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Changes in Land Cover Temperature and Humidity Parameters Resulting from Spruce Forests Decay in the Centre of the Šumava National Park

MARTIN HAIS

University of South Bohemia, Faculty of Agriculture
Laboratory of Applied Ecology

Abstract

The article focuses on detection of landcover quality changes from remote sensed data in the core zone of the extreme flood in August 2002 – in central part of Šumava National Park. The author describe changes of temperature – humidity parameters of the landscape surface in consequence of the mountain spruce forest decay in the central part of Šumava through the comparison of the multispectral satellite analyses of scenes from years 1987 and 2002.

The results confirms the assumption that decay of mountain spruce forests in central Šumava leads to changes in land cover relative temperatures, specifically to a significant warming. Such changes are supported by the fact that the relative seven-grade temperature scale mostly showed shifts from the first (the coldest) class to the seventh class (the warmest) in the bark beetle calamity areas.

Key words: remote sensing, land cover temperature and wetness, forest decay

1. Introduction

All types of land cover have their typical temperature and humidity characteristics. In warmer periods of the year and mainly in summer (except periods of extreme precipitations or temperature differences), the temperature and humidity distribution in the geographical latitude of the Czech Republic is as follows: water and forest ecosystems in summer months show relatively the lowest temperature and the highest humidity values, while barren land, build-up areas and agricultural land are characterised by the highest temperature and the lowest humidity. Such characteristics can be used to assess landscape changes as well as landscape functions. In this connection the landscape functions means the fluxes of energy, water and matter in the specific part of catchment area depending on the condition of vegetation (Zichová, 2000). Driving factors of changes in land cover temperature and humidity may be numerous. The physical principle is the change of proportion of sun radiance reflection, evapotranspiration and sensible heat (Pokorný, 2001).

The objective of the paper is to study the impact of Šumava mountainous spruce forest decay on changes in the land cover temperature and humidity and subsequent modification of landscape functions. Changes in land cover temperature and humidity distribution could have consequences for the microclimate and energy balance of the area (Ripl, 1992; Ripl et al., 1996) as well as for the water outflow regime and matter losses, which reflects the ability of landscape retention and microclimate conditions.

Remote sensing is an excellent tool for assessment of changes in land cover temperature and humidity. Unlike point measuring methods, remote sensing collects data representing whole areas, which enables us to make a better picture of temperature and humidity values distribution in the studied area. Older satellite scenes (e.g. Landsat 4 and 5) also allow us to analyse conditions of twenty years ago, assess situations prior to the bark beetle calamity, and to compare results with the current state.

The aim of this study is to describe changes of temperature – humidity parameters of the landscape surface in consequence of the mountain spruce forest decay in the central part of Šumava through the comparison of the multispectral satellite analyses of scenes from years 1987 and 2002. The purpose of the study comes out some basic assumptions and hypothesis. The basic presumption of the hypothesis is the fact, that the mountain spruce forest decay caused by bark beetle will cause that the spruce forests will stop to serve as a vegetation, which appear as a decrease of water accumulation, evaporation, and subsequently by the change of Bowen ratio in favour of sensible heat. The analysis of Landsat satellite scenes was used to verify this hypothesis. The area of interest is scanned by the satellite every 16 days, always at 9:31 a. m. of the local time (i.e. 10:31 of the summer time), when the vegetation cover surface starts to differentiate according to temperature and humidity. The size of the smallest picture segment (called pixel) varies according to the scanner type (TM, ETM+) and spectral channel from 30 x 30 m (all channels except the 6th thermal), through 60 x 60 m (6th channel ETM+), to 120 x 120 m (6th channel TM). Thereby it is possible to notice also the differences in the landscape structures: living forest, death forest and openings.

