EFFECT OF WATER DRAINAGE ON THE FOREST MICROCLIMATE: CASE STUDY OF TWO SMALL CATCHMENTS IN THE ŠUMAVA MOUNTAINS

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Abstract

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Changes in land cover temperatures as a result of anthropogenic intervention in the water regime in selected localities of the Šumava mountains (the Czech Republic) were identified. The research was conducted in two subcatchments of similar size, altitude and relief. The subcatchment of the Bonarův stream was chosen as an area affected by water drainage. Subcatchment of the Ferdinandův stream, not affected by drainage, was chosen as a reference area. Distribution of land cover temperatures measured directly and obtained from Landsat TM satellite data was evaluated for both catchments. Temperature recording was performed in four locations of each of the catchments and in four levels of spruce forest between July 7 and November 4 of 2005. Comparison of the temperature values of both subcatchments showed that the temperature behaviour in both areas did not differ in average but was significantly different in its variance and mainly in daily amplitudes. Results show that in the drained area, the temperatures fluctuate more during the day. The processed satellite data show that the differences in temperature values between the subcatchments are significant and that the drained area shows higher temperatures. Results support an application of the Landsat TM data for evaluation of the land cover temperature as pattern of landscape functioning.

Key words: water drainage, surface temperature, remote sensing, spruce forest

Introduction

Decrease of the subsurface water level in large areas of forest stands results in changes of energy balance, decrease of evapotranspiration, and distribution of temperature in the area. The temperature extremes in the area increase. The proportion between sensible and latent heat changes significantly (Pokorný, 2001). Decrease of water level in soil profile leads to acceleration of organic matter decomposition. Nutrient flows in the ecosystem change. The nutrient concentrations of the effluent waters rise with all of its negative results (increase of NOx, eutrophication of valley reservoirs etc.). Soil acidity increases as well, due to the release of cations and protons in oxidative processes. Such processes lead to imbalance of forest ecosystems. Another result of these changes in water regime is an adverse effect on the outflow pattern (Pokorný et al., 2002). Overall summary of the role of water in the energy distribution and balance of the matter in the biosphere was described by Ripl (2003).

Changes of energy fluxes in ecosystems arising as a result of changes of the proportion between evaporated water and released heat appear in temperature changes of the land cover. Temperatures can be monitored both by direct measurement with sensors located in soil and different vertical levels of the stand profile, and by remote sensing– measurement of radiation temperatures. Such approach, developed and used by Ripl, 1995; Hildmann, 1999, was verified by our team (Procházka et al., 2001a,b), and used in many other projects (Pokorný et al., 2002), during research of forest and wetland ecosystems in the Šumava National park by Hais and Pokorný (2004) and Hojdová et al. (2005). A detailed and elaborate study of intact forest ecosystem in the Alps focused on matter and energy flows, was accomplished by a team led by Ripl et al. (2004). Results of the quoted works prove that temperatures between both locations (in space) and daytimes (in time) are balanced in ecosystems with sufficient of vegetation and water. Water flowing from such ecosystems contains usually less dissolved matter. Organic matter is accumulated in soil. Soil of such well-working ecosystems has a neutral pH. Change of the temperature distribution and humidity in land cover affect microclimate and energetic balance of the given area (Ripl, 1995; Ripl et al., 1994) as well as water outflow conditions that reflect water holding capacity of the landscape and microclimatic conditions. Water is the principle factor influencing the physiological condition of the vegetation cover. Significant anthropogenic intervention in the water regime may there result in physiological changes in the forest growth. There can be many of causes of temperature changes and humidities of the land cover. Nevertheless, from the physical point of view, it is a change of the proportion between reflection of solar radiation, evapotranspiration and sensible heat (Pokorný, 2001). Dieback of trees in large areas is accompanied by decrease of transpiration and thus shifts energy fluxes from latent heat to sensible heat. Increase in the amount of sensible heat and decrease of latent heat was proved by ground measurement in declined mountain spruce forest (Hojdová et al., 2005).

Study and quantitative description of differences in temperature characteristics of spruce forests on drained and not-drained localities was the aim of this work. In the drained localities, we expected higher average temperatures and higher fluctuations of temperature progress in the diurnal cycle.

