Remote monitoring of forest response to changed soil moisture regime due to river regulation

S. Tewari[1], J. Kulhavý[1], B. N. Rock[2], P. Hadaš[1]

[1]*Mendel University of Agriculture and Forestry, Faculty of Forestry and Wood Technology, Brno, Czech Republic*

[2]*University of New Hampshire, Complex System Research Center, Durham, USA*

ABSTRACT: Floodplain forest response to changed soil moisture regime and nutrient availability due to river regulation was studied using remote sensing (ETM) data. Images of May and October 2001 were used to prepare NDVI, SAVI, 5/4-ratio images and ETM band 7. Comparisons of the LAI, NDVI, 5/4-ratios and ETM band 7 mean values were done to find out the differences between the flooded and non-flooded sites. Unsupervised clustering of images was done using single transformed channels, i.e. NDVI, SAVI, 5/4-ratio and ETM band 7 to find seasonal variations in the values of these indices. The results were found to be in agreement with ground research.

Keywords: floodplain forest; flood elimination; soil moisture regime; LANDSAT ETM; LAI; NDVI; SAVI

General features of the alluvial forests such as structural complexity, species richness, and primary productivity are linked to floods (Trèmoliéres et al. 1998). The literature is unanimous on the relationship between hydrology (flooding duration and frequency, annual ground water level fluctuations) and ecosystem functioning (ground water chemistry, bio-geochemical cycle, productivity, species richness and diversity) (e.g. Carbiener 1970, 1984; Johnson et al. 1976; Klinge et al. 1983; Klimo 1985; Trèmoliéres et al. 1998). Examples of negative effects such as decrease of biomass, lower landscape diversity were developed in studies in the Missouri and other river floodplains (Johnson et al. 1976; Lugo et al. 1990). Dams and channel diversions considerably alter environmental conditions for riparian and aquatic organisms (Allan, Flecker 1993; Dynesius, Nilsson 1994) and greatly modify fluvial dynamics (Galay 1983), the natural regime of disturbance (e.g. Ward, Stanford 1979; Petts 1984; Dynesius, Nilsson 1994), and also the links between surface and ground water systems, which leads to bio-diversity impoverishment (Claret et al. 1999). The relationship between hydrological and vegetation characteristics was quantified in some interesting models in order to predict changes in the floodplain forest characteristics following dam construction and forestry (e.g. Phipps 1997; Brody, Pendelton 1987; Trèmoliéres et al. 1998).

Researchers (Rock et al. 1986; McLallan et al. 1991; Martin, Aber 1994; Martin et al. 1998) have found relationships between vegetation properties and remotely sensed variables. Remote sensing methods have the potential to provide low-cost, long-term and large-scale monitoring of forest health. They are based on the analysis of the spectral reflectance properties of vegetation, related to the amount, anatomical structure and chemical composition of the vegetation. Remote sensing instruments such as the Enhanced Thematic Mapper (ETM) on LANDSAT 7 offer a unique perspective from which to study the Earth's vegetation. Acquiring data from an altitude of 705 km, such sensors provide a synoptic view not available with standard aerial photography. The data gathered simultaneously from within a single LANDSAT scene produce an image of a ground area measuring 185 km on a side. In addition, ETM's spectral coverage extends well out into the reflected infra-red region of the electromagnetic spectrum, far beyond the range covered by infrared-sensitive films. Since satellite data are acquired in digital form, they can be manipulated through image processing and enhancement to maximize the usefulness of the information each scene contains (Rock et al. 1986). The objective of our study was to determine the impact of eliminating the floods on the hardwood alluvial forest, in terms of changes in the remotely sensed indicators of forest health and functioning, e.g. water ratio (ETM band 5/4-ratio),

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NDVI (Normalized Difference Vegetation Index), SAVI (Soil Adjusted Vegetation Index), SWIR (Short Wave Infra Red/ ETM Band 7) and LAI (Leaf Area Index). These indicators were calculated for the flooded and non-flooded areas, using LANDSAT ETM data. LANDSAT ETM data were successfully used to detect damage in conifer forests of the mountainous area Krušné Hory in the Czech Republic (ALBRECHTOVÁ et al. 2001) and on the Camel Hump mountain, located in the Green Mountains of Vermont, United States (ROCK et al. 1886). We hypothesized that the reported loss of soil moisture (KULHAVÝ et al. 2001; HADAŠ et al. 2001) in Dyje-Morava floodplain forests due to flood cessation may not have produced physiological/anatomical or morphological symptoms (i.e. accelerated leaf loss/drought deciduousness, leaf rolling/orientation change) in vegetation that are visible to naked eye, yet might have changed the LAI and daily actual transpiration (ET). We further hypothesized that these changes, even though minute, can be detected by remote sensing methods as the digital radiance value of certain electromagnetic wavelengths from vegetation is very sensitive to such changes. Such scaling up from experimental to macroscopic plot (remote sensing) is the focus of forest science promising to lower labour cost of monitoring the forest health and also to supply scientists dealing with large-scale modelling of climate with more extensive and precise data on forest health. The monitoring of these changes is important for the conservation and restoration of these complex forest ecosystems.