2. Site

The study focuses on central Šumava, particularly on the zone affected by a significant decay of mountainous spruce forests. The area is delimited by Velká and Malá Mokrůvka in the east, and Roklan in the west. The northern frontier copies the line connecting Medvědí (1224 m) – Studená (1298 m) mountains and the southern end of the area follows the state border and cuts into Germany (0.5–1 km). The height above the sea level varies between 1100–1200 m and the highest peaks in the Czech part are Velká Mokrůvka (1370 m) and Špičník (1351 m) while the German area is dominated by Luzný (1373 m) and Roklan (1453 m). In hydrological terms, the whole site falls under the rivers basins of Roklanský and Modravský streams (96 km^2) and the Otava river. The geological subsoil is made of moldanubicum and the whole area is mostly located at the geological site knows as Královský hvozd (Royal Forest) (gneiss) characterised by magma bodies rising to the surface – e.g. in the central moldanubic plutonic rocks in the Vydra river massif (biotic granite, adamellites, granodiorites) (Kočárek, 2003). In terms of meteorology, the area shows the highest total precipitation volume and Březník is thought to be the place of the highest precipitation volumes (1552 mm annually) (Strnad, 2003). The area is mostly covered by spruce forests, peat (Rokytská, Rybárenská, Roklanská fens and others), and mountainous meadows. The high percentage of peat and wetland results from relatively high precipitations. In the past, there were certain efforts to drain the area and to transform it into production spruce monoculture forests (Hais, 2003).

3. Spruce Forests Decay Caused by Ips Typographus

The most radical change, affecting the mountain spruce forests of the Šumava and Bavarian Forest National Parks in 20th century, was the bark beetle calamity that started in 1991. As is stated in Skuhravý (2002), its origins could be traced back to 1983 when 173 ha of the Bavarian Forest National Park were destroyed by a hurricane. At that time, 88 ha were left without any treatment, which resulted in spread of eight-toothed spruce bark beetle (Ips typographus) that in 1986 attacked also other trees due to lack of damaged fallen trees. Despite further hurricanes in 1990 (Vivian and Veibke), the calamity seemed to have diminished in 1988–1992 and Bavarian experts voiced optimistic opinions on its end. However, in 1993, affected areas started to spread again, particularly towards the northwest from Luzný in the direction to Velký and Malý Špičník and further northwards and eastwards. Czech air photos of the area delimited by Špičník and Blatný vrch in the direction towards Roklan, taken in 1992, show individual affected trees and 12 larger pest focus sites (15–20 trees). In later stages, the area was affected by bark beetle leading to creation of many new focus sites in surrounding areas. In 1995 the Šumava National Park administration declared the non-intervention zone. It was enlarged to the southwards from the road between Roklanská hájenka and Březník and reaches the total area of 1450 ha in 1997.The bark beetle attack reached its peak in 1996 when it involved 80% of the non-intervention zone. Outside the zone, the Šumava NP administration adopted measures to clean affected wood and stop calamity progress. Ten percent of cleaned trees were unbarked and left in their original place. Since 1996, new trees have been planted in clearings, mainly spruce, but also rowan, beech, fir, and sycamore. To return future forest generations to the original state it's important to mix spruce with other species (Zatloukal et. al., 2001). The overall calamity results as of 2002 are specified in Tab. 1.

Tab. 1 Dead forest and clearing values in the Bavarian Forest and Šumava National Parks (*Kůrovec a jeho kalamity*, Skuhravý, 2002 – *Bark Beetle Calamities*)

National Park	Dead forest (ha)	Clearing (ha)	Scope in mil. m^3
Bavarian Forest	3650	270	1.5–1.7
Šumava	1450	1150	1.1–1.3
Total	5100	1420	2.6–3.0

4. Methodology

To assess temperature and humidity parameters, the multispectral distance data were analysed, specifically Landsat 5 TM and Landsat 7 ETM+ satellite images because satellites equipped with TM (thematic mapper) scanners have been in operation since 1982 (Lillesand et al., 2004), which is very beneficial for temporal change assessment.

So in this study it is possible to work with data from the time before the bark beetle calamity in Šumava, which starts in 1984. Satellite scenes taken on July 11, 1987 and July 28, 2002 were transformed geometrically into the JTSK coordinate system according to ortorectified *Družicová mapa ČR©* 2002 ARCDATA PRAHA, s.r.o. To enhance geometrical accuracy in central Šumava, the existing grid of ground control points was completed by points taken from aerial ortofotomaps provided by Šumava National Park administration for the purposes of the project. Data were resampled by applying the nearest neighbour method to preserve original radiometric values for subsequent data processing. Satellite images were subject to atmospheric corrections applying the ATCOR module to eliminate unwanted marks of water vapour in the atmosphere.

