NELDA TEST SITE REPORT

Border region of Poland, Slovakia, and Ukraine in the Carpathians

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1 Site location

1.1 Country, State, Province

The test site is part of four different countries Poland (Podkarpatie Voivodship), Slovakia (Presovsky and Kosicky Kraj),Ukraine (Zakarpatska and Lvivska Oblast), and Hungary (Szabolcs-Szatmar-Bereg.and Borsod-Abaúj-Zemplén Counties).

1.2 Center coordinates

49°05'00"N, 22°44'00"E (Landsat WRS-2 Path 186 / Row 026)

1.3 Geographic setting and environmental characteristics

The site is located in the border region of Poland, Slovakia, Ukraine, and Hungary. Most of the region is part of the Carpathian Mountain range and is characterized by mountainous terrain. The center of the site's south is characterized by flat terrain and is part of the Pannonian Plain. Besides the Carpathain Mountain range, major geographical features of the site include the rivers of Borzera, Dnister, Laborec, Latorycja, Ondava, San, and Uzh, as well as the Solina, Sirava, and Ondava water reservoirs. Altitudes vary from 100m to above 1,400m above sea level. The bedrock is largely dominated by sandstone and shale, but some andesite-basalts occur in the southwest of the study area. Dominating soils include cambisols and podzols in the mountainous regions; podzoluvisols, greysems, and gleysols in the plains; and fluvisols in alluvial plains. Climate in the region is moderately cool and humid with marked continental influence. Average annual precipitation amounts to 1,100-1,200mm, mean annual temperature is 5.9°C (at 300m), and the growing season ranges from >270 days below 500m altitude to <220 days above 800m. Potential natural vegetation of the region occurs in three altitudinal zones. The foothills (< 600m) are mostly covered by broadleaved forests, consisting of European beech (*Fagus sylvatica*), pedunculate oak (*Quercus robur*), sessile oak (*Quercus petraea*), lime (*Tilia cordata*), and hornbeam (*Carpinus betulus*). The montane zone (600-1,100m) is dominated by European beech (*Fagus sylvatica*), mixed with silver fir (*Abies alba*), Norway spruce (*Picea abies*), European maple (*Acer pseudoplatanus*), and white alder (*Alnus incana*). The timberline of dwarfed beech (1,100-1,200m) directly borders alpine meadows on hilltops.

1.4 Land Use

Some of Europe's last primeval forests are found in the study area, but centuries of land use have substantially affected most natural ecosystems, creating a complex pattern of forests, arable land and pastures. The region was part of the Austro-Hungarian Empire for a period of ~150 years until 1918. During that period, land use intensified markedly, mainly due to technological advancements and population growth, and considerable farmland expansion into forests occurred. During the 20th century, forest cover generally increased in the region. However, great efforts were taken under socialist rule to utilize the region's natural resource and to industrialize the agricultural sector. Forests were often overexploited and forest management led to widespread replacement of natural forest ecosystems with Norway spruce and Scots pine monocultures (*Pinus sylvestris*). Farmland in most areas was collectivized and managed in large-scale agricultural enterprises, even in marginal regions such as mountain valleys. In the Polish region of the site, some areas were depopulated after 1947 following border changes between the Soviet Union and Poland, resulting in large-scale reforestation on abandoned farmland. After the demise of the Soviet Union, land reforms were launched to privatize farmland and to individualize land use. New land and forest management policies committed to multifunctionality were adopted across Eastern Europe to comply with international agreements and to meet European Union (EU) environmental standards. The site also harbors several protected areas, most notably the trilateral East Carpathians Biosphere Reserve 213,000ha and the Skole Beskydy National Park in Ukraine (40,000ha), both established in 1999.

Forestry is an important factor for the local economy and the majority of the forests in the region are used commercially. Most of the harvested timber is used to meet the demand of wood products in the respective countries and is not exported. Farming conditions vary in the study area and are relatively marginal in the montane zone. Dairy products, cattle, flax, oat, and potatoes are the main agricultural products here. In the foothill zone (including the plains in the north and south of the study area), farming conditions are more favorable, allowing to cultivate a diversity of crops, including grain (e.g., winter wheat, buckwheat), oil crops (e.g., rape, sunflowers), sugar beets, corn, and potatoes. Milk, cheese, and meat production are also significant agricultural activities in the foothill zone.

1.5 Major types of vegetation disturbance and land cover change

Land cover changes in the region are almost exclusively due to human activities:

- Logging is the main cause of forest disturbances in the region. Harvesting practices differ among the countries in the region, resulting in different disturbance types and spatial patterns of disturbances. In Poland, forest harvesting is mainly based on selective logging. In Slovakia, harvesting is based on long and narrow (<150m) clear cuts parallel to downward slopes. Harvesting in Ukraine is largely based on large clear cuts, but selective logging is also substantial.
- Some forest disturbances occur due to infrastructure development
- Clear cuts regenerate normally by hardwood species or a mixture of hardwood and coniferous species in coniferous forests. Forest management in all countries aims for replacing coniferous monocultures with natural broadleaved or mixed forest communities. Whereas forest regeneration in Poland and Slovakia is actively managed by the Forest Service, most forest regeneration in Ukraine occurs via natural regeneration (due to a lack of funding).

