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Microclimate of a peat bog and of the forest in different states of damage in the Šumava National Park

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Abstract
The study deals with the comparison of the microclimate of damaged and healthy forest in the Šumava National Park, in connection with the interventions against bark beetle. In the living forest, dead forest, clearing and peat bog, temperature of soil and temperature in stands were recorded continuously during two vegetation seasons (2002 and 2003) and air humidity in 2003. The stations were situated in the Luzenské Údolí valley and close to Novohuťské Slatě peat bog. The results show clearly that the temperature fluctuations are lowest in the living forest. The maximum daily temperature amplitude in the living forest reached 17.9 °C above the herbal floor, in contrast to the other stations, where the temperature amplitudes were much higher – in the dry forest on average by 14.5 °C, in the peat bog by 11.5 °C and in the clearing by 16.7 °C. The highest daily temperature amplitude from all the observed stations was in the peat bog, 42.7 °C in 2002 and 50.2 °C in 2003. Measurements in stands were supplemented with satellite pictures in the infrared scale to show the distribution of temperatures in the whole area at a given time. The coolest structures appear to be the areas of living forest; on the contrary, the hottest are clearings and the dry forest area. The measured data are discussed in terms of radiation balance and water cycle.

Key words: dying forest, microclimate, peat bog, remote sensing, temperature amplitudes

Introduction

Temperature amplitudes are indicators of the ecological function of the landscape. Temperature reflects the energetic processes, such as reflection of radiation, evapotranspiration and on the contrary, water condensation back to the liquid state, and heat release. High temperature amplitudes reflect low evaporation and poor condensation, indicate the disturbed water cycle, i.e. lack of water in the small cycle (soil-plant-atmosphere-condensation). On the contrary, low amplitudes reflect that the most of solar energy is consumed for transformation of water into vapor. Heat remains in this latent form until the air cools down to the dew point and then is released during the condensation of water. Detailed study about temperature courses in the landscape was elaborated by Hildmann (1999) on the basis of Ripl's study (1995, 1996).

The main goal of our monitoring was to assess the differences in temperature and humidity at stations with forest in different states and in a peat bog in the Šumava NP. Although such monitoring is performed routinely, the results of continual monitoring aimed at comparison of forest in different states of damage and peat bogs have not been published yet. However, they give an information about the effect of different interventions on the microclimate and could be helpful for the Management of the National Park.

Continual recording of temperatures by platinum thermometers is advantageous, because it records the deviations caused by sunshine, cloudiness or shading. This spot measuring was completed with remote sensing, to see the distribution of temperatures in large areas. The satellite picture from the satellite Landsat gives the information about the temperature distribution at 9:30 a.m. The results contribute to the discussion on effect of drainage or large scale forest damage to dissipation of solar energy.

Methods

Land-based measurements were carried out in the years 2002 and 2003 in the Šumava NP, Forest Management Modrava. Temperatures were recorded during two, air humidity during one vegetation season. Every year, measurements were performed at four stations. Three stations were the same during the entire period, one of them was changed in 2003. The stations were situated at two locations, in the Luzenské Údolí valley (about 6 km southward from Modrava) and close to Nohovuťské Slatě peat bog (about 4 km from Březník). The schematic map of the area is given in Fig. 1.