STUDY AREA AND BACKGROUND

The Dyje (also known as Thaya) and the Morava rivers are the decisive water courses of the Morava watershed in the South Moravian Region of Czech Republic, and the floodplain forest along their alluvium represents an extensive wetland system. These hardwood floodplain forests, amounting to 15,840 ha, i.e. about 50% of the total area of floodplain forests in the Czech Republic (KLIMO, KULHAVÝ 1999), are the rarest and the most endangered ecosystems in Central Europe (PIŽL 1999). The study area belongs to the southernmost part of Southern Moravia in the Czech Republic, near the frontier with Austria and Slovakia (Fig. 1). It involves the territory of a discontinuous complex of floodplain forests on the lower reaches of the Dyje and Morava rivers including their confluence. This whole area can be defined by the coordinates 16º43′–16º59′E and 48º37′–48º51′N, and by the altitude ranging between 150 m (confluence of the Dyje and Morava rivers) and 165 m (Křivé Geezer National Nature Reserve). The study area is mainly built of the Tertiary layers and Holocene sediments with developed alluvial soils. Man began to interfere with the natural evolution of these floodplain areas during the time of the Great Moravian Empire, more than 1,000 years ago. The clearing of forests on the floodplain caused large-scale soil erosion and destructive flooding. In the second part of the last century other negative influences came such as industrial and city pollution. However, the biggest interference was river regulation. From the beginning of the last century to the 60's more than 90% of the Morava river was regulated. From the confluence of the Morava and Danube to the confluence of the Dyje and Morava, the length of the river was shortened from 80 km to 69 km. Recent water regime regulation by the construction of Nové Mlýny retention reservoir was the most important intervention into the environment of the South Moravian floodplain forests. The measure resulted in the cessation of regular floods since 1972. The intervention caused some negative impacts in the functioning of floodplain forest ecosystems (KLIMO, KULHAVÝ 1999).

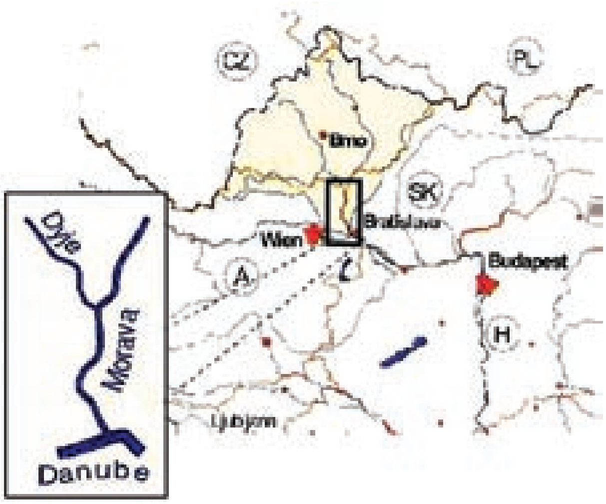


Fig.1. Study area

MATERIALS AND METHOD

To detect changes resulting from the changed soil moisture regime due to flood cessation, we selected two areas. The first one was the area of Lednice which, before 1970, was yearly inundated during the spring and often also summer periods by overflows of the Dyje River and its tributaries. After the most extensive hydrological measures in 1960–1980, when river damming and reservoir construction was carried out, floods were eliminated from this region. The other area was that of Pohansko. No hydrological measures were taken in this area and it is still flooded in a natural way. These areas were chosen because except the flooding, all the other variables (soil, forest type, age, and forest management) that can affect the resultant spectral signature of a pixel are almost the same in both areas. The details are given in Table 1. Based on the ground truth, both sites were selected on the images in such a way that they represent only pure forest pixels. The Lednice site was covered by 96 pixels and Pohansko by 54 pixels (each pixel is 30 × 30 m).

Once we had selected the two study sites, two LANDSAT images, each covering both sites, were used for the study. These images were acquired on 24th May and 30th October 2001. These dates were chosen as they corre-

Table 1. Details of the study plots

Site	Lednice	Pohansko
Forest type	*Querceto-Fraxinetum*	*Querceto-Fraxinetum*
Age	124 years	110 years
Main species	*Quercus robur*, *Fraxinus excelsior*, *Tilia cordata*, *Populus*, *Carpinus betulus*	*Quercus robur*, *Fraxinus angustifolia*, *Acer campestre*, *Ulmus laevis*, *Carpinus betulus*
Soil type	typical Fluvisol	typical Fluvisol
Soil texture	loamy to clay-loam soil	loamy to clay-loam soil
Water regime	free of surface floods since 1970	yearly surface floods
Management	low intensity	low intensity
Area	96 pixels (each pixel is 30 × 30 m)	54 pixels (each pixel is 30 × 30 m)

spond to the end of leaf flushing period and end of leaf fall period, respectively, for both localities.