- Much farmland that was managed by the state before the breakdown of socialism was abandoned or set aside after the system change. Natural succession and reforestation is widespread on these areas.
- Some forest planting on former farmland occurs, mainly in Poland where the Forest Service acquired state-owned farmland after 1989.
- Expansion of weekend and holiday homes occurs since the breakdown of socialism, particularly in the Polish region of the study area. In Ukraine, several skiing and other tourist facilities have been developed.

Natural disturbance are overall relatively rare

- Insect defoliation, wind throw, and avalanches result in local forest disturbance
- Large-scale fire events do not occur in the region
- Floods can occur in the Dnister and Tisza river floodplains

2 Satellite Imagery

- Six Landsat TM/ETM+ images were used:
  - Landsat 7/ 06 June 2000 (GeoCover)
  - Landsat 5 / 21 August 2000
  - Landsat 7 / 30 September 2000 (<10% clouds in the NE region of the image, GeoCover)
  - Landsat 5 / 04 July 1994 (<1% clouds in the N region of the image)
  - Landsat 4 / 27 July 1988 (<5% clouds in the SE region of the image)
  - Landsat 5 / 02 October 1986
- A void-filled version of the SRTM DEM was acquired from the (http://srtm.csi.cgiar.org)
- Three IKONOS images (22 August 2002, 04 May 2003, and 24 August 2004) were available for the Polish region of the site.
- Quickbird data acquired between 2002 and 2006 and available in GoogleEarth covers about 60-70% of the site

3 Ground Data

Ground truth points were gathered in the field, from the high-resolution images, and from ancillary datasets. Field work was carried out in summer of 2004, spring of 2005, and spring of 2006, using non-differential Global Positioning System (GPS) receivers. We considered only locally homogeneous areas (i.e., 90×90m or 3×3 Landsat pixels) to rule out erroneous assignments due to positional uncertainty. To cover broad areas, and to avoid deterioration of the GPS signal under closed canopies, some areas were photo-documented from view points (e.g. mountain ridges). The view points were georeferenced using GPS receivers, and the view angle and distance of the area depicted in the photo were noted. This allowed digitizing ground truth points on screen using the Landsat images and topographic maps as geometric references. Quickbird images available in GoogleEarth and the three IKONOS images, and forest inventory maps for parts of the Polish region and for Zakarpatsky Oblast in Ukraine were used to collect additional ground truth points. Ground truth points were digitized on screen using the same criteria that were applied in the field and photo mapping. In total, about 1,700 ground truth points were mapped (about 500 based on ground visits and about 1,200 from high-resolution images).

A detailed description of the ground truth collection is found in:

- Kuemmerle, T., Hostert, P., Perzanowski, K., & Radeloff, V.C. (2006). Cross-border comparison of land cover and landscape pattern in Eastern Europe using a hybrid classification technique. *Remote Sensing of Environment, 103*, 449-464
- Kuemmerle, T., Hostert, P., Radeloff, V.C., Perzanowski, K, and Kruhlov, I. (2007): Post-socialist forest disturbance in the Carpathian border region of Poland, Slovakia, and Ukraine, *Ecological Applications*, 15, 1279-1295.

4 Mapping legend

The following classes of the NELDA Land Cover Legend were identified to be present in the site:

Class_ID	Description	Examples
1	Tree.Needleleaved.Evergreen.Closed	
2	Tree.Mixed.Closed	
3	Tree.Broadleaved.Deciduous.Closed	
4	Shrub.Mixed.Open (includes shrub-dominated succession areas, open settlements with garden, etc)	

5	Herbaceous.Closed.CultivatedLand	
6	Herbaceous.Closed.Grassland.LowIntensity (includes permanent grasslands such as mountain meadows, pastures with low-intensity grazing, and abandoned or set-aside grasslands)	
7	Herbaceous.Closed.Grassland.HighIntensity † (includes hay meadows and intensively grazed pastures)	
8	Bare.BuiltUp	
9	Bare.Other	
10	Water	

5 Land Cover Map

5.1 Pre-processing

All images were geometrically rectified, corrected for relief displacement using the SRTM digital elevation model, and co-registered to the Universal Transverse Mercator (UTM) coordinate system. Atmospheric correction included transferring all images to surface reflectance using a 5S radiative transfer model that incorporated a terrain-dependent illumination correction. Thermal bands were not retained due to their coarser resolution.

For details on the geometric rectification and atmospheric correction please see:

- Kuemmerle, T., Hostert, P., Perzanowski, K., & Radeloff, V.C. (2006). Cross-border comparison of land cover and landscape pattern in Eastern Europe using a hybrid classification technique. *Remote Sensing of Environment, 103*, 449-464
- Hill, J., & Mehl, W. (2003). Geo- and radiometric pre-processing of multi- and hyperspectral data for the production of calibrated multi-annual time series. *Photogrammetrie - Fernerkundung - Geoinformation (PFG), 2003*, 7-14 (in German)

Clouds and cloud shadows were hand digitized. The 1994 image contained some single-band artifacts due to ground receiving problems. These artifacts were removed by replacing erroneous band values with values from the best matching spectra in the neighborhood of the distorted spectra. Details of this method are proved in:

- Kuemmerle, T. and Damm, A. (2008): A method to detect and correct single-band missing pixels in Landsat TM and ETM+ data. *Computers and Geosciences*, 34, 445-455.