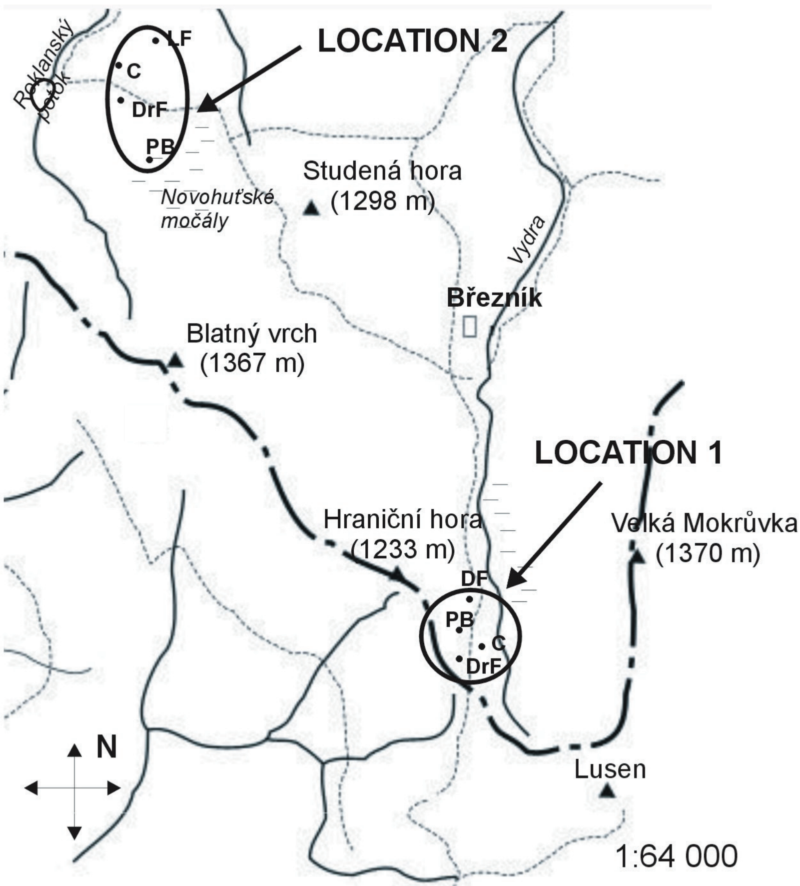

Fig. 1. Map of the observed area: LF – living forest, C – clearing, DF – dying forest, DrF – dry forest, PB – peat bog.

At the locations, three stations with forest in different states (living forest, dry forest and clearing) and one station in a peat bog were selected. The stations had a sufficient size (at least 300 m^2) and at the same time almost the same slope exposure (zero dip), with the altitude fluctuating around 1180 m above the sea level. The station types and their coordinates are shown in Table 1.

Table 1. Station types and their coordinates.

		location 1 (Luzenské Údolí valley)	location 2 (Novohuťské Slatě peat bog)
1	dry forest	48°56.792' N 13°29.334' E	48°98.473' N 13°44.389' E
2	clearing	48°56.882' N 13°29.352' E	48°98.558'N 13°44.447' E
3	2002 – dying trees 2003 – living forest	48°57.113' N 13°29.339' E	48°98.658' N 13°44.836' E
4	peat bog	48°56.852' N 13°29.341' E	48°98.210' N 13°44.721' E

The stations were also selected with regard to remote sensing. The station size corresponds with the size of the smallest pixel of Landsat ETM 7+- (thermal channel): 60×60 m. Because of failure of the above-mentioned satellite, it was necessary to use data from alternative Landsat TM5. Its pixel size is 120×120 m (Lillesand et al. 2004).

Temperature and humidity were recorded by data loggers Comet and by data loggers M4216 (in the dry forest and in the peat bog in the Luzenské Údolí valley). Temperatures were measured by a platinum resistive thermometer covered by steel tube of high reflectivity (length ca 40 mm, diameter 5 mm). The sensors were not inserted in a standard meteorological screen in order to allow exchange of long wave radiation and get information on temperatures within the stand. For humidity of the air a capacitive sensor was used.

Temperature sensors were placed at 4 levels: 15 cm in the soil, on the ground surface, above the herbal floor and 2 m above the ground (see Fig. 2). Daily courses of temperature at individual levels are compared in the graph in Fig. 3.

The sensor on the ground surface wasn't placed directly in the sun, but it was covered by vegetation. The sensor above the herbal floor was partly shaded because of the growing vegetation. The sensor at 2 m above the ground surface was placed directly in the sun, in contrast to sensors in meteorological stations. The sun phase is therefore clearly seen contrary to the rain or cloudy phase.

Temperatures were recorded continuously, every 15 minutes. Every day, 96 data were recorded on each sensor. Humidity of the air was measured above the herbal floor, with the same frequency as the temperatures.

For parameters and data loading from the data logger M4216 to PC, the program MOST32 was used and for data logger Comet, the program "Black box". The total memory capacity of Comet data logger is about 4000 data; in our case it meant that it was necessary to read the data every six weeks.

Data processing

In this study three daily courses of temperature for each station are shown (see Fig. 4). As an example we show temperature courses throughout the days with high temperature amplitude. There is the highest sun energy income and the temperature differences between the stations are well evident.