Image characteristics

Date of data collection: 24th May 2001 and 30th September 2001

Instrument: ETM sensor aboard the LANDSAT 7

Image size: Each scene covers 180 × 180 km, a sub-scene covering the whole floodplain forest area was created for the study use. Ground resolution was 30 m for each band used in the study.

To see the changes between the two sites we created the NDVI, SAVI and 5/4 transformed ratio, and SWIR (ETM band 7) images for both sites. LAI was calculated for the two sites using remote sensing methods to see if there exist some anomalies. Band rationing is the division of the digital radiance value of one band by another on a pixel by pixel basis. The major advantage of ratio images is that they convey the spectral or color characteristics of image features, regardless of variations in scene illumination conditions. A ratioed image of the scene effectively compensates for the brightness variation caused by varying topography and/or changing atmospheric conditions and emphasizes the color content of the data. Ratio images were also used to generate false color composites by combining three monochromatic ratio data sets. This has the advantage of combining data from more than two bands and presenting the data in color, which further facilitates the interpretation of subtle reflectance differences.

Vegetation indices

Numerous investigators have related the NDVI to several vegetation phenomena. These vegetation phenomena range from seasonal vegetation dynamics at a global and continental scale to tropical forest clearance, leaf area index measurement, biomass estimation, percentage ground cover determination, and photosynthetically active radiation estimation. In turn, these vegetation attributes are used in various models to study photosynthesis, carbon budget, water balance and related processes (LILLESAND, KIEFER 1999). NDVI calculations are based on the principle that actively growing green plants strongly absorb radiation in the visible region of the spectrum while they strongly reflect radiation in the near infrared region. There is a strong correlation between the red and near-infrared transmittance ratio and LAI. Chlorophyll absorbs high red energy while plant foliage has relatively low transmittance (reflectance) of red energy. Plant cell walls, in particular lignin, cause scattering of near-infrared energy resulting in high near-infrared transmittance and reflectance (TURNER et al. 1999). The relationship between near-infrared and red reflectance by plants has led to the development of a variety of remote sensing vegetation based indices.

NDVI is calculated as:

$$\text{NDVI} = \frac{\text{NIR} - \text{R}}{\text{NIR} + \text{R}}$$

where: NIR – near-infrared reflectance (ETM band 4),
R – red reflectance (ETM band 3).

The range is theoretically between –1 and 1 but red is rarely larger than infrared (SCHULTZ, ENGMAN 2000). The NDVI is preferred for global vegetation monitoring because the NDVI helps compensate for changing illumination conditions, surface slope, aspect, and other extraneous factors (LILLESAND, KIEFER 1999). An NDVI image displays visible red (ETM band 1) in red color plane, NDVI (transformed band) in green color plane and visible blue (ETM band 3) in blue color plane.

SAVI uses the same principles as NDVI but adjusts for the effect of soil conditions.

SAVI is defined as:

$$\text{SAVI} = \frac{(1+\text{L})\,(\text{NIR} - \text{R})}{\text{NIR} + \text{R} + \text{L}}$$

where: L = 0.5 (SCHULTZ, ENGMAN 2000 and TURNER et al. 1999).

Water ratio (ETM5/ETM4) image displays a ratio of two bands (MIR/NIR) in the red color plane in conjunction with MIR in the green color plane and visible reflectance in the blue color plane. The ETM 5/4 image displays the damaged areas by showing the affected area in red. The higher the ratio value, the greater damage is present, and the brighter the shades of red depicted. The MIR band is sensitive to water content and non-living biomass. The symptoms of forest damage can include leaf drying and reduced biomass and the evidence of these symptoms appears more obvious when the MIR and NIR bands are ratioed. Ratios such as ETM 5/4 can enhance information by reducing the effect of topography as this ratio band produces relative measures of reflectance which minimizes the illumination differences that result from topography. Moreover, as our study area is almost flat, we assumed there was no effect of topography. Forest damage shows clearly, with high ratios characterizing high damage sites and low ratios showing low damage sites. This means the drier the leaf becomes, the higher the ratio. This is due to the fact that when a leaf becomes drier, its reflectance increases in the mid-infrared band (ETM5) in contrast to the near-infrared band (ETM4) that is relatively unaffected by changes in moisture content.