5.2 Land cover classification

A land use / land cover map for a portion of the site was available from a previous study. This land cover map was generated based on the three Landsat TM/ETM+ images from different seasons for 2000 using a hybrid classification strategy. The hybrid approach encompassed (1) the pre-stratification of the layerstack of the three images using ISODATA, (2) the selection of unambiguous clusters based on field visits and ancillary data, (3) a supervised maximum likelihood classification using pure clusters identified in the second stage as training signatures. A detailed description of the approach is found in:

- Kuemmerle, T., Hostert, P., Perzanowski, K., & Radeloff, V.C. (2006). Cross-border comparison of land cover and landscape pattern in Eastern Europe using a hybrid classification technique. *Remote Sensing of Environment, 103*, 449-464

The initial land cover map was recoded to match the NELDA land cover legend. One class ('open settlements') was not directly compatible to the NELDA legend and an NDVI-threshold of 0.4 was used to distribute this class among the classes Bare.built-up (<0.4 NDVI) and Shrubland.open (>0.4 NDVI). The threshold was set based on high-resolution –imagery available in GoogleEarth™. Grasslands were categorized into high and low intensity based on an available map of farmland abandonment. Details on this map are provided in:

- Kuemmerle, T., Hostert, P., Radeloff, V.C., van der Linden, S., Perzanowski, K., & Kruhlov, I. (2008). Cross-border comparison of post-socialist farmland abandonment in the Carpathians. *Ecosystems, 11*, 614-628

To extend the classification to the full site, the three images from 2000 were stacked and classified using the available land cover map for automated training sample search. As a classifier, Support Vector Machines (SVM) were used. SVM are a supervised, non-parametric classification approach that categorize data by fitting a separating hyperplane between training samples. SVM only describe class boundaries rather then the classes itself, and thus require fewer training data than comparable approaches. By transforming training data into a higher dimensional space using kernel functions, complex, linearly non-separable classes can be distinguished. Such classes are typical for multi-temporal datasets.

Illustration for the SVM approach.

Left: A hyperplane is fitted to separate two classes (green and blue) based on training data (points). Thus, SVM require only a few training samples that describe the class boundaries (circles).

Right: SVM can solve highly complex, non-linear classification problems

For each class 500 random points per class were selected as training data based on the existing land cover classification. Once an SVM model was trained, the stack of the three 2000-images was classified to derive an area-wide and cover map for the site. A 10%-region of the site in the southwestern corner (Hungary) had been masked prior to atmospheric correction. This region was classified separately based on raw images and both land cover maps were mosaicked. The SVM-based image classification was carried using the IDL-based software imageSVM, developed by the Geomatics Department, Humboldt-University Berlin:

- Janz, A., van der Linden, S., Waske, B., & Hostert, P. (2007). imageSVM - a user-oriented tool for advanced classification of hyperspectral data using support vector machines. In I. Reusen & J. Cools (Eds.*), Proceedings of the conference EARSeL SIG Imaging Spectroscopy*. Bruges, Belgium

5.3 Post-classification processing

Several post-classification steps were carried out

- All patches <5 pixels were eliminated and replaced by the dominant surrounding land cover class.
- All cultivate lands and built-up area patches above 900m altitude were assigned to the class Bare.Other
- All intensively used grassland patches above 900m elevation were assigned to the low-intensity grassland class
- Mixed forest patches below 350m elevation were assigned to the broadleaved forest class
- A few obviously misclassified built-up patches were assigned to the water class and cultivated land class manually.

The firsts step was carried out in ERDAS Imagine using the clump/eliminate method (using an 8-neighbor rule). The last four steps were carried out in eCognition.

5.4 Accuracy assessment

A random stratified sample of 1,000 points was selected out of the available ground truth points. The classes Bare.Other and Bare.BuiltUp were merged into a single class, because the class Bare.Other covered only 0.03% of the site. The two grassland classes were also merged in into a single category, because ground truth on land use intensity on grasslands was not available for all regions of the site. Overall accuracy for this classification was 87.00% (Kappa 0.84).