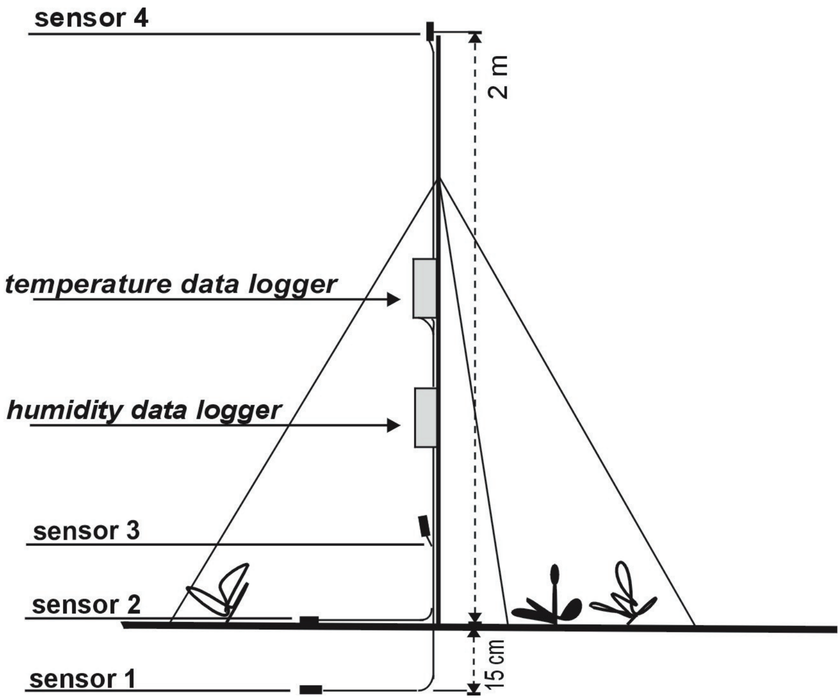

Fig. 2. Schematic picture of a data logger.

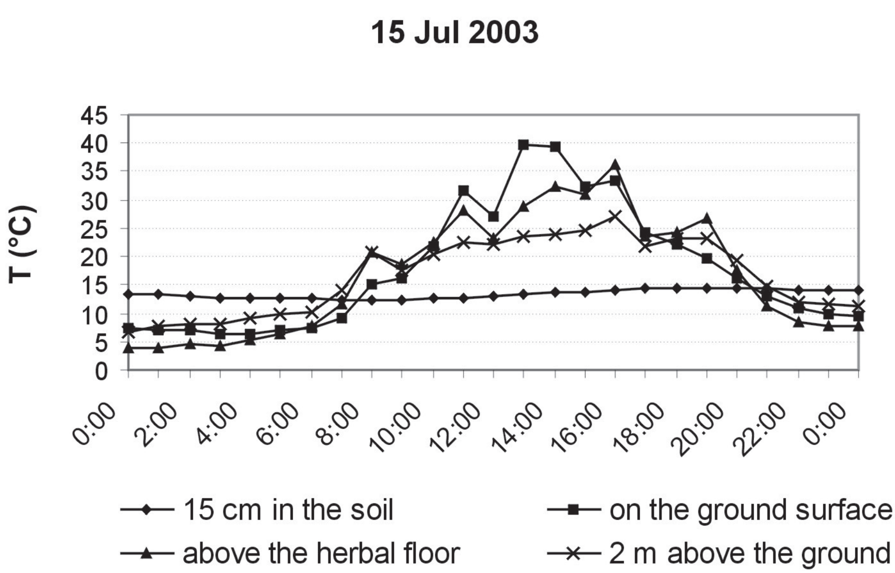

Fig. 3. Daily courses of temperature, measured at four levels in the dry forest (15 Jul 2003).

Temperature amplitudes for individual stations were counted from the maximum and minimum values for the entire observation period.

All data were statistically evaluated with the program SPSS. Average differences of temperatures between the stations were counted and differences of temperature amplitudes were compared.

In 2003, humidity of the air was also measured, expressed as the relative humidity. In this study, the course of relative humidity during the day with high sun radiation is shown.

Satellite pictures

An aerial photo and a satellite picture in infrared scale are shown for illustration. Distribution of temperatures (heat potentials) in large areas is shown in the satellite picture (see Fig. 10).

Rectified aerial photos were adapted to raster mosaic, which was then used for transformation of the Landsat TM satellite picture section (8 Aug 2003) to coordinate system JTSK. Radiometric values from 6 thermal channels were converted to land cover temperatures using module ATCOR2_T (Geomatica Algorithm Reference 2004). Temperatures were then calibrated according to values measured in stands. Temperatures recorded during satellite flight on the vegetation surface of one peat bog in Novohuťská Slať peat bog were used as calibration values for satellite data. As the value of a pixel from clearing, in which ground temperature were measured, were influenced by adjoining forest stands, a value of a pixel from neighbouring forest was used as a reference. In forest stands, temperatures were monitored on the herbal floor (not on tree crowns) and therefore those values were not used for calibration of satellite pictures.

Results

Typical courses of temperature

As an example of temperature courses we have selected sunny days, when the stands are exposed to high solar radiation and due to high solar energy income, temperature differences between the stations are created. On days with a short period of sunshine, temperature differences between the stations are very small.

One sunny day has been chosen from the beginning of the season, one from the middle and one from the end. Daily temperature courses are shown in Fig. 4. Temperature courses for one level from each station are compared in the graphs.