To calculate the land cover temperature, I used the 6^{th} thermal channel TM and ETM+ comprising records in the electromagnetic radiation interval of 10.4–12.5 μm (Campbell, 2002). DN values were transformed to temperature values by applying ATCOR2_T and recalculating radiometric values of surface radiation to temperature of an ideal black body. To enhance accuracy, the ATCOR2_T model was completed by supplementary calibration data: geographic location, medium height above the sea level, Sun zenith angle at the time of image taking (calculated in the SUN programme), the visibility range (data provided by the CHMI), and the season. The output comprises maps of the land cover temperature absolute values. Satellite data from different periods can be compared only after transforming temperature values into relative values.

When remote sensing methods are applied to assess humidity, it isn't possible to use directly some of the Landsat satellite spectral bands. Soil water content (Šúri et al., 1994) or land cover relative humidity values can be determined by using spectral indexes. Most methods apply the wetness index that forms part of the Tasseled Cup linear transformation. With respect to Landsat TM or ETM+ satellite data, the Tasseled Cup transformation processes 6 spectral bands (1–5, and 7) applying a method based on the Principle components analysis. For comparability reasons, values were again transformed into relative categories. In this case, I used the equiareal method. The histogram of satellite images was divided so that each interval contained ideally the same number of values. Reducing the span of discrete class histogram, I acquired deviations in numbers of values between individual intervals. When the difference of summary values within individual intervals is too big, it is necessary to choose a different numbers of intervals. Nevertheless, the number of intervals is limited by the maximum number of values of one class as specified below:

$$In \leq \frac{\sum c}{L_{\max}}$$

where In stands for the maximum number of equiareal intervals, $\sum c$ is the sum of values of all classes, and $L_{\max}$ is the class with the highest number of values. The equiareal distribution is characterised by marginal intervals comprising under normal conditions many classes, which leads to extremes averaging. On the other hand, this distribution method provides a good picture of the values distribution in space.

Temporal comparison of relative data (temperature, the wetness index) was performed on the basis of a matrix analysis (Geomatica Algorithm Reference, 2003).

It resulted in a visual record where the pixel value represented the combination of coinciding classes, mutually corresponding in terms of their location, as is specified bellow:

COINCIDENCE MATRIX:

	1	2	3	4	5	6	7	*Channel B*
1	**1**	2	3	4	5	6	**7**	
2	8	**9**	10	11	12	13	14	
3	15	16	**17**	18	19	20	21	
4	22	23	24	**25**	26	27	28	
5	29	30	31	32	**33**	34	35	
6	36	37	38	39	40	**41**	42	
7	**43**	44	45	46	47	48	**49**	
Channel A								

The chart shows values applicable to all combinations of corresponding classes coincidence. When class 1 of channel A corresponds to class 7 of channel B, the resulting value of the pixel is 7. This represents the maximum possible change (e.g. increase in temperature). The same applies to the resulting pixel value of 43, but the change is in the opposite direction (e.g. decrease in temperature). With respect to diagonally distributed values (1, 9, 17… 49), classes of both compared visual records mutually correspond and the result therefore equals zero, i.e. no change (e.g. table temperature). Building on the matrix analysis, we also made a table of a percentage coincidence of all combinations of selected intervals.

5. Results

The comparison of scenes from 1987 and 2002 clearly showed lighter zones in the 2002 image around the Luzenský stream cutting in the east through Mokrůvka further to Germany and towards Roklan in the west (Fig. 1a). Such zones represent decayed spruce forests and newly formed clearings. Colour differences between clearings and dead forests in the no-intervention zone aren't very clear (clearings are marked by a lighter shade). Fig. 1b shows the same areas in both monitored years as Fig. 1a, but the black-and-white scale represents land cover temperature values transferred into a relative equiareal scale for comparability purposes. The Fig. clearly shows an increase in land cover temperature that in many cases rose from the lowest to the highest values on the relative scale. This phenomenon is documented by Fig. 2a. It shows the matrix analysis results where pixel values are represented on the basis of overlapping classes combination. The biggest change of relative temperature, in other words a shift from the lowest land cover temperature class in 1987 to the highest land cover temperature class in 2002, was detected in the western slope of Mokrůvka hills, on the whole Špičník border ridge, on Blatný vrch, in the Roklanský forest, and clearings eastwards