		Reference Data								
		TN	*TM*	*TB*	*S*	*HC*	*HG*	*B*	*W*	*Σ*
Classified Data	*Tree.Needleleaved.Evergreen.Closed (TN)*	67	11			1			3	82
	Tree.Mixed.Closed (TM)	5	60	7	2					74
	Tree.Broadleaved.Deciduous.Closed (TB)	1	8	307	5	1	5		1	328
	Shrub.Mixed.Open (S)		2		60	6	13	2	2	85
	Herbaceous.Closed.CultivatedLand (HC)				5	150	5	1		161
	Herbaceous.Closed.Grassland (HG)			1	20	16	175			212
	Bare (B)				3	3		29	1	36
	Water (W)								22	22
	Σ	73	81	315	95	177	198	32	29	1000

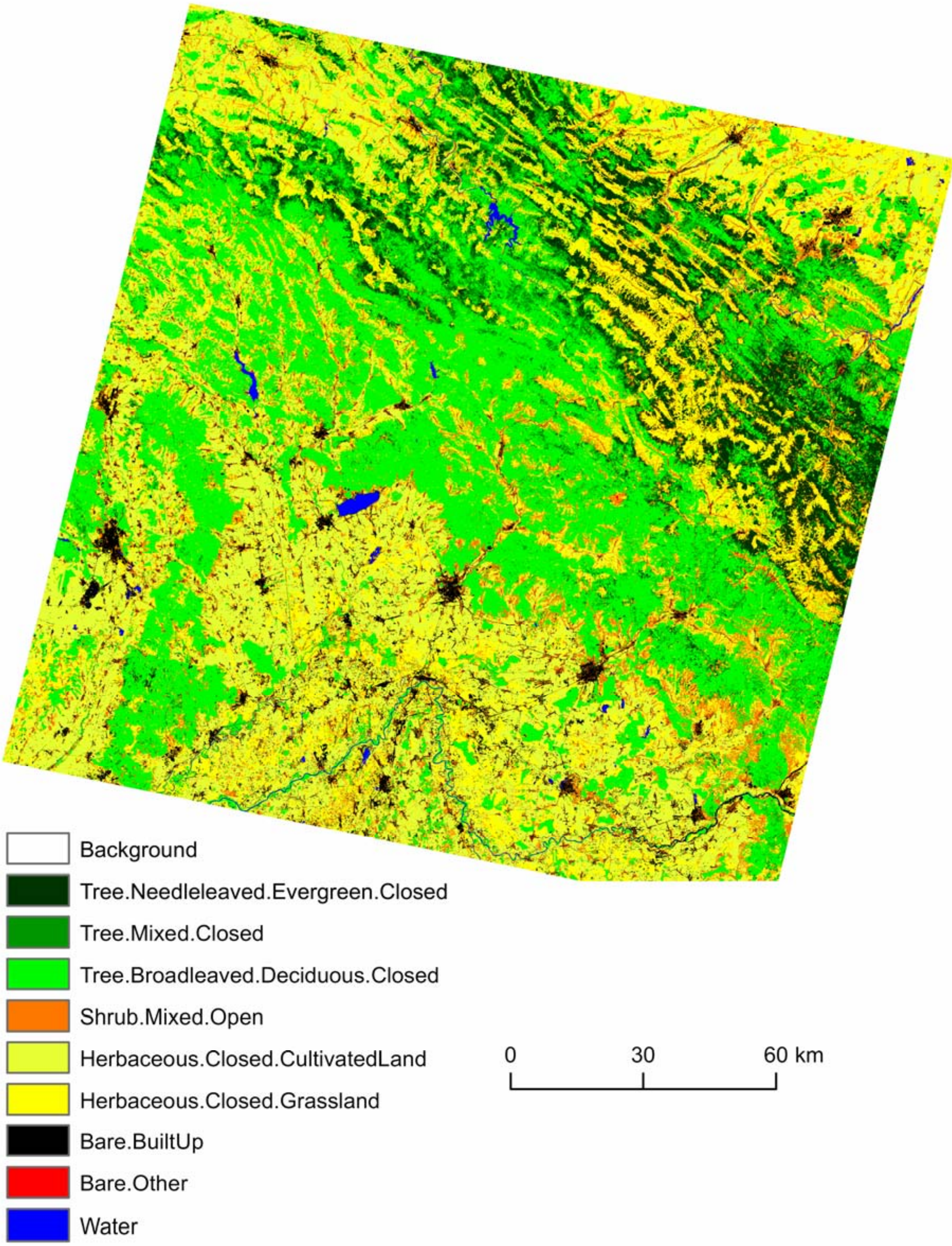
Class	*Reference Totals*	*Classified Totals*	*Number Correct*	*Producers Accuracy*	*Users Accuracy*	*Kappa*
Tree.Needleleaved.Evergreen.Closed	73	82	67	91.78%	81.71%	0.8027
Tree.Mixed.Closed	81	74	60	74.07%	81.08%	0.7941
Tree.Broadleaved.Deciduous.Closed	315	328	307	97.46%	93.60%	0.9065
Shrub.Mixed.Open	95	85	60	63.16%	70.59%	0.675
Herbaceous.Closed.CultivatedLand	177	161	150	84.75%	93.17%	0.917
Herbaceous.Closed.Grassland	198	212	175	88.38%	82.55%	0.7824
Bare	32	36	29	90.63%	80.56%	0.7991
Water	29	22	22	75.86%	100.00%	1

A second accuracy assessment was carried after categorizing the 8 land cover classes to the 5 general NELDA land cover types: ‘Tree dominated’, ‘Shrub dominated’, ‘Herbaceous’, ‘Bare’, and ’Water’. Overall accuracy for this classification was 92.20% (Kappa 0.87).