The lowest temperatures throughout the day were evidently in the living forest, the maximum temperature reached 28.1 °C. At the other stations the maxima were considerably higher, 51.9 °C in the peat bog, 36.1 °C in the clearing and 48.7 °C in the dry forest (measured on the ground surface).

On summer sunny days (15 Jul, 23 Aug 2003), the highest temperature amplitudes and maximum temperatures were measured in the peat bog whereas on 20 Sep 2003, the temperature amplitude and maxima it the peat bog was slightly lower than in the dry forest and similar to the clearing. This effect could be explained by lower transpiration ability of senescing leaves of herbs in the clearing and in the dry forest.

Courses of temperature amplitude

Temperature amplitudes were counted from all data, i.e. for 169 days in 2002 and 138 days in 2003. The courses of amplitude are shown in Figs 5–7. The graphs always show the amplitude courses at individual stations. This work shows amplitudes above the herbal floor and

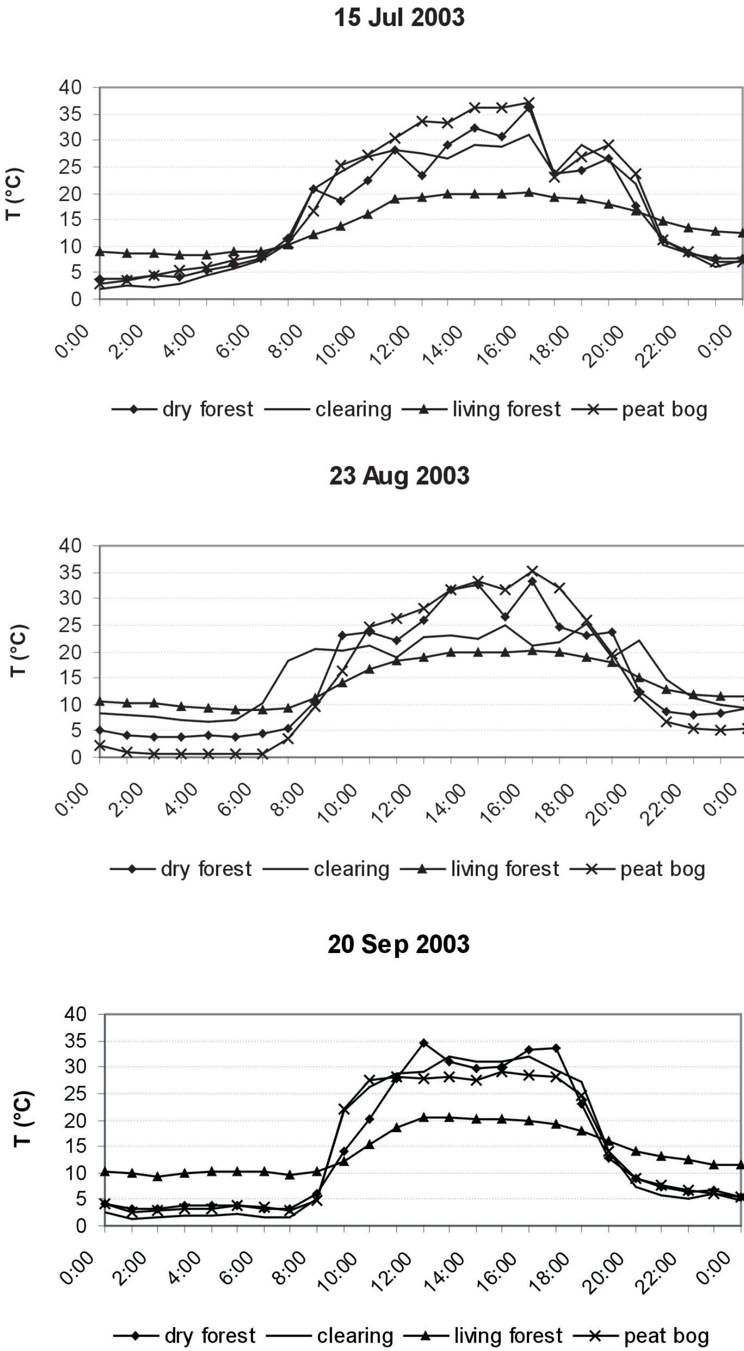

Fig. 4. Typical daily courses of temperature, measured during sunny days in 2003 above the herbal floor.