Scennes: **11. 7. 1987** **28. 7. 2002**

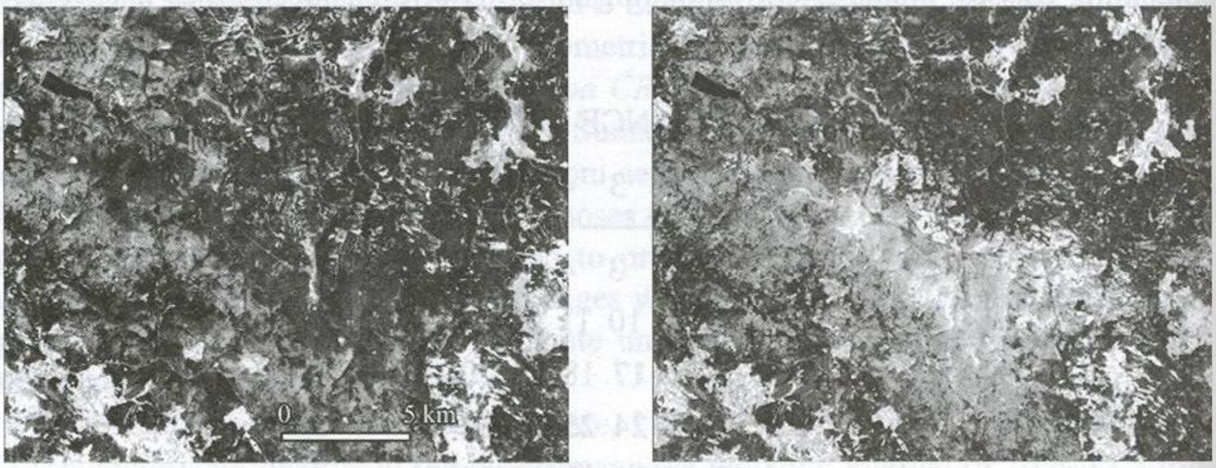

Fig. 1a Landsat 5 TM 5th channel Landsat 7 ETM+ 5th channel

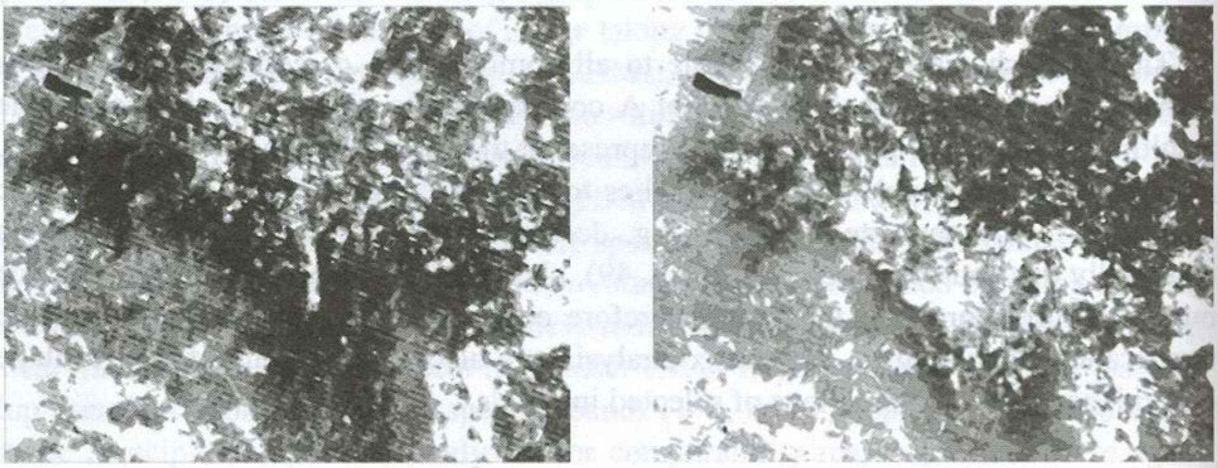

Fig. 1b Relative land cover temperatures low high

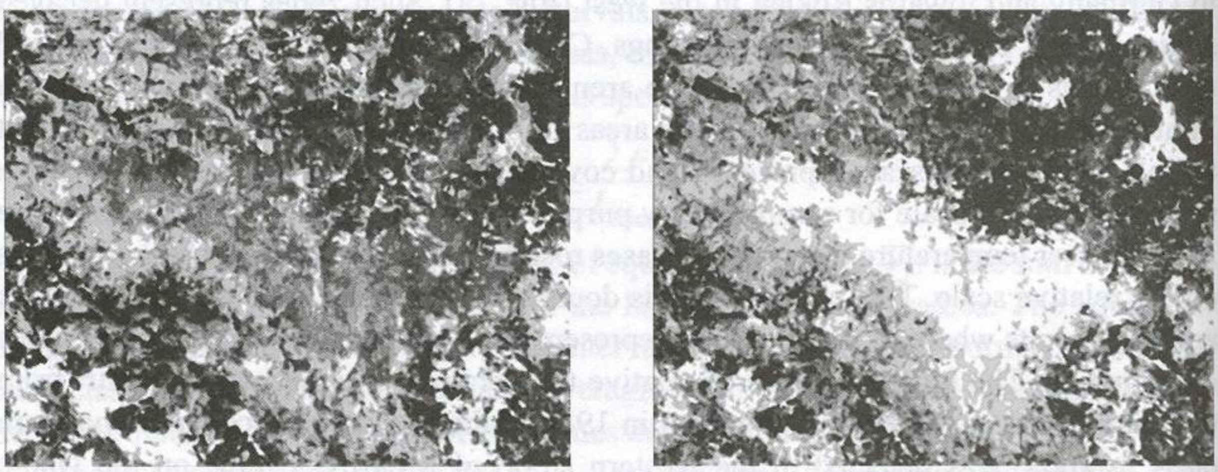

Fig. 1c Relative values of index wetness low high

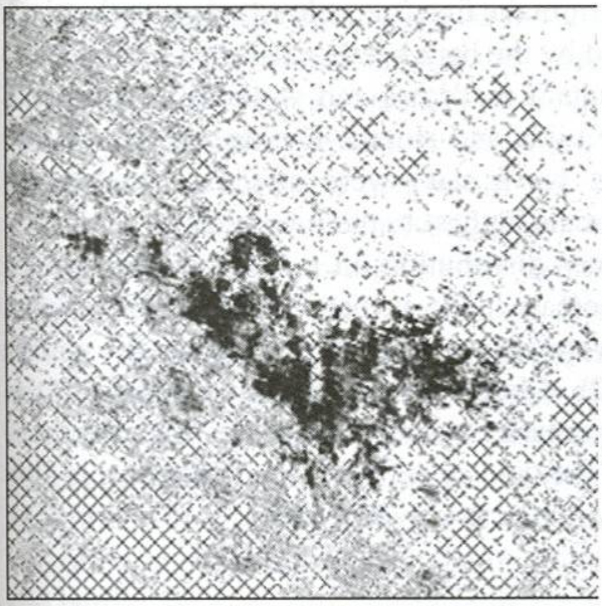