		Reference Data				
		TD	*SD*	*H*	*B*	*W*	*Σ*
Classified Data	Tree dominated (TD)	466	7	7		4	484
	Shrub dominated (SD)	2	59	19	2	2	84
	Herbaceous (H)	1	26	346	1		374
	Bare (B)		3	3	29	1	36
	Water (W)					22	22
	Σ	469	95	375	32	29	1000

Class	*Reference Totals*	*Classified Totals*	*Number Correct*	*Producer's Accuracy*	*User's Accuracy*	*Kappa*
Tree dominated (TD)	469	484	466	99.36%	96.28%	0.8027
Shrub dominated (SD)	95	84	59	62.11%	70.24%	0.7941
Herbaceous (H)	375	374	346	92.27%	92.51%	0.9065
Bare (B)	32	36	29	90.63%	80.56%	0.675
Water (W)	29	22	22	75.86%	100.00%	0.917

5.5 Analysis of mapping results



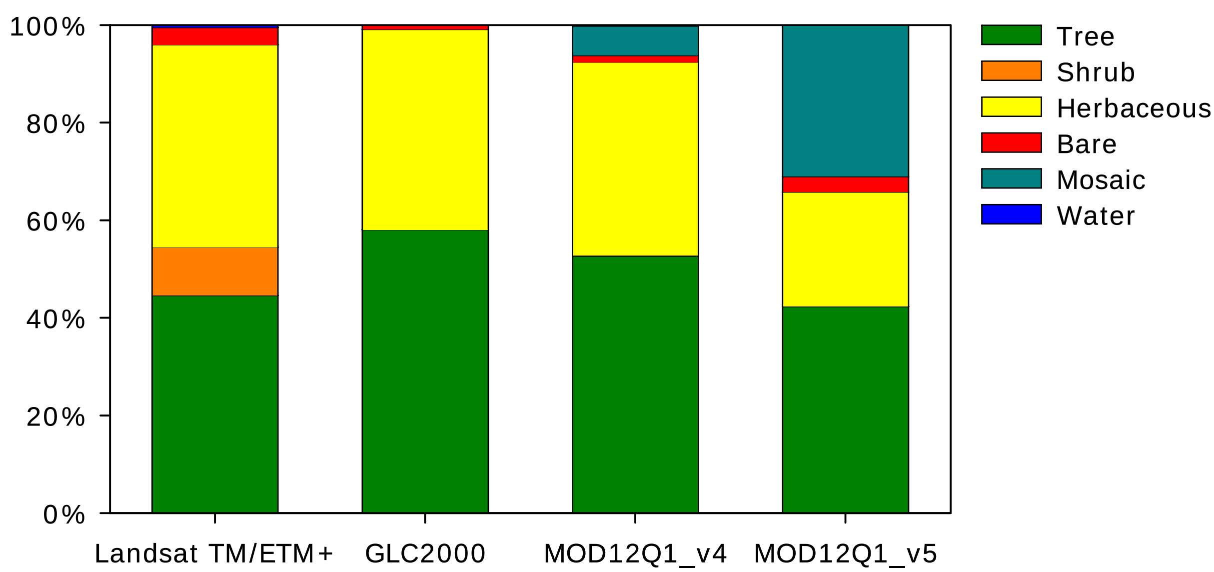
Distribution of land cover classes:

Class	*Pixel*	*Area [ha]*	*% of site*
Tree.Needleleaved.Evergreen.Closed	2294484	206503.6	6.66
Tree.Mixed.Closed	2553920	229852.8	7.42
Tree.Broadleaved.Deciduous.Closed	10505115	945460.4	30.50
Shrub.Mixed.Open	3412500	307125	9.91
Herbaceous.Closed.CultivatedLand	7317788	658600.9	21.25
Herbaceous.Closed.Grassland.LowIntensity	3576535	321888.2	10.38
Herbaceous.Closed.Grassland.HighIntensit	3398639	305877.5	9.87
Bare.BuildUp	1194036	107463.2	3.47
Bare.Other	8311	747.99	0.02
Water	180729	16265.61	0.52