LAI calculations

Drought conditions influence canopy gas exchange, LAI and ET (WARING, RUNNING 1998). This study attempts to quantify the LAI from both sites using remote sensing techniques as the modified soil moisture regime due to flood elimination is said to have changed the LAI and daily evapotranspiration (ET) in the study area. LAI is a good indicator of daily ET and can be calculated using remote sensing techniques with fair amount of accuracy. Other tested remote sensing techniques measure ET using climatic data, particularly temperature (CARLSON et al. 1995). LANDSAT 7 images are consistently taken at 10:30 AM. Temperature values need not reflect the maximum daily ET. Leaf area is a gradual indicator of transpiration and does not respond to diurnal changes as quickly as temperature, therefore, it can be a more appropriate indicator of ET.

Since there were only two images, two sites, there could be no real statistical determination of LAI using NDVI or SAVI. Other studies were conducted that determined a non-linear relationship between LAI and SAVI, this relationship was applied in the study. According to SCHULTZ and ENGMAN (2000), LAI is related to SAVI.

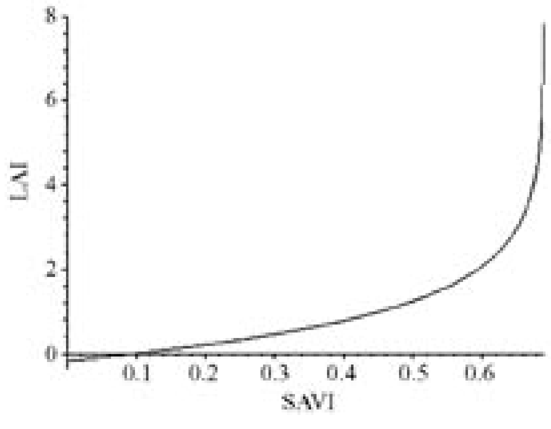


Fig. 2. Plot of SAVI versus LAI (SCHULTZ, ENGMAN 2000)

$$\mathrm{SAVI} = C_1 - C_2\, e^{-C_3\,\mathrm{LAI}}$$

where: $C_1 = 0.69$
$C_2 = 0.59$
$C_3 = 0.91$

Therefore: LAI = – ln (SAVI + 0.371)/0.48

$$\mathrm{LAI} = \frac{\ln\left(\dfrac{C_2}{C_1 - SAVI}\right)}{C_3}$$

LAI values for the two sites were calculated to see if there was any difference in these values.

As is evident from Fig. 2, which is the plot of SAVI versus LAI, the equation of SCHULTZ and ENGMAN (2000) holds good only for the lower values of SAVI, and hence we could calculate the values of SAVI only from the October scene. Hence, for our study we used the equation derived from the study of SAITO et al. (2001) that was conducted on the site of deciduous broadleaf forest using six sets of LANDSAT data. The correlation of NDVI and LAI values was derived from satellite data and monthly field observations for regression curves. Least-squares method was applied for this regression. According to SAITO et al. (2001), the correlation is as follows

LAI = 0.57.exp (2.33.NDVI)

$$\mathrm{LAI} = 0.57e^{(2.33\ \mathrm{NDVI})}$$

Visual interpretation and unsupervised classification

Enlarged hard copy printouts of SAVI, NDVI and 5/4 ratio images were overlaid manually on a toposheet (1:25,000) of the areas to mark the exact location of drier areas on the toposheet. These localities were visited in the

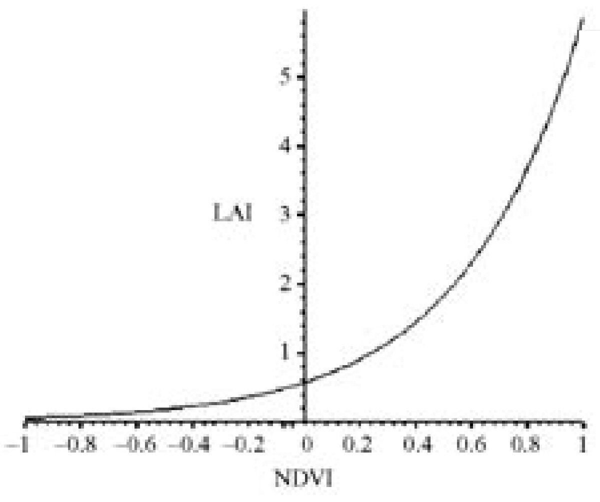


Fig. 3. Plot of NDVI and LAI values (LAI, NDVI = –1...1) for deciduous forests (SAITO et al. 2001)

Table 2. Sum of monthly (January to October) temperature, precipitation and potential evaporanspiration in the year 2001 at both study sites. Point A is Lednice site and point B is Pohansko site