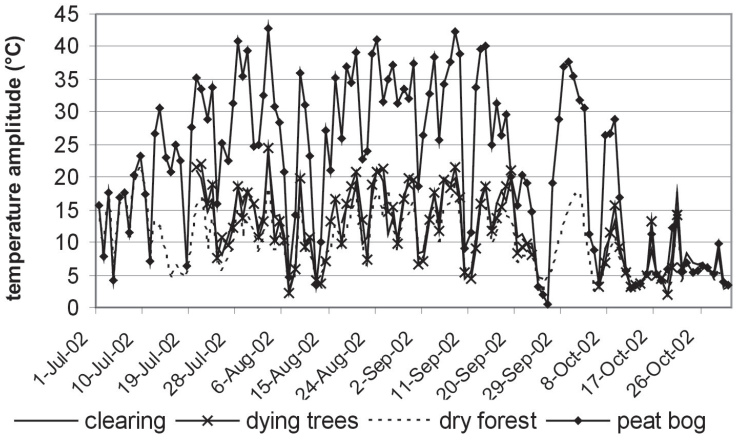

Fig. 5. The course of temperature amplitudes at 2 m above the ground in 2002.

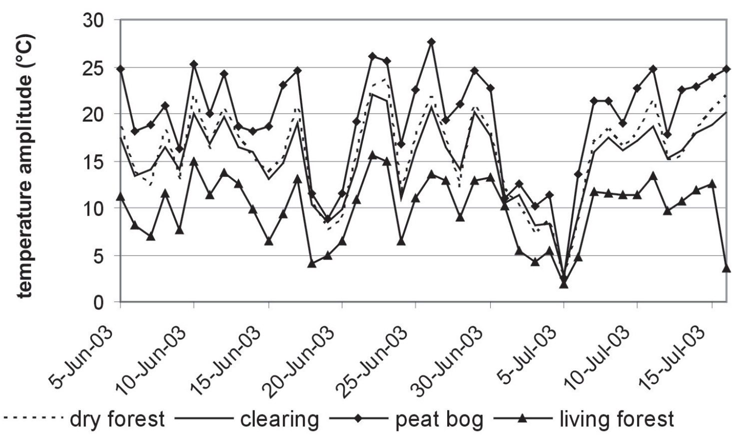

Fig. 6. The course of temperature amplitudes at 2 m above the ground in 2003

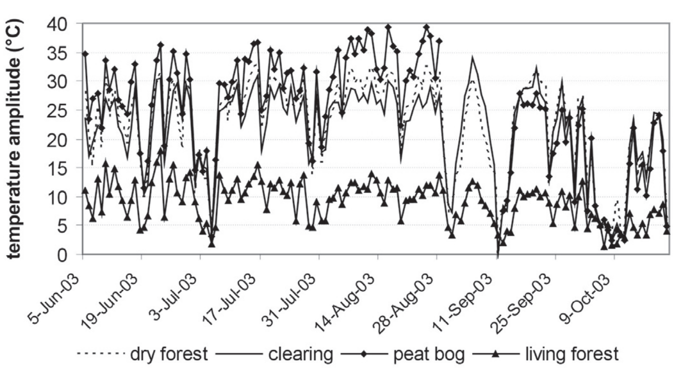

Fig. 7. The course of temperature amplitudes above the herbal floor in 2003.

plitude courses at individual stations. This work shows amplitudes above the herbal floor and 2 m above the ground. Because of technical problems with the data logger in the living forest, the data at 2 m above the ground are shown only up 17 Jul 2003.

The station in the living forest shows a markedly different microclimate; the other stations have higher temperature amplitudes and their amplitudes are quite similar.

The maximum daily amplitude in the living forest was 17.9 °C on 23 Jun 2003 above the herbal floor. The biggest differences between the stations were on the ground surface, where the amplitude in the clearing was on average by 16.7 °C higher, in the dry forest by 14.5 °C and in the peat bog by 11.5 °C higher.

In both years, the highest temperature amplitudes were found in the peat bog. In 2003, we recorded extremely high fluctuations, 50.2 °C on 19 Jul in the top layer of dry *Sphagnum* stand (Pt thermometer located horizontally in the stand ca 2 cm under the surface). High amplitudes were mainly above the herbal floor, namely 39.4 °C on 16 Aug 2003. In 2002, temperature amplitudes in the peat bog were even higher, 42.7 °C on 3 Aug 2002 (2 m above the ground).

In the clearing and in the dry forest the maximum amplitudes were on the ground surface. In the dry forest it was 42.9 °C on 25 Aug 2003, in the clearing 33.3 °C on 17 Jun 2003. In 2 m above the ground, the maximum amplitudes were recorded in the dry forest, 24.3 °C on 20 Sep 2003, and in the clearing, 22.1 °C on 22 Jun 2003.

Differences of temperature amplitudes under the dying trees, monitored in 2002, and in the clearing are very small. The highest fluctuations were on the ground surface, in the clearing it was 27.9 °C on 24 Aug 2002, under the dying trees 26.5 °C on 3 Aug 2002.