Fig. 2a Comparison of land cover temperatures between years 1987 and 2002

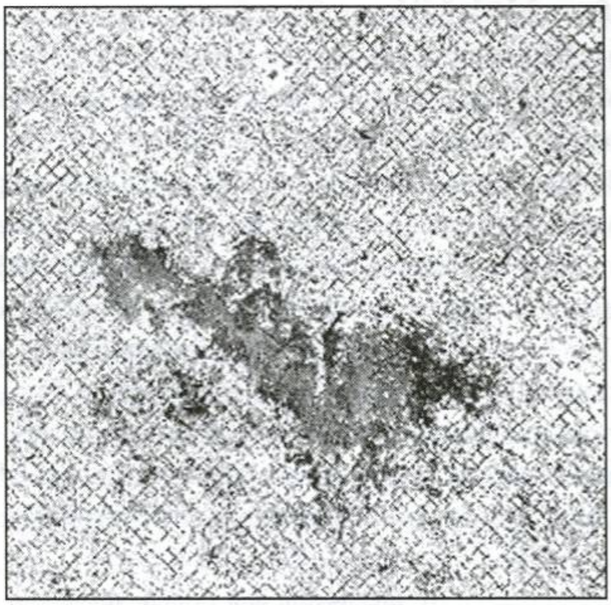

Fig. 2b Comparison of wetness index values between years 1987 and 2002

- increase by 7 classes
- increase by 6 classes
- increase by 5 classes
- increase by 4 classes
- increase by 3 classes
- increase by 2 classes
- no change
- decrease