Point	Longitude	Latitude	Elevation										
Mean monthly temperature of air in 2001 (°C)				T-01	T-02	T-03	T-04	T-05	T-06	T-07	T-08	T-09	T-10
A	16 47 00	48 42 30	170	0.13	1.98	6.05	9.19	16.80	16.54	20.42	20.83	13.23	12.23
B	16 54 00	48 42 30	152	0.11	2.15	6.31	9.29	16.78	16.71	20.52	20.98	13.39	12.44
Sum of monthly precipitation in 2001 (mm)				S-01	S-02	S-03	S-04	S-05	S-06	S-07	S-08	S-09	S-10
A	16 47 00	48 42 30	170	27.72	24.54	55.5	50.19	45.89	50.67	115.64	70.05	94.02	13.19
B	16 54 00	48 42 30	152	26.70	23.91	54.3	49.42	44.97	48.58	114.91	69.35	93.11	12.06
Sum of monthly potential transpiration in 2001 (mm)				PET-01	PET-02	PET-03	PET-04	PET-05	PET-06	PET-07	PET-08	PET-09	PET-10
A	16 47 00	48 42 30	170	0.2	5.3	24.8	45	105	104.6	134.7	137.4	63.3	51.3
B	16 54 00	48 42 30	152	0.2	5.7	25.7	45.2	104.4	105.3	135	137.4	63.8	52

field for actual checking of the vegetation. As both localities are extensively researched by researchers of Institute of Forest Ecology, Mendel University of Agriculture and Forestry, Brno, the ground data on the soil moisture, soil nutrients (KULHAVÝ et al. 2001) and evapotranspiration (ČERMÁK et al. 2001) were available. Attempts were made to find the agreement and/or disagreement between the ground truth and the remotely sensed forest health indicators, such as NDVI, SAVI, 5/4 ratio and SWIR (ETM band 7).

Histograms for both localities were prepared from all the three images to further enhance the image interpretation; then all the three images were clustered (unsupervised) using single channels, namely NDVI band, 5/4-ratio band, and band 7. The minimum cluster size was kept at 1 pixel. The percentages of pixels from each site belonging to different classes were calculated.

All image processing was done in MultiSpec program. MultiSpec is a microcomputer version of many of the mainframe LARSYS/LARSFRIS programs developed at LARS, Prude University with the addition of many new algorithms. The software is ERDAS data format compatible and is designed for hyperspectral analysis as well as more standard multispectral analysis (LANDGREBE, BIEHL 1993).

RESULTS AND DISCUSSION

Temporal and spatial variation in NDVI

The spatial and temporal variations in NDVI were studied by numerous researchers; they were found to be linked with temperature and precipitation regimes (e.g. SCHULTZ, HALPERT 1993; DI et al. 1994; YANG et al. 1997), plant evapotranspiration (e.g. CIHLAR et al. 1991; YANG et al. 1997), root zone soil moisture (e.g. NARASIMHA RAO et al. 1993) and soil physical properties (e.g. LOZANO et al. 1991; YANG et al. 1997). NDVI is also fully dependent on the precipitation and air temperature regime. For the purpose of our study we wanted to be sure that we are quantifying the normal values of NDVI in the months of May and October. This was possible in the year 2001; the precipitation was quite normal. The mean monthly precipitation and temperature of air are given in Table 2. It is evident from Table 2 that there is a very minute change in these values for both sites. This is because both sites are only 20 km apart.

Temporal variability of NDVI was found to be linked closely to the temperature regime while the NDVI-precipitation and the NDVI- evapotranspiration relationships exhibited time lags. These results are in agreement with those reported from other parts of the world (YANG et al. 1997). As it is evident in the NDVI-composite and also in Table 3, the NDVI values are almost the same in both areas in the May image that corresponds to the end of leaf-flushing periods at both sites. In October scene NDVI value of flooded site (Pohansko area) is considerably higher (Fig. 4).