Relative humidity of the air

The humidity of the air was monitored in 2003 at three stations (living forest, dry forest and peat bog). Humidity courses in sunny days are shown in Fig. 8. Each graph compares the humidity of individual stations. Throughout the day the highest humidity was evidently in the living forest. The highest humidity was during the night and it was very similar at all stations.

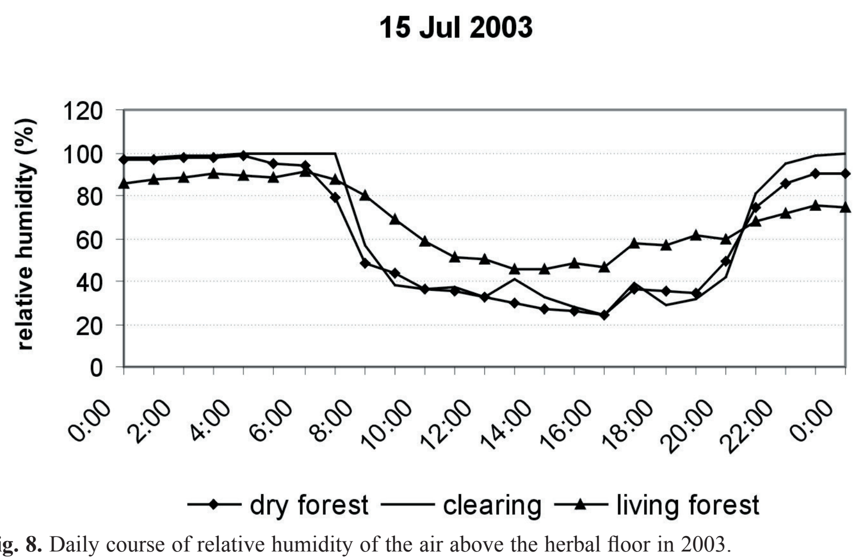

Fig. 8. Daily course of relative humidity of the air above the herbal floor in 2003.

Remote sensing

This study presents an aerial photo (Fig. 9) and a satellite picture (Fig. 10) from 8 Aug 2003. At the aerial photo all stations are highlighted. The satellite picture represents the same area as the aerial photo, but it is depicted in infrared scale and represents the temperature map of the landscape. Data that were land-based recorded and data from the pixel of the satellite picture are presented for individual stations.

With regard to the temperature distribution in the landscape cover, the lowest temperatures were evidently in the area with living forest, contrary to the highest temperature in the clearing and also in the dry forest.

Comparison between data measured above the herbal floor near the ground and data from satellite pictures is shown in Fig. 10. Temperatures measured in the peat bog above the herbal floor were 25 °C, data from satellite pixel 25.2 °C. In the clearing it was 30.7 °C and 30.1 °C, respectively. The temperatures in the living and dry forest were not measured in the tree crowns; that is why they do not correspond with satellite data very well; 18.8 °C (near the ground), 23.5 °C (from the satellite pixel) for the living forest and 25.9 °C and 26.3 °C, respectively for the dry forest.

Discussion

The main goal of our monitoring was to assess the differences in the microclimate of the forest in different states in the Šumava NP in connection with the interventions against bark beetle; for comparison we also monitored a peat bog.

The lowest temperature amplitudes, the most balanced temperature course and the best temperature damping during the whole vegetation season at all were in the living forest. The maximum temperatures at the other stations were much higher and differences among them were, in contrast to the living forest, very small. Among them, the highest temperature extremes were found in the peat bog.

The results of our monitoring are not surprising when we take into account the power of tree transpiration. The effect of transpiration of living trees is evident, contrary to the reduced transpiration in the dry forest and in the clearing. The importance of transpiration for the surrounding environment lies in the regulation of temperatures and humidity in the plant surrounding. The plant behaves like a very efficient air-conditioning (Pokorný 2001). In the clearing and in the dry forest the air-conditioning efficiency and shading by trees is evidently missing.

We explained the low amplitudes in the living forest, i.e. damping of daily maxima and night minima, mainly by evapotranspiration during the day, reduction of reflexive radiation at night and creation of dew. In other words, throughout the day, during high radiation the main part of solar energy is bound to water vapor and the daily temperature maximum is thus damped. On the contrary, at night the latent heat is released back by condensation and the temperature minimum is thus damped. Long-wave radiation from the soil to the sky is damped by vegetation and higher content of water in the air. Such shading is missing or is very limited in the other three types of forest.