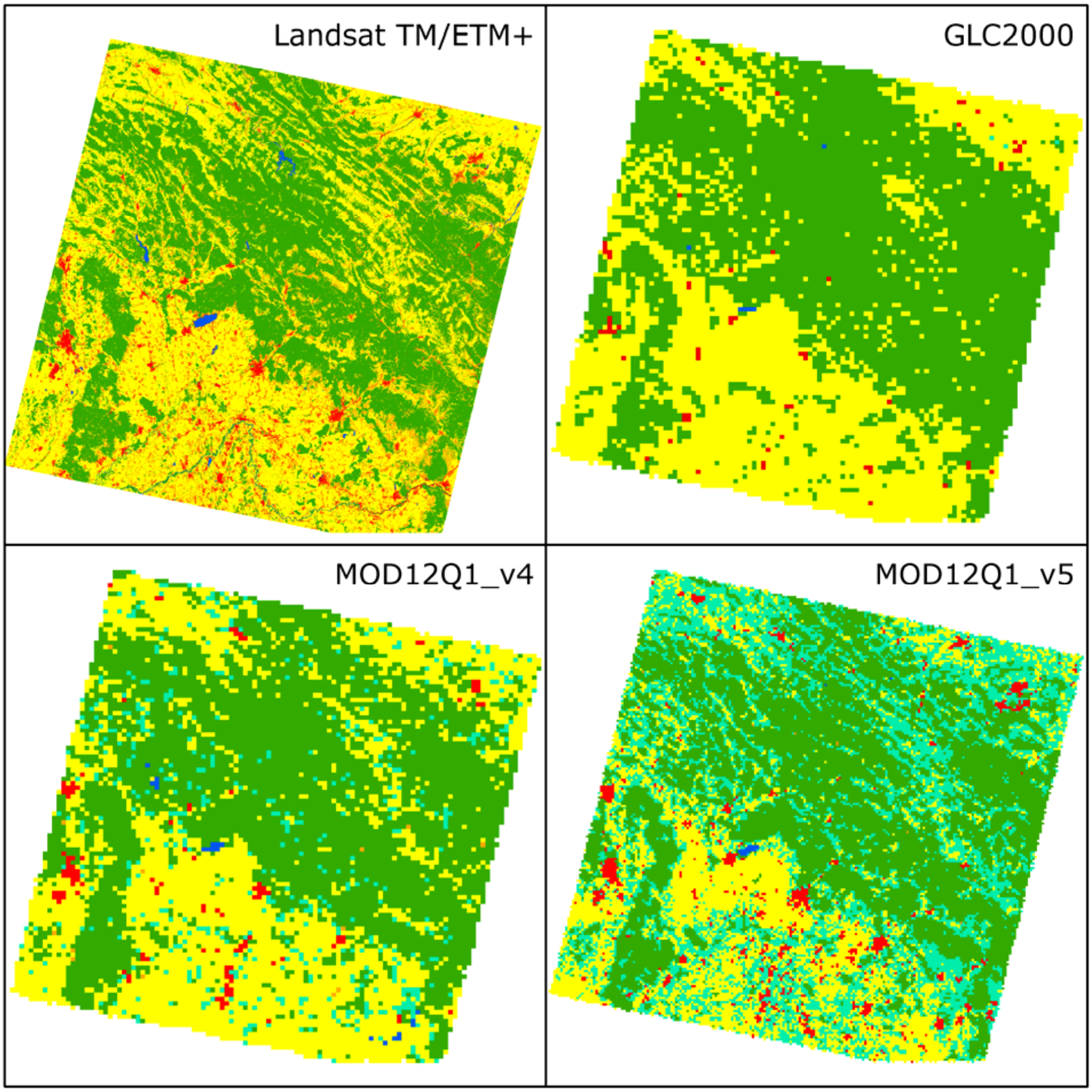
5.6 Comparison to broad-scale land cover maps

Distribution of land cover types in the Landsat, GLC2000, and MODIS (MOD12Q1) land cover maps (percent):

	TM	*GLC2000*	*MOD12Q1_v4*	*MOD12Q1_v5*
Tree dominated	44.58	58.05	52.63	42.31
Shrub dominated	9.91	0.00	0.21	0.04
Herbaceous dominated	41.50	41.04	39.56	23.42
Bare	3.49	0.75	1.34	3.14
Mosaic	N/A	0.08	6.06	31.00
Water	0.52	0.08	0.20	0.09



Comparison of Landsat-based, GLC2000, MOD12Q1_v4, and MOD12Q1_v5 land cover maps (for a legend see graph above):



6 Land Cover Change Map

6.1 Pre-processing

See Section 6.1

6.2 Change detection

Two major land cover change processes occurred in the site between 1988 and 2000:

- Forest cover changes due to logging and reforestation
- Cropland conversion to grassland due to farmland abandonment

Other land cover changes (e.g., urban development, construction of holiday houses, infrastructure development, etc) were not widespread or occurred at scales too fine to be mapped based on Landsat TM/ETM+ images. All settlements and water bodies were masked prior to the change analyses. Mapping land cover changes was carried out in two stages. First, a forest/non-forest map was calculated for 1988. Second, forest disturbance was mapped for all forest areas, and farmland abandonment and reforestation was mapped for all non-forest areas. Land cover change was mapped only for a subset of the site (~57% of the site, excluding the Hungarian region and some cloud covered areas).

Forest/non-forest map
ISODATA clustering was used to separate forest and non-forest areas based on the 1986 and 1988 images. To assess pre-1988 logging, all non-forest patches within bigger forest patches were checked whether they represented permanent openings or forest disturbances using available GeoCover Landsat MSS images from 1977-79.

Forest disturbance mapping
Forest disturbance was mapped by first calculating the forest disturbance index for the 1988-, 1994-, and 2000(June)-images and second carrying out a multi-temporal classification to derive the classes 'undisturbed forest', 'disturbance before 1988', 'disturbance in 1988-1994', and disturbance 1994-2000'. The class 'disturbance before 1988' refers to disturbances that occurred in the 6 years before 1988 , NOT the full time period between the acquisition of the MSS images and 1988. Training data for this classification was mapped in the field in 2004-06, from high-resolution images, and from ancillary data (e.g., forest inventory maps).