Temporal and spatial variation in SAVI

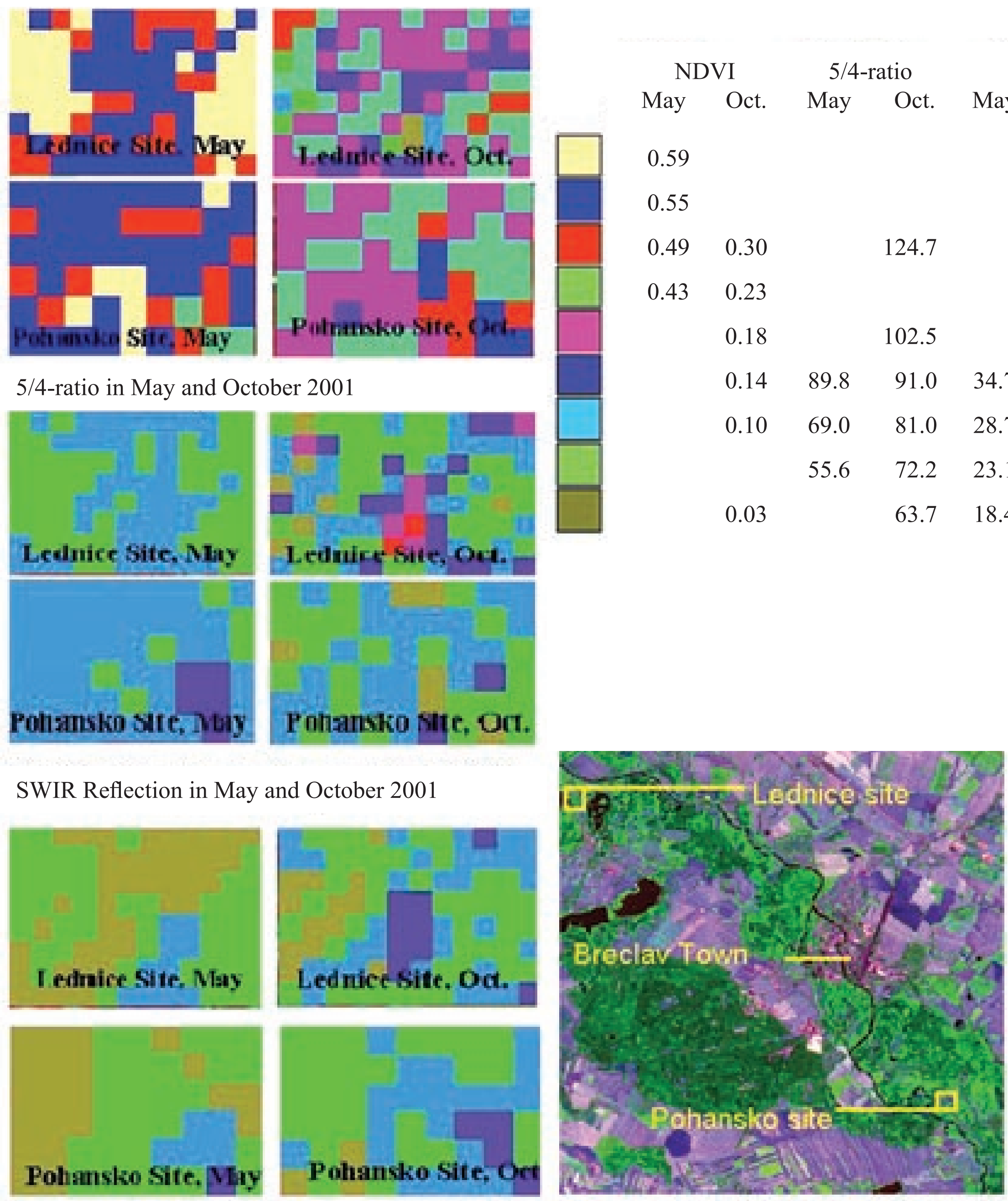
The seasonal and site variations in SAVI (mean values) are given in Table 4. Considering the ground situation, the SAVI, which is higher at Pohansko site (regularly flooded) both in May and October, does a better assessment than the NDVI.

Seasonal and site variation in SWIR (ETM band 7/leaf moisture content/transpiration)

Studies have found SWIR reflection inversely proportional to the leaf moisture content and transpiration. Accordingly, the wavelengths in these spectral regions are referred to as water absorption band. Throughout the range beyond 1.3 μm leaf reflectance is approximately inversely related to the total water present in a leaf. This total is

Table 3. Temporal and site variation in mean values of NDVI at both sites

Mean values of NDVI		
Study site	May	October
Lednice area (non flooded)	0.554	0.190
Pohansko area (regularly flooded in natural way)	0.526	0.234



NDVI		5/4-ratio		SWIR	
May	Oct.	May	Oct.	May	Oct.
0.59					
0.55					
0.49	0.30		124.7		
0.43	0.23				
	0.18		102.5		
	0.14	89.8	91.0	34.7	62.0
	0.10	69.0	81.0	28.7	45.1
		55.6	72.2	23.1	35.2
	0.03		63.7	18.4	28.6

Fig. 4 Distribution of NDVI, 5/4-ratio and SWIR reflections in May and October, 2001, at Lednice and Pohansko sites, obtained after unsupervised classification of the ratio images

a function of both the moisture content and the thickness of the leaf (LILLESAND, KIEFER 1999). The mean values of percentage reflectance of SWIR for both sites (Fig. 4) are given in Table 4.

The temporal variation in the values is in agreement with field studies (ČERMÁK et al. 2001) conducted in different years. These studies found out that irrespective of significant changes during the particular years, the seasonal course of tree transpiration remained very similar during all years when the studies were conducted. The transpiration was maximum in mid and late summer and minimum in the fall.