Material and methods

The research was conducted in two subcatchments of the Bonarův and Ferdinandův stream in the area of Trojmezenská hornatina in the Šumava mountains (south-western part of the Czech Republic). These subcatchments are comparable in the size, altitude and relief. The subcatchment of Bonarův stream is affected by water drainage. Subcatchment of Ferdinandův stream is the reference area of stream not affected by the drainage. For determination of possible differences in the temperature regime of both subcatchments, we used automatic R0141 Comet temperature dataloggers with 0.2 °C accuracy in range of -50 to +100 °C. We installed four dataloggers in each of the subcatchments with four temperature probes (Pt 1000) connected to each. Temperature recording was performed on the top of the crown of the spruces, under the main crown, in two meters above the ground and on the ground surface. The recording took place between July 7 and November 4 of 2005 in thirty-minute intervals. Only the data from the top of the spruce crowns were used for this work and considered as land cover temperatures for comparison with remote sensing data. Unfortunately, during data collection, we discovered a failure of the D3 sensor in the catchment of Bonarův stream. Data from Landsat TM 5 with localisation 191/26 were used for the objectives of this project as well. The scene was acquired at 10.30 of summer time on September 7 of 2005. The satellite scene was geocoded into the S-JTSK coordinate system. Furthermore, temperature values of the land cover have been obtained from the data as well (ATCORT 2) (Geomatica Algorithm Reference, 2003). The resulting map was expressed in pseudocoloured projection. Subsequently, we statistically compared the temperature data of the land covers (monitored on the top of spruce crowns) from both catchments.

For comparison of the individual stations with each other, we used Repeated Measures ANOVA and Scheffe's post-hock test. For comparison of average values we used Student's t-test. For independent samples and for variance comparison we used Fisher's F-test.

Data on the land cover temperature obtained from Landsat TM were tested by non-parametric methods as they did not show a normal distribution. In this case we used non-parametric Mann-Withney test. All test were assessed at d = 0.05 level of significance.

Results

Results of automatic data logging and their comparison in both evaluated subcatchments are shown in Table 1.

Data comparison by Repeated Measures ANOVA shows that variance values for individual stations vary significantly, $F = 384.47$; $df = 3$; $p < 0.05$.

T a b l e 1. Basic characteristics of the measured temperatures from the tree crown surface (N: non-drained locality – Ferdinandův stream, D: drained locality – Bonarův stream). Values are shown in °C. From the data recorded in this period, we compared variability of the temperature data in the scope of accordance of variances and averages of the measured data, and accordance of variances and averages of mean daily amplitudes between both localities. SD – standard deviation

July 22 to September 9, 2005									Ferdinandův stream	Bonarův stream
	N1	N2	N3	N4	D1	D2	D3	D4	“non-drained”	“drained”
Mean	13.9	13.9	13.8	13.8	13.5	13.3	–	14.7	13.9	13.9
Minimum	5.0	4.7	4.8	5.0	3.1	2.8	–	4.6	4.9	3.5
Maximum	34.5	32.0	33.6	31.1	32.2	35.5	–	36.7	32.8	34.8
Amplitude	29.5	27.3	28.8	26.1	29.1	32.7	–	32.1	27.9	31.3
SD	4.2	4.2	4.2	4.0	4.4	4.4	–	5.7	4.1	4.8
Median	13.5	13.5	13.4	13.5	13.3	13.1	–	13.5	13.5	13.3

Differences in variance between the two locations as well as between individual measurements were evident from these datasets.

For comparison of differences between both drained and non-drained localities, mean values of temperature courses were computed. These values were compared by t-test for dependent samples and by F-test: $t = 0.49$; df $= 2635$; $p = 0.622$; $F = 1.28$; $p < 0.05$. The result shows that the localities do not differ in temperature course in the scope of mean values, but differ in the variance of values. Summary of the data is shown in Fig. 1.