For the first approximation we suggested similar values of reflection for all types of forest. In the peat bog light absorption could be higher and reflection lower. Soutjesdijk & Barkman (1992) gives values of albedo for coniferous forest 9–13%, for vegetation with dominant heather 10.2–15.2% and for wet meadow 17.9%. Values either for the clearing or for the peat bog are unfortunately not available. Higher reflection could be expected in the dry forest. That is why our statement is only hypothetical and should be confirmed by direct measurement in the dry and living forest.

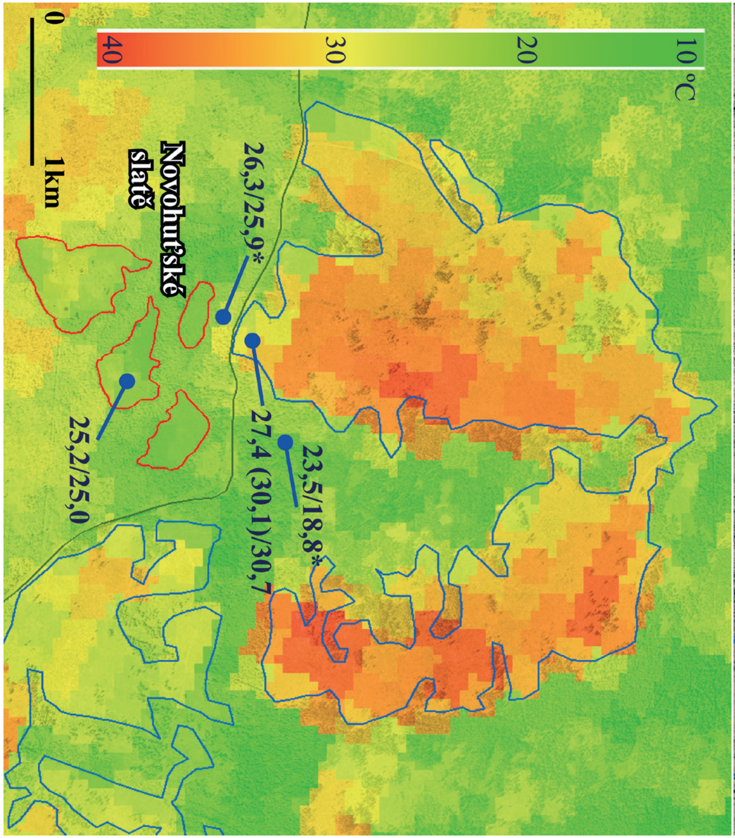

Fig. 10. Distribution of temperatures in the landscape. Temperature scale is shown on the left. Before slash - data from the Landsat TM5 satellite, the thermal channel. Behind slash - data measured near the ground by Pt thermometers. () – more precise value from the neigbouring pixel. * - land-based data from dry and living forest, which does not correspond with satellite data very well (measured above the herbal floor, not on the tree crowns). They are shown only for comparison between the stations.

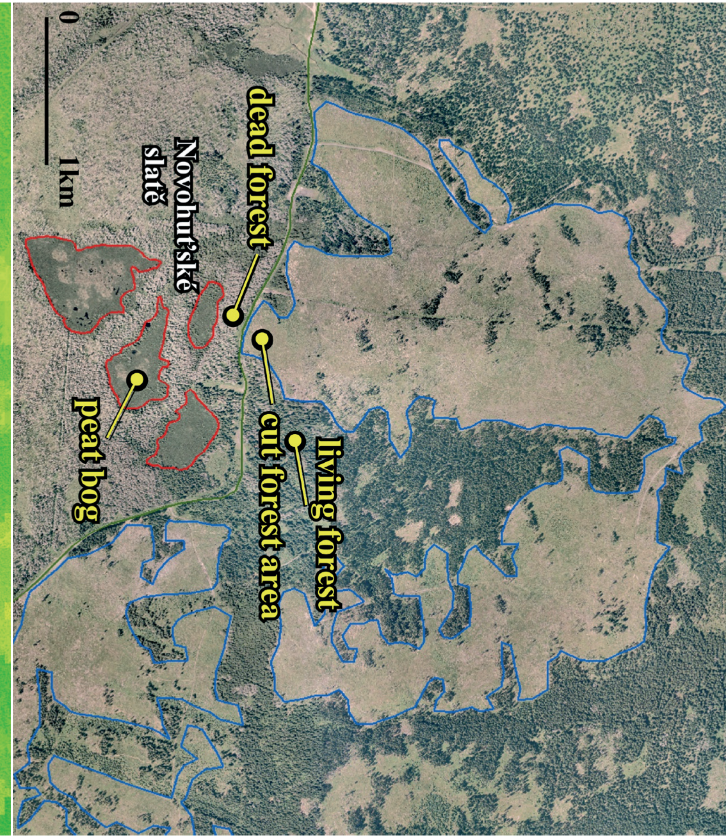

Fig. 9. An aerial photo of the observed stations (yellow points). Clearings are marked with blue polygons, peat bogs with red lines. Disturbed forest stands are marked in the left corner with a green line.