As no significant difference is found in the mean value of SWIR reflectance, we can say that there is no difference

Table 4. Temporal and site variations of NDVI (mean values) at both sites

Mean values of SAVI		
Study site	May	October
Lednice area (non flooded)	0.78	0.29
Pohansko area (regularly flooded in natural way)	0.83	0.36

Table 5. Temporal and site variations of SWIR percentage reflectance (mean values of band 7% reflectance [in DN]) at both sites

Study site	May	October
Lednice area (non flooded)	13.08	9.88
Pohansko area (regularly flooded in natural way)	13.28	9.92

in the transpiration at two sites. This result is in agreement with field research (ČERMÁK et al. 2001) at these study sites which confirmed that at Lednice site where the flooding ceased due to river regulation, the original status of transpiration has developed as the trees developed new root systems to cope with the decreased water table regime. Repeated measurement of sap flow over the years showed a gradual increase in transpiration, both in absolute and relative values at the stand level as well as at the tree level (ČERMÁK et al. 2001). Field research also indicated that even old trees were evidently able to adopt their root system (to form deeper and wider roots) and thus they gradually renewed their water absorption abilities.

Seasonal and site variation in LAI

The ground research (unpublished) done by various researchers of our faculty (Faculty of Forestry, Mendel University of Forestry and Agriculture) by indirect and direct destructive methods suggest much higher values of LAI in both localities. These values of LAI range from 3.3 to 4.9 (ČERMÁK pers. commun.) in the month of May, 2001. Hence it is evident that it was not possible to accurately estimate the LAI using remote sensing methods and standard equations. However the trend of seasonal changes in LAI was in agreement with ground research. The seasonal and site variations in LAI are given in Table 6.

Table 6. Seasonal and site variation in mean values of LAI (SAITO et al. 2001)

Study site	May	October
Lednice area (non flooded)	2.0723	0.8874
Pohansko area (regularly flooded in natural way)	1.9415	0.9832

Insight into forest response to water stress at pixel level

The results of unsupervised clustering are given in Table 7. Clustering allowed to see the seasonal variation in NDVI, 5/4-ratio, and SWIR values on the pixel by pixel basis. In May for the first two highest mean 5/4 values, the number of pixels was considerably higher in Pohansko locality, suggesting higher dryness in that locality (Fig. 4). A reverse trend is observed in the October image. A similar seasonal trend is noticed for the SWIR values. The NDVI values were lower in Pohansko in May image and higher in October image. The result of unsupervised classification was three images. The areas of Lednice and Pohansko sites from these images are given in Fig. 4.

Though SWIR band and ratios like NDVI and 5/4 give an estimation of leaf area index, biomass, percentage ground cover, and percentage of actively growing vegetation, transformed band 5/4 has been found best for exactly

Table 7. Result of unsupervised classification

	Cluster No.	May 2001			October 2001		
		Mean value	% of pixels Lednice area	% of pixels Pohansko area	Mean value	% of pixels Lednice area	% of pixels Pohansko area
5/4-ratio	1	89.8	0	9	124.7	2.08	
	2	69.0	46	80	102.5	6.25	
	3	55.6	54	11	91.0	15.62	3.70
	4				81.0	30.20	44.44
	5				72.2	38.54	40.47
	6				63.7	7.29	11.11
NDVI	1	0.59	35	12	0.30	6.25	11.11
	2	0.55	42	61	0.23	35.41	37.03
	3	0.49	23	22	0.18	35.41	40.74
	4	0.43	0	5	0.14	16.66	11.11
	5				0.10	40.16	
	6				0.03	2.08	
SWIR	1	62.0		2	34.7	9.37	7.40
	2	45.1	10	9	28.7	33.33	37.63
	3	35.2	47	50	23.1	43.75	50.50
	4	28.6	53	39	18.4	13.54	5.55

marking the relatively dry areas, as is the case of Pohansko site where clusters of 5 pixels have a 5/4-ratio value 89.8 (DN). These are the only pixels with such value of 5/4-ratio in both localities. Also, for mapping the drier areas 5/4 image (5/4, 4, 3) is the best as it highlights the drier areas in bright red color. This study shows that it was possible to see the forest response to changed water regime in terms of NDVI, 5/4-ratio and SWIR reflectance. Unsupervised classification of images from different periods, based on single channels like NDVI, 5/4-ratio and SWIR, enables to see the change over time on the pixel by pixel basis. As the assessment of forest response by the remotely sensed indicators is more or less in full agreement with the field assessment, this study further proves the point that moderate resolution satellite data can be used successfully to provide low-cost, long-term and large-scale monitoring of deciduous hardwood forest response to water stress.