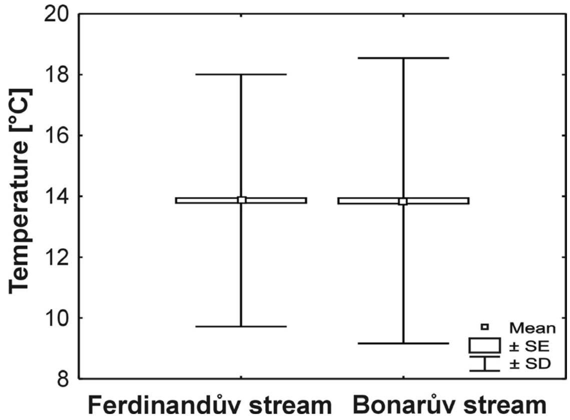

Fig. 1. Summary of mean temperature values in individual locations. SE – standard error, SD – standard deviation.

Mean daily amplitudes were another of the evaluated parameters. Comparison of data from individual stations by Repeated Measures ANOVA shows that variance values of data from individual stations also differ ($F = 121.31$; df = 3; $p < 0.05$).

It is obvious that for the mean values from both localities there is a statistically significant difference between the localities in the range of average values ($t = 14.38$; df = 54; $p < 0.05$). There was no statistical difference noticed in the dispersion ($F = 1.45$; $p = 0.18$). Summary of the data is shown in Fig. 2.

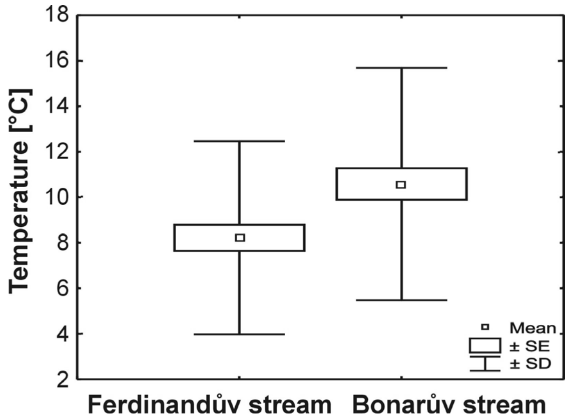

Fig. 2. Summary of mean daily amplitudes in monitored localities. SE – standard error, SD – standard deviation.

To avoid some interferences (e.g. precipitation, mist), we compared three consequent warmest days with high solar energy input from July 27 to July 29 of 2005. Summary of the main statistical data is shown in Table 4. It is obvious from the results, that the mean temperatures in both localities do not differ, however, maxima and primarily temperature amplitudes are evidently higher at the surface of the tree crowns of the drained catchment of Bonarův stream.

