthall C.L., Daughtry C.S.T., Hunt H. Jr. (2002): Narrowband to broadband conversions of land surface albedo. Remote Sensing of Environment, **84**: 25–41.

Lillesand T.M., Kiefer R.W., Chipman J.W. (2004): Remote Sensing and Image Interpretation. 5th Ed., John Wiley & Sons, Inc., New York.

Makarieva A.M., Gorshkov V.G., Li B.L. (2006): Conservation of water cycle on land via restoration of natural closed-canopy forests: implications for regional landscape planning. Ecological Research, **21**: 897–906.

Marková I., Janouš D., Marek M.V. (2006): Total net radiation of the mountain Norway spruce stand at Bílý Kříž (The Czech Republic). Ekológia (Bratislava), **25**: 352–365.

Moran M.S., Jackson R.D., Raymond L.H., Gay L.W., Slater P.N. (1989): Mapping surface-energy balance components by combining Landsat Thematic Mapper and ground-based meteorological data. Remote Sensing of Environment, **30**: 77–87.

Neal C., Reynolds B., Neal M., Pugh B., Hill B., Wickham H. (2001): Long-term changes in the water quality if rainfall, cloud water and stream water for moorland, forested and clear-felled catchments at Plynlimon, mid-Wales. Hydrology and Earth System Sciences, **5**: 459–476.

Peters-Lidard C.D., Blackburn E., Liang X., Wood E.F. (1998): The effect of soil thermal conductivity parametrisation on surface energy fluxes and temperatures. Journal of the Atmospheric Science, **55**: 1209–1224.

Piao S., Friedlingstein P., Ciais P., de Noblet-Ducoudré N., Labat D., Zaehle S. (2007): Changes in climate and land use have a larger direct impact than rising CO_2 on global river runoff trends. Proceedings of the National Academy of Sciences of the United States of America, **104**: 15242–15247.

Pokorný J. (2001): Dissipation of solar energy in landscape – controlled by management of water and vegetation. Renewable Energy, **24**: 641–645.

Pokorný J., Šíma M., Rejšková A., Brom J. (2007): The role of vegetation in water cycling and energy dissipation. In: Hazell P., Norris D. (eds): Proc. 1st Natural Sequence Farming Workshop. Natural Sequence Farming: Defining the Science and the Practice. October 31–November 1, 2006, NSW, Bungendore.

Priestley C.H.B., Taylor R.J. (1972): On the assessment of surface heat flux and evapotranspiration using large scale parameters. Monthly Weather Review, **100**: 81–92.

Procházka J., Hakrová P., Pokorný J., Pecharová E., Hezina T., Wotavová K., Šíma M., Pechar L. (2001): Effect of different management practices on vegetation development, losses of soluble matter and solar energy dissipation in three small sub-mountain catchments. In: Vymazal J. (ed.): Transformations of Nutrients in Natural and Constructed Wetlands. Backhuys Publishers, Leiden, 143–175.

Procházka J., Včelák V., Wotavová K., Štíchová J., Pechar L. (2006): Holistic concept of landscape assessment: case study of three small catchments in the Šumava Mountains. Ekológia (Bratislava), **25** (Suppl. 3): 5–17.

Procházka J., Brom J., Pechar L., Štíchová J., Pokorný J. (2008): Changes in concentrations of dissolved solids in precipitation and discharge water from drained pasture, natural wetland and spruce forest during the years of 1999–2006 in Šumava Mountains, Czech Republic. In: Vymazal J. (ed.): Wastewater Treatment, Plant Dynamics and Management. Springer Science + Bussines Media B. V., Heidelberg, 39–51.

Rees R.M., Ribens J.C.H. (1995): Relationships between afforestation, water chemistry and fish stock in an upland catchment in south-west Scotland. Water, Air & Soil Pollution, **85**: 303–330.

Ripl W. (1995): Management of water cycle and energy flow for ecosystem control – the Energy-Transport-Reaction (ETR) model. Ecological Modelling, **78**: 61–76.

Ripl W. (2003): Water: the bloodstream of the biosphere. Philosophical Transaction. The Royal Society of London B, **358**: 1921–1934.

Savenije H.H.G. (1995): Does Moisture Feedback Affect Rainfall Significantly? Physics and Chemistry of the Earth, **20**: 507–513.

Sivakumar M.V.K. (2007): Interaction between climate and desertification. Agricultural and Forest Meteorology, **142**: 143–155.

StatSoft, Inc. (2005). STATISTICA (data analysis software system), Version 7.1. Available at www.statsoft.com.

Van de Griend A.A., Owe M. (1993): On the relationship between thermal emissivity and the normalized difference vegetation index for natural surfaces. International Journal of Remote Sensing, **14**: 1119–1131.

Wattenbach M., Zebich,M., Hatterman F., Gottschalk P., Goemann H., Kreins P., Badeck F., Lasch P., Suckow F., Wechsung F. (2007): Hydrological impact assessment of afforestration and change in tree-species composition – A regional case study for the Federal State of Brandenburg (Germany). Journal of Hydrology, **346**: 1–17.

Yoshino M.M. (1975): Climate in a Small Area. An Introduction to Local Meteorology. University of Tokyo Press, Tokyo.

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