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Dálkové monitorování lesní odezvy na změněný vlhkostní režim v důsledku říční regulace

S. Tewari[1], J. Kulhavý[1], B. N. Rock[2], P. Hadaš[1]

[1]*Mendelova zemědělská a lesnická univerzita, Lesnická a dřevařská fakulta, Brno, Česká republika*

[2]*Univerzita New Hampshire, Výzkumné centrum pro komplexní systémy, Durham, USA*

ABSTRAKT: Za použití dálkového průzkumu (ETM data) byla studována reakce lužních lesů na změnu půdního vlhkostního režimu a dostupnosti živin v důsledku regulace vodního toku. K znázornění indexů NDVI, SAVI, podílu 5/4 a ETM pásma 7 byly využity snímky z května a října 2001. Byly porovnávány průměrné hodnoty LAI, NDVI, podílu 5/4 a ETM pásma 7 za účelem zjištění rozdílů mezi zaplavovanými a nezaplavovanými stanovišti. Ke zjištění sezonních rozdílů mezi indexy (NDVI, SAVI, podíl 5/4 a ETM pásmo 7) bylo provedeno nekontrolované seskupování snímků za použití jednoduchých transformovaných kanálů. Zjištěné výsledky jsou v souladu s terénním výzkumem.

Klíčová slova: lužní les; eliminace záplav; vlhkostní režim půdy; LANDSAT ETM; LAI; NDVI

Odchýlení přehrad a koryt řek značně mění přírodní podmínky pro břehové a vodní organismy a značně modifikuje říční dynamiku, přírodní disturbance, vazby mezi povrchovými a podpovrchovými vodními systémy a vede k poklesu biodiverzity. Vědci znají vztah mezi vegetací a dálkově snímanými proměnnými. Metody dálkového snímání umožňují monitorování zdravotního stavu lesů při zachování nízkých nákladů, dlouhodobého sledování a širokého měřítka. Jsou založeny na analýze spektrálního odrazu od vegetačního pokryvu v závislosti na jeho anatomické struktuře a chemickém složení.

Vzájemný vztah mezi hydrologickými a vegetačními charakteristikami byl uveden v některých zajímavých modelech koncipovaných za účelem předpovídání změn ve vlastnostech lužního lesa ve spojitosti se stavbou přehrad a lesním hospodařením. Dyje a Morava jsou hlavní vodní toky v povodí Moravy v jihomoravském regionu České republiky. Lužní les podél jejich aluvia je po zastavení záplav ovlivňován pozměněným vlhkostním režimem.

Cílem našeho studia bylo zjistit vliv eliminace záplav na opadavý aluviální les při stanovení změn v dálkově snímatelných indikátorech zdravotního stavu lesního stanoviště, např. vodní stupeň (ETM pásmo 5/4 stupeň), NDVI (normalizovaný rozdíl vegetačního indexu), SAVI (nastavený vegetační index půdy), SWIR (krátkovlnný infračervený/ETM stupeň 7) a LAI (pokryvnost listoví). Tyto indikátory byly počítány pro zaplavovaná a nezaplavovaná území s využitím dat LANDSAT RTM. Vyobrazení květnových a říjnových dat z roku 2001 bylo použito pro přípravu NDVI, SAVI, 5/4 – poměr zobrazení a ETM pásma 7.

Porovnání LAI, NDVI, 5/4 poměrů a průměrných hodnot ETM pásma 7 bylo provedeno pro zjištění rozdílů mezi zaplavovanými a nezaplavovanými místy. Shlukování obrazů bylo provedeno pomocí jednoduše transformovaných kanálů, tj. NDVI, SAVI, 5/4 – poměr a ETM stupeň 7 za účelem zjistit sezonní změny těchto indexů. Hodnoty NDVI jsou téměř shodné v obou oblastech u zobrazení z května. To koresponduje s koncem tvorby listoví na obou místech. V říjnu je výstup hodnoty NDVI na zaplavované lokalitě (Pohansko) značně vyšší. Protože nebyly nalezeny signifikantní rozdíly v průměrné hodnotě odrazivosti SWIR, můžeme konstatovat, že zde nebyly žádné rozdíly transpirace mezi oběma studovanými plochami. Tento výsledek souhlasí s terénním výzkumem. Na těchto plochách bylo potvrzeno, že na stanovišti Lee, kde byly záplavy zastaveny regulací, bylo původní úrovně transpirace dosaženo, jakmile se z důvodu uniknutí z místa snížené hladiny podzemní vody rozvinul nový kořenový systém porostů. Základní výzkum (nepublikováno) uskutečněný vědci z Lesnické a dřevařské fakulty Mendelovy zemědělské a lesnické univerzity v Brně, uskutečněný s použitím nepřímých a přímých destruktivních metod, naznačil mnohem vyšší LAI na obou lokalitách.

Tyto hodnoty LAI se pohybovaly v rozmezí od 3,3 do 4,9 v měsíci květnu roku 2001. Je zřejmé, že nebylo možné přesně stanovit LAI metodami dálkového průzkumu a standardními rovnicemi, přesto však byl trend sezonních změn LAI ve shodě se základním výzkumem.

Corresponding author:

SANJAY TEWARI, Mendelova zemědělská a lesnická univerzita, Lesnická a dřevařská fakulta, Lesnická 37, 613 00 Brno, Česká republika
tel.: + 420 545 134 012, fax: + 420 545 134 018, e-mail: tewari@mendelu.cz