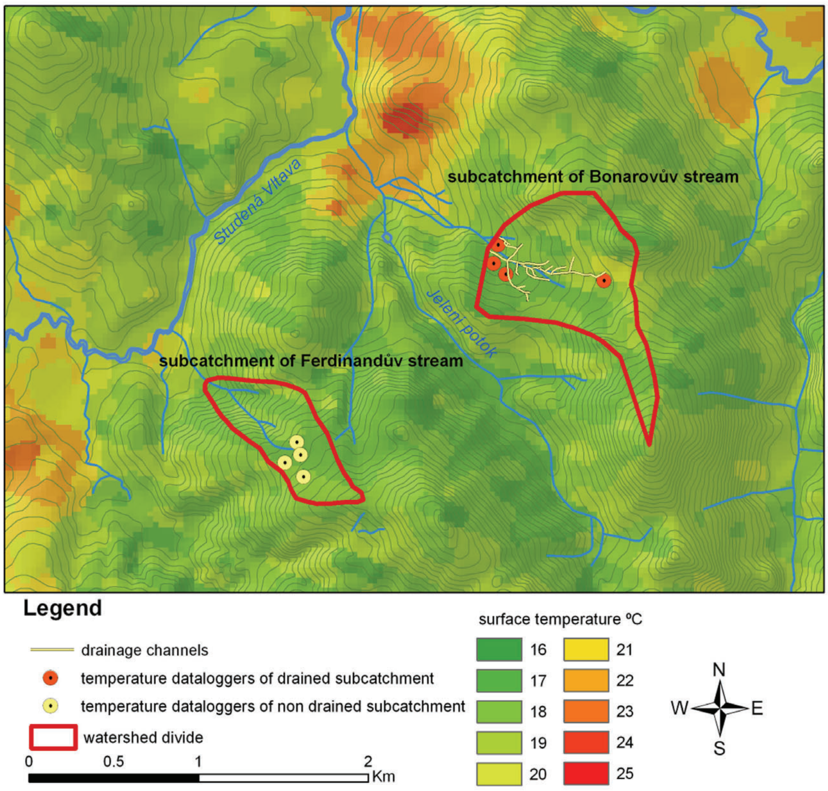

Fig. 3. Map of land cover temperatures from 2005-09-07 from Landsat TM 5 satellite data.

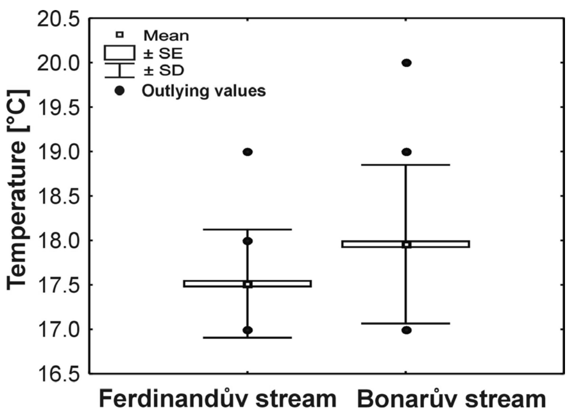

Fig. 4. Comparison of distribution of the land cover temperatures in the catchments of Bonarův (drained) and Ferdinandův stream (non-drained). SE – standard error, SD – standard deviation.

T a b l e 2. Basic characteristics of recorded temperature values from the surface of tree crowns (N: non-drained locality – Ferdinandův stream, D: drained locality – Bonarův stream). Values are expressed in °C. SD – standard deviation

July 27 to 29, 2005									Ferdinandův stream	Bonarův stream
	N1	N2	N3	N4	D1	D2	D3	D4	“non-drained”	“drained”
Mean	21.9	22.0	21.5	21.6	20.7	20.5	–	23.9	21.7	21.7
Minimum	12.5	12.7	12.3	12.6	11.4	11.0	–	12.3	12.5	11.6
Maximum	34.5	32.0	33.6	31.1	32.2	35.5	–	36.7	32.8	34.8
Amplitude	22.0	19.3	21.3	18.5	20.8	24.5	–	24.4	20.3	23.2
SD	5.8	5.5	5.8	5.3	6.4	6.7	–	7.2	5.6	6.8
Median	21.2	21.6	20.7	21.0	20.2	19.8	–	24.0	21.1	21.3

To be able to compare temperatures of the land cover of both catchments of our interest, we had to convert radiometric values of thermal spectrum of Landsat satellite to real temperature values. The results of this conversion are shown in Fig. 3, presenting temperature distribution of the land cover. The highest temperatures were in the deforested or built-up areas. The comparison of the land cover temperatures between both of drained and non-drained localities is shown in Fig. 4.

Discussion

The resulting statistical summary of the data shows the following

In the case of both temperature courses and daily amplitudes, individual temperatures differ from each other not only between both locations but also between each other in one location. This fact is caused probably by slight differences in the microclimatic conditions and topography, where the temperature probes were located. Comparison of mean values and daily mean temperature amplitudes of the monitored localities provided much more significant results. The analysis shows that the temperature course in the localities does not differ in averages but in variance; it follows that in the drained area, there appears to be much greater oscillation of the temperatures during the day. In measurements, a statistical analysis of mean daily amplitudes confirms this fact as well. It was shown that mean amplitudes were higher in the drained location than in the non-drained one. The comparison of the warmest recorded sunny days shows that in the drained growth, there appears to be much more noticeable temperature fluctuation than in the non-drained area. There were higher mean amplitudes, but also higher standard deviations, which serve as a criterion of ambivalence of temperature values during the day. Conclusions made on the basis of the data from the whole monitored period, when some dissimilarities may be blurred and affected by meteorological conditions and higher number of cloudy days. Moreover, it is to be noted, that the year 2005 had precipitation 70% above the average of past 15 years (1990–2004). In August and September this was only 12 to15% above the long-term precipitation average. This should substantially decrease the assumed difference of water regime (deficit) and cooling capabilities of both different locations, as shown in the presented results. We suppose that the differences will be more evident in years with larger number of sunny days.