Farmland abandonment mapping
Farmland abandonment was mapped for all unmasked non-forest areas. To include phenology information important to separate farmland in use from abandoned or set-aside farmland, both images from 1986/88 and two images from 2000 (June and September). Support Vector Machines were used to categorize the stack of the four images into the classes 'unchanged areas', 'fallow land', and 'reforestation'. The fallow land class contained cropland that converted to grassland and cropland that converted to successional shrubland (initial tests suggested that grasslands and shrublands were spectrally highly collinear – see also section 5.4). Reforestation referred to forest expansion on farmland (not post-clear-cut forest regeneration which was captured in the forest disturbance mapping). Training data for this classification was mapped in the field during 2004-06 and from high-resolution images.

Both maps, the forest disturbance map and the farmland abandonment map, were merged into a single land cover change map.

6.3 Post-classification processing

Forest disturbances at elevation higher than 1050m and narrow bands of disturbances at the forest fringe represented mostly misclassifications due to phenological differences between the images and were labeled as unchanged forest. The minimum mapping unit for the forest disturbance analyses and the farmland abandonment map was set to 7 pixels (0.63ha), treating all forest disturbances as a single class.

The forest/non-forest mapping and the forest disturbance mapping are described in detail in:

- Kuemmerle, T., Hostert, P., Radeloff, V.C., Perzanowski, K, and Kruhlov, I. (2007): Post-socialist forest disturbance in the Carpathian border region of Poland, Slovakia, and Ukraine, *Ecological Applications*, 15, 1279-1295.

A detailed description of the farmland abandonment mapping is provided in:

- Kuemmerle, T., Hostert, P., Radeloff, V.C., Perzanowski, K, and Kruhlov, I. (2008): Post-socialist farmland abandonment in the Carpathians. *Ecosystems*, 11, 614-628.

6.4 Accuracy assessment

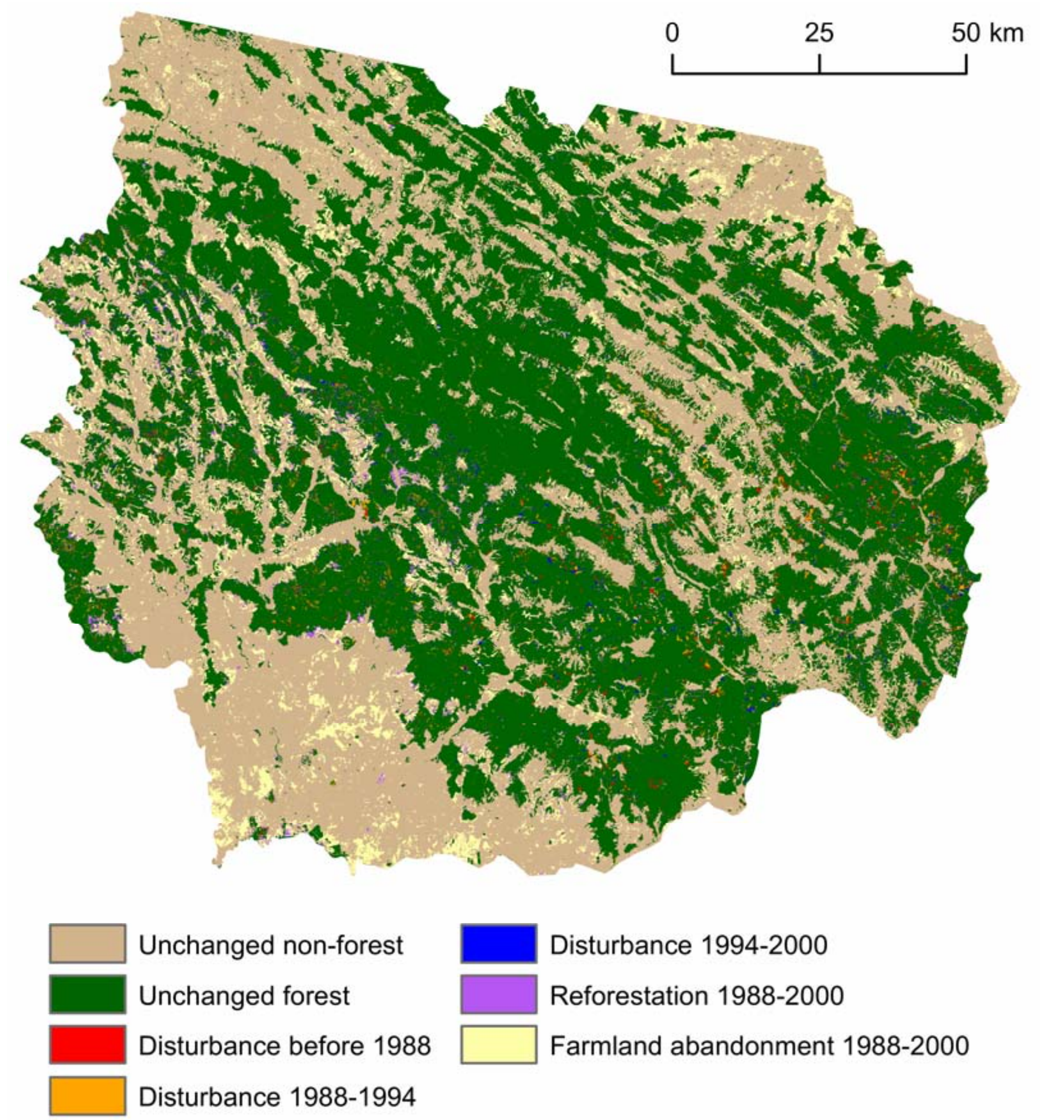
The accuracy of the forest disturbance map was evaluated based on 1,347 ground truth points mapped in the field, from high-resolution images, and from the Landsat images (for some large disturbances) and had an overall accuracy of 94,8% and an overall kappa of 0.93.