Noticeably high temperature amplitudes were found in the peat bog, both in 2002 with extremely high precipitations and in the very dry year 2003. High temperatures of leaves in the Červené Blato peat bog were also recorded by Kolmanová (1996), namely 43°C on 22 Jul 1995.

The surface of growing peat bogs is mainly covered by a carpet of *Sphagnum.* The *Sphagnum* moss does not possess either roots or conducting tissue and the entire water transport runs only by slow diffusion. In the summer, in the period without precipitations and by radiation weather, the heads of *Sphagnum* dry up, albedo increases, the vapor decreases significantly and the temperature near the ground increases (Kolmanová 1996).

Dry *Sphagnum* creates a thin layer and low rooting plants in the upper layer do not reach the ground water table and can not use this water. Even though the peat bog does not lose water, its narrow surface layer dries up and covers lower wet peat like a lid. After a rainfall, *Sphagnum* recovers again; on the contrary, litter fall of higher plants is dry and starts to decompose.

In addition, the heat capacity of the dry humus layer and its heat conductivity are very low. In comparison with the clearing there is lower heat conductivity of soil, i.e. lower income of heat from the soil to the cool surface at night, i.e. strong cooling of the surface of the peat bog.

In peat bogs covered by dwarf pine, roots of the trees reach under the sphagnum layer and can lead water for transpiration. These peat bogs behave more like a young forest and the temperature circumstances are not so extreme there as in the bare peat bogs.

Continual recording of temperatures at a given site (point measurements) is advantageous because the deviations caused by sunshine, cloudiness, penetration of sunrays to the soil surface in the living forest or by shading are recorded during the day.

On the contrary, distribution of temperatures in large areas is shown in satellite pictures. Comparison between data measured above the herbal floor near the ground surface and data from satellite pictures (see Fig. 10) point out the transpiration loss in damaged forest. Higher temperatures and humidity in a disturbed spruce grove are shown in Hais (in press). The author has compared satellite data from 1987 (before the bark beetle calamity in the central part of the Bohemian Forest started) with data from 2002.

Another possibility is to take recordings with a thermal camera. With its help it will be possible to create a temperature map of the landscape in the corresponding hour when the temperature differences are created.

Conclusions

The results of our work show that the living forest best damps the temperature fluctuations and so differs from the other stations (dry forest, clearing, peat bog). The living forest damps both the daily maxima and the night minima. The maximal temperature measured in the living forest was 28.1 °C (in 2003), contrary to the other stations, where the maxima fluctuate around 40 °C (42.8 °C in the dry forest, 42.3 °C in the peat bog and 36.1 °C in the clearing).

The highest temperature amplitude in the living forest was 17.9 °C. At the other stations the amplitude values were much higher and quite similar. The highest amplitudes in the dry forest were on the ground surface, 21.7 °C in 2002 and 42.9 °C in 2003, in the clearing they were 27.9 °C and 33.3 °C in the same years.

At both stations the climatic effect of trees is missing. In the living forest the main solar energy is bound to water vapor, which is at night released by condensation and damps the temperature decrease. In addition, the forest absorbs a major part of sun radiation and shades. At the other stations the amount of water vapor is clearly lower and a major part of energy is converted to sensible heat. The climatic effect of the dry forest and the clearing is quite similar. The temperature amplitudes in the dry forest and in the clearing were very similar, especially in 2003. The differences between them at 2 meters above the ground were on average 2.7 °C in 2002 and in 2003, 0.4 °C. The difference on the ground surface was higher, 4.6 C in 2002 and 2.2 °C in 2003.

The highest temperature amplitudes from all stations were in the peat bog. The hypothesis that the peat bog, wet mire, strongly damps temperature fluctuations was absolutely excluded. In 2002 the highest amplitude was 42.7 °C and in 2003 it was 50.2 °C. In comparison with the clearing the temperature amplitudes in 2002 and 2003 were in the peat bog by 14.4 °C and by 4.2 °C higher, respectively. In comparison with the living forest they were by 16.3 °C higher (above the herbal floor) and by 9.5 °C higher on the land surface.

As we expected, in the satellite picture from 8 Aug 2003, the lowest temperatures were evidently in areas with living forest; on the contrary, the highest temperatures were in the clearing and also in the dry forest. Land-based data measured above the herbal floor in the dry forest correspond approximately with the data from satellite pictures.

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