The above-mentioned results obtained from stand temperature measurements are in accordance with satellite data comparison of both subcatchments. This evaluation also shows that the differences in temperature values between the subcatchments are significant. Higher temperature values of the land cover were demonstrated in the drained subcatchment of the Bonarův stream. Although spruce forests do not usually have the ability of high intensity of transpiration and reach maximal daily values of 1.5–3 mm d^{-1} (Köstner, 2001), they are probably (in case of availability of water) able to regulate their surface temperature more effectively than forests in drained location. It is clear that spruce forests significantly react to environmental conditions (e.g. comparison of different spruce (coniferous) forests monitored within the EUROFLUX project shows that yearly amount of evapotranspiration varies significantly between individual locations with different abiotic conditions from 291 to 482 mm $year^{-1}$ (Bernhofer et al., 2003). One of the important results of changes in temperature behaviour of forests is the connection with CO_2 cycle. Lindroth et al. (1998) expressed an exponential dependence between temperature and night respiration in a spruce forest.

Remaining question is the role of water stress in the drained area. We see the water stress as one of the causes of higher fluctuations of temperatures in the drained location. During the water stress, leaf stomata may close before reaching photic compensation point of photosynthesis and overheating of the assimilation surface may appear during sunny days when plants have no possibility to cool effectively. This condition may lead to weakening of the forest and higher sensitivity to diseases and pests. It would be useful to verify the questions about the water stress e.g. by measuring of stomata conductance.

Conclusion

The comparison of continuously measured temperatures in subcatchments of Bonarův (drained) and Ferdinandův (non-drained) streams shows that the temperature progress in the locations does not vary in terms of averages, but differs in variance and particularly in the characteristics of mean daily amplitudes. Our measurements show that the drained location manifests much higher fluctuations of temperatures during the day.

On the basis of processing the satellite data, we have found that the differences of temperature values between the subcatchments are significant and that higher temperatures of the land cover were found in the drained subcatchment of Bonarův stream. Beside the water availability and related values of evapotranspiration, orography can play a significant role here and its effect on temperatures should be paid attention in further research.

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Hais M., Brom J., Procházka J., Pokorný J.: **Vliv hydromelioračních odvodňovacích úprav na mikroklimatické podmínky lesních porostů – případová studie na dvou šumavských subpovodích.**

Cílem této práce je identifikovat případné změny teplot krajinného krytu v důsledku antropogenního zásahu do vodního režimu na vybraných lokalitách Šumavy. Výzkum byl prováděn na dvou subpovodích srovnatelných z hlediska rozlohy, nadmořské výšky a reliéfu. Subpovodí Bonarova potoka bylo vybráno jako území ovlivněné odvodňovacími hydromelioračními úpravami. Srovnávacím územím je subpovodí Ferdinandova potoka, prakticky neovlivněné odvodňovacími úpravami. Na obou povodích byla hodnocena distribuce teplot krajinného krytu přímým měřením a na základě zpracování dat družice Landsat TM. Záznam teplot byl prováděn na čtyřech místech pro každé povodí a ve čtyřech výškách ve smrkovém porostu od 22. 7. do 4. 11. 2005. Ze srovnání hodnot teplot obou subpovodí vyplývá, že se průběh teplot na stanovištích neliší z hlediska průměrů, ale liší se významně variancí a zejména charakteristikou průměrných denních amplitud. Výsledky ukazují, že na odvodněném stanovišti dochází k mnohem většímu kolísání teplot během dne. Ze zpracovaných družicových dat vyplývá, že rozdíly v hodnotách teplot mezi subpovodími jsou signifikantní a vyšší hodnoty teplot krajinného krytu vykazuje odvodněné povodí.