		Reference Data						
		NF	F	D2000	D1994	D1988	∑	Users AC
Classified Data	Non-Forest (NF)	**440**	10	5	3	7	465	94.6
	Unchanged Forest (F)	7	**431**	12	2	13	465	92.7
	Disturbances in 1994-2000 (D2000)	0	1	**194**	3	0	198	98.0
	Disturbances in 1988-1994 (D1994)	0	1	2	**120**	1	124	96.8
	Disturbances before 1988 (D1988)	0	1	0	2	**92**	95	96.8
	∑	447	444	213	130	113	1347	
	Producers Accuracy (PAC)	98.4	97.1	91.1	92.3	81.4		
	Conditional Kappa	0.92	0.89	0.98	0.96	0.97		

The accuracy of the farmland abandonment map was assessed based on 573 ground truth points mapped in the field and from high-resolution images. The change map had an overall accuracy of 90.9% and an overall kappa of 0.82.

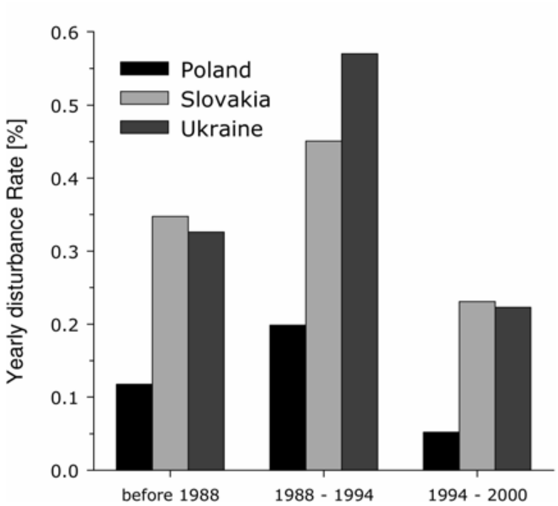
		Reference data				
		unchanged areas	fallow farmland	reforestation	Σ	user's accuracy [%]
Classified data	unchanged areas	349	19	4	372	93.82
	fallow farmland	24	136	1	161	84.47
	reforestation	3	1	36	40	90.00
	Σ	376	156	41	573	
	producer's accuracy [%]	92.82	87.18	87.80		

6.5 Results of the land cover change map

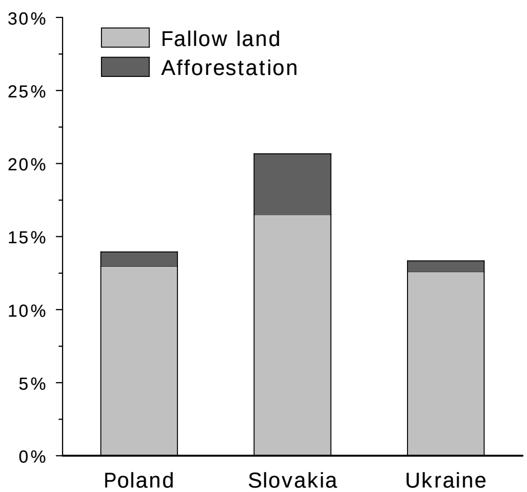


Distribution of land cover change classes:

Class	*Pixels*	*ha*	*% of study region*
Unchanged non-forest	7665113	689860.17	39.09
Unchanged forest	9958770	896289.3	50.79
Disturbance before 1988	113343	10200.87	0.58
Disturbance 1988-1994	279194	25127.46	1.42
Disturbance 1994-2000	174300	15687.00	0.89
Reforestation 1988-2000	166099	14948.91	0.85
Farmland abandonment 1988-2000	1250834	112575.06	6.38



Disturbance rates per time period (relative to total forest) for the Polish, Slovak, and Ukrainian region of the site. Disturbance rates before 1988 were referenced to a 6-year period for better comparison



Farmland abandonment (relative to the total unmasked non-forest area) for the Polish, Slovak, and Ukrainian region of the site (1988-2000).

7 Publications using the site data

- Kuemmerle, T., Kozak, J., Radeloff, V.C., and Hostert, P. (2008): Differences in forest disturbance rates among land ownership types in Poland during and after socialism. *Journal of Land Use Science*, forthcoming.
- Kuemmerle, T., Hostert, P., St-Louis, V., and Radeloff, V.C. (2008): Using image texture to map field size in Eastern Europe. *Journal of Land Use Science*, forthcoming.
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