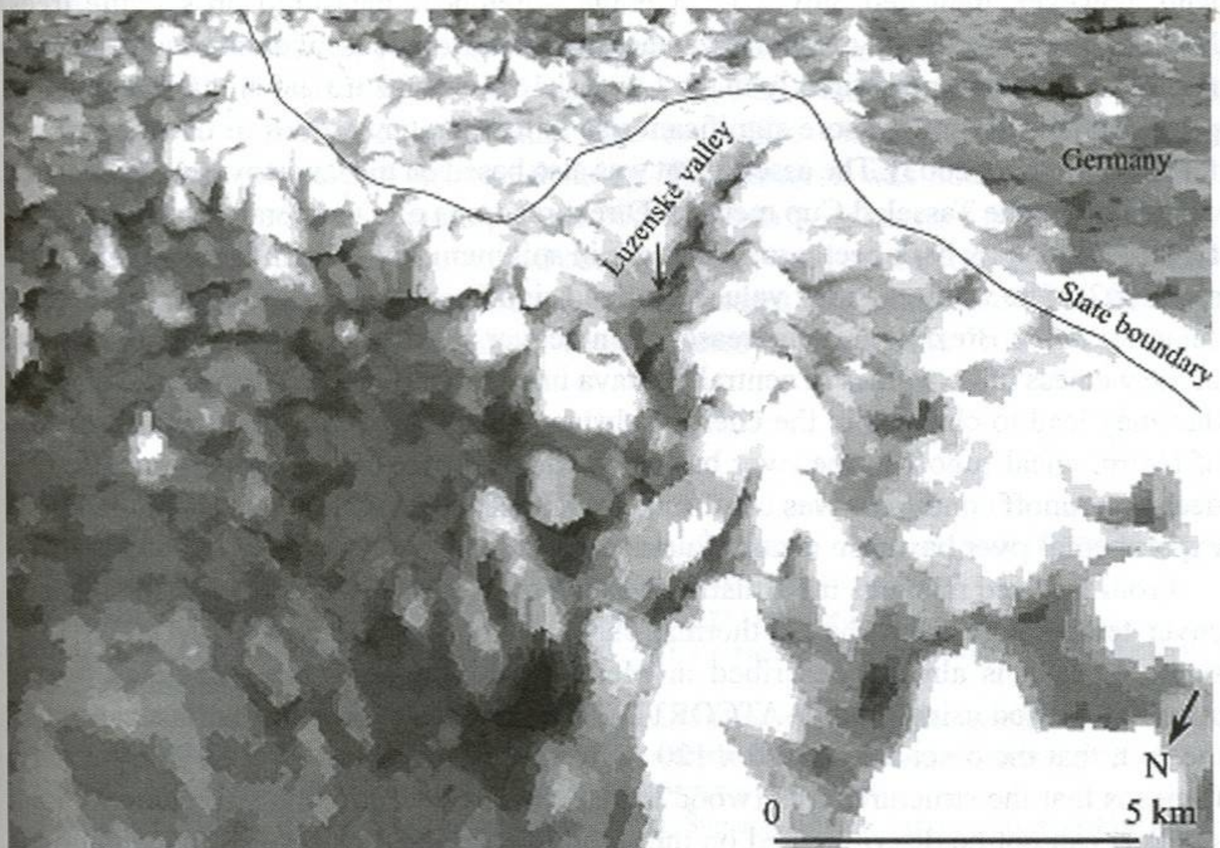

Fig. 3 3D Graph of relative temperature differences between years 1987 and 2002. The highest differences (white colour) are in spruce forest affected by bark beetle

from Medvědí hora. Significant movements from the first (the coldest) class to the sixth or fifth class apply to the whole area affected by the bark beetle calamity. Temperature differences are also shown in Fig. 3. Mountain meadows and wetland in Luzenské valley, around Modrava, at Filipova Huť, Kvilda and Horská Kvilda are free of any temperature changes. Some locations (e.g. Nová slať) were affected by opposite developments, i.e. temperature dropped from the highest to the lowest class.

Fig. 1c indicates the wetness index values distribution on a seven-grade relative scale. Comparison of both scenes shows a decrease in the wetness index values between 1987 and 2002. The wetness index results were also compared by applying the matrix analysis and the outcome is shown in Fig. 2b. Class changes are found mainly in the areas of decayed spruce forests and newly formed clearings. Decrease in the wetness index values implies a relative reduction of the land cover humidity. However, in this case changes mostly involve shifts from medium to the lowest values.

6. Discussion and Conclusions

The study confirms the assumption that decay of mountain spruce forests in central Šumava leads to changes in land cover relative temperatures, specifically to a significant warming. Such changes are supported by the fact that the relative seven-grade temperature scale mostly showed shifts from the first (the coldest) class to the seventh class (the warmest) in the bark beetle calamity areas. Links between beetle bark calamities and temperature changes are mentioned by Aldrich (1979) who, however, indicated only 1 C° average differences measured on specific trees. Nevertheless, results of comparative measurements of dead and unaffected forests microclimate performed directly in the Luzenské valley and around Nová Huť marshes prove statistically much more significant rise in temperature values of decayed spruce forests (Hojdová, 2003). The assessment was also based on the land cover wetness index calculated by the Tasseled Cup method. Direct relations of a temperature rise in spruce forests infested by bark beetle to a decrease in soil humidity were indicated by Swift et al., (2002). The wetness index values declined significantly also during the bark beetle calamity in the Březník area. Increase in land cover relative temperature and decrease in the wetness index values in central Šumava imply significant environmental changes that may lead to changes in the energy-substance balance of the area, or to formation of hydrological runoff in the river basin. Potential impact of mountain spruce forests decay on runoff conditions was confirmed by Křovák a Kuřík (2001) who studied three experimental river basins in central Šumava.

From the used methods the situation was the most simple when calculating the land cover temperature from the 6th thermal channel from the Landsat 5 TM a 7 ETM+ satellite. As it is already described in Methods, this values were calculated by the standard method using module ATCORT2_T. But there are some limitations caused by the fact, that the pixel size is 120 x 120 m by Landsat TM, and 60 x 60 m by ETM+. It means that the structure units (wood lands, openings etc.) in this size category (and smaller) can not be discriminated on the satellite scene. In this respect the situation is more favourable by counting wetness index, because both the input and output size of pixel is 30 x 30 m. But the wetness index have another limitations given directly by the method of calculation and the interpretation of results. On the one hand, the values of wetness index express the correlation with the relative humidity of the land cover, not the quantity itself. The field calibrating measurements are necessary to determine potential deviation. The Tasseled Cup Method itself could be the second limitation, because it is based on the linear transformation, which correspond to Principle Components Analysis. The wetness index represent the third component here, and this fact appears like the decreasing degree of the radiometric information acquired from the distant data. The dividing of the both temperature and wetness index values was made by dividing the interval into so-called equiareal classes. This dividing was used by Šíma to compare changes of the landscape surface temperatures in the area of "Podkrušnohorské" soil heaps (Pokorný et al., 2002). Some limitation of this method is given by the fact, that the fewer relative classes we have, the more the marginal extremes are hidden in the Gauss histogram of values. However, the equiareal distribution of classes gives better knowledge about the distribution of temperatures in the landscape than for example equidistant distribution.

According to this study it is possible to state, that the hypothesis of the increasing relative temperature of land cover and decreasing the wetness index values in the bark beetle calamity area was proved. It would be necessary to use data with higher resolution for more detail study of particular landcape components.

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ZMĚNY TEPLOTNĚ-VLHKOSTNÍCH PARAMETRŮ KRAJINNÉHO KRYTU JAKO DŮSLEDEK ROZPADU HORSKÝCH SMRČIN V CENTRÁLNÍ ČÁSTI NP ŠUMAVA

Résumé

Povrchy základních strukturních složek v krajině mají svůj typický teplotně-vlhkostní projev. Pro teplejší část roku, zejména v létě (bez výrazných srážek či extrémních výkyvů teplot) se v našich zeměpisných šířkách uspořádá distribuce teplot a vlhkostí: vodní a lesní ekosystémy mají v letních měsících relativně nejnižší teploty a nejvyšší vlhkost, naopak holé půdy, zástavba a zemědělské plochy vykazují relativně nejvyšší teploty a nejnižší vlhkosti. Těchto vlastností je možné využít nejen pro hodnocení změn v krajině, ale i krajinných funkcí. Příčin změn teplot a vlhkostí krajinného krytu může být celá řada. V této studii je středem zájmu vliv rozpadu horských smrčin na Šumavě na změnu teplot a vlhkostí krajinného krytu a následná změna krajinných funkcí.

Změna distribuce teplot a vlhkostí krajinného krytu může mít na jedné straně důsledky pro změny mikroklimatu a energetické bilance daného území a na druhé straně pro odnos látek (Ripl, 1992; Ripl et al., 1996). Dalším možným projevem je i změna odtoku, který odráží retenční schopnost krajiny a rovněž i mikroklimatické podmínky.

Zájmovým územím studie je oblast centrální Šumavy, přičemž hlavní pozornost je věnována lokalitě s významným rozpadem horských smrčin. Významný podíl rašelinišť a zamokřených půd, který je odrazem relativně vysokých srážek v této oblasti, zde vedl v minulosti k hydromelioračním odvodňovacím zásahům ve snaze přeměnit tyto plochy na produkční les smrkových monokultur (Hais, 2003). Nejvýznamnější změnou v krajině, která postihla horské smrčiny Národních parků Šumava a Bavorský les je kůrovcová kalamita, za jejíž počátek je považován rok 1991. Původ celého problému má kořeny již v roce 1983, kdy velký orkán v NP Bavorský les zničil porosty v rozsahu 173 ha, přičemž 88 ha bylo ponecháno bez jakéhokoliv ošetření.

Zde došlo k rozvoji lýkožrouta smrkového (Ips Typographus), přičemž v roce 1986 z důvodu nedostatku polomové hmoty byly napadeny i stojící stromy. Přes následné polomy v letech 1990 (orkány Vivian a Veibke) a 1990 se rozsah kalamity nezvětšoval. V roce 1993 však začal prudce stoupat podíl napadených ploch a následovalo šíření kůrovce, projevující se zejména vznikem ohnisek a rozsevem v zapojeném porostu. Maxima napadení bylo dosaženo roku 1996, kdy se napadení rozšířilo na 80% celkové plochy.

Pro hodnocení teplotně-vlhkostních parametrů byla využita analýza multispektrálních distančních dat. V tomto případě byly zpracovány scény družicového systému Landsat 5 TM a Landsat 7 ETM+.

Pro výpočet teplot krajinného povrchu byl využit 6. termální kanál TM a ETM+, obsahující záznam v intervalu elektromagnetického záření 10.4–12.5 µm. Při hodnocení vlhkosti metodami DPZ není možné využít přímo některé ze spektrálních pásem družice Landsat. Pro určení obsahu vody v půdě případně při vyjádření relativních hodnot vlhkosti krajinného krytu je možné využít spektrálních indexů. Pro hodnocení byl použit index „Wetness", který je součástí lineární transformace Tasseled Cup. Transformace Tasseled Cup zpracovává v případě dat z družice Landsat TM nebo ETM+ 6 spektrálních pásem (1–5, a 7 kanál) metodou, která je založena na principu analýzy hlavních komponent. Stejně jako v případě teplot byly i hodnoty z důvodu vzájemné porovnatelnosti převedeny do relativních tříd pomocí metody ekviareálních ploch.

Studie podle potvrzuje předpoklad, že rozpad horských smrčin v oblasti centrální Šumavy se projevil na změně relativních teplot krajinného krytu a to směrem k výraznému oteplení. O průkaznosti této změny navíc hovoří fakt, že u relativní sedmistupňové škály teplot došlo v oblasti kůrovcové kalamity většinou ke změně z první (nejchladnější) třídy na sedmou (nejteplejší).

Zvýšení relativní teploty krajinného krytu a snížení hodnot indexu „wetness" prokázané v oblasti centrální Šumavy indikuje významnou změnu v přírodním prostředí, která se může odrazit v energeticko-látkové bilanci tohoto území, případně se projevit ve formování hydrologického odtoku v příslušném povodí.

Author's full address:
MARTIN HAIS
University of South Bohemia, Faculty of Agriculture
Laboratory of Applied Ecology
Studentská 13, 370 05 České Budějovice
mhais@hotmail.com