An assessment of land-use/land-cover change of Bistrishko branishte biosphere reserve using Landsat data

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Abstract. Land-Use/Land-Cover (LU/LC) change detection using satellite data has gained momentum with the advance of the pre-operational phase of regional and global earth observation programmes such as GEOS, GMES, and GOFC-GOLD to name but a few. Present study aims at revealing LU/LC change of Bistrishko Branishte biosphere reserve using Landsat 5 TM and Landsat 7 ETM+ radiometer satellite data. The LU/LC classification of the study area is done for the period 2007-2012, and difference images, between LU/LC maps, have been created. The classification scheme follows CORINE2000 Level 3 with few additional classes introduced to map changes. The methods used in the study are geoinformation, cartography, and statistical. The results show that in effect of 2012 wildfire 0.72 km$^2$ from reserve territory was devastated. The temporal changes which are taking place after the 60 ha windthrow in 2001, the 200 ha bark-beetle outbreak in 2003-2011 and the wildfire from June 2012 were further investigated using ASD HH FS spectrometer in 2011. As a result the increase in ‘331 Broad-leaved forest’ and ‘312 Coniferous forest’ LU/LC classes is attributed to the increase of the territory of deciduous species after a large bark beetle outbreak, which took place between 2003 and 2011, which devastated most of the old Picea abies trees, while the decrease of ‘Outbreak’ and ‘332 Bare rock’ LU/LC classes is mainly due to the wildfire which took place in June 2012.

Keywords: Landsat, land use/land cover change, Ips typograpus, wildfire, SID, SVM, NN

1. Introduction

Land-Use/Land-Cover (LU/LC) change detection is used as one of the main tools to detect changes on the terrestrial part of the Earth. With the advancement of GMES the LU/LC will become an even more important tool to get insight of changes [1]. The intact and pristine forests on the Earth and Europe in particular, are relatively small in area. However, their role in preserving and sustaining valuable habitats and biodiversity, in the transformed by human activities environment, is crucial. One of these reserves is Bistrishko Branishte – a UNESCO MAB biosphere reserve [2].

The present study aims at assessment of LU/LC change for Bistrishko Branishte biosphere reserve using high-resolution satellite data from Landsat 5 TM and Landsat 7 ETM+. The time frame of the
The study is between 2007 and 2012. During this period a significant change in the reserve's LU/LC has been observed due to an insect outbreak caused by *Ips typographus* L. and a wildfire in 2012. Lately, such natural disturbances have become quite widespread in coniferous forests and caused much debate. Thus, studies on the natural dynamics especially of Norway spruce-dominated forests and their development after natural disturbances are crucially needed [3].

The study objective is to assess to what extent LU/LC has changed. In order to accomplish the objective, several tasks have been defined and carried out:

- Data pre-processing: field spectrometry, satellite data collection, atmospheric and geometric correction, conversion to reflectance, spectral and spatial sub-setting and resampling;
- Data analysis: Maximum Likelihood Classification (MLC), Neural Network (NN), and Support Vector Machines (SVM) classifications; Spectral Angle Mapper (SAM) and Spectral Information Divergence (SID), thematic change detection (Thematic Change);
- Data post-processing: accuracy assessment of LU/LC classifications, thematic change detection.

1.1 Study area

The study area of *Bistrishko Branishte* biosphere reserve is situated in the upper part of the *Bistrica* river basin in the *Vitosha* Mountain between 1430 and 2280 m a.s.l. The reserve was designated as a biosphere reserve by UNESCO-MAB Programme in 1977. The total protected area is 1061.6 ha [2], from which 52% are forests, and the rest part is covered with sub-alpine meadows, rocks and screes [2, 4]. Dominant tree species is Norway spruce (*Picea abies* Karst), represented by 7 forms and varieties aged 140-150 year, with diameter breast height (DBH) up to 1.30 m. and height up to 25 m.

On 22 May 2001, 13.6% (or nearly 62 ha) of the old growth Norway spruce trees in the reserve were windthrown by a severe wind storm [5]. In 2003 after a sudden outbreak of European Spruce bark beetle (*Ips typographus* L.) infestation more than 30 ha from the reserve’s area have been devastated [6]. According to [7] the area affected by the bark beetle, after a computer-aided visual interpretation of SPOT 4 and SPOT 5 images acquired accordingly in 2004 and 2008, is estimated to 200 ha. The vegetation cover of the study area was assessed in 2010 [5]. Classification result was achieved using the WorldView-2 multispectral bands with 2.4 m spatial resolution. The fraction of the vegetation classes classified using SPEAR Tools in ENVI 4.7 is as follows: the ‘No Vegetation’ class covers 27.79% of the spatial subset (1.74 km²), ‘Sparse Vegetation’ class is (41.80%) of the entire territory (2.61 km²), the ‘Moderate Vegetation’ class is (27.82%) or (1.74 km²), and the smallest part belongs to ‘Dense Vegetation’ class with (2.59%) or (0.16 km²).

1.2 Materials and methods

The satellite images from Landsat 5 TM and Landsat 7 ETM+ were acquired on 26 July 2007 and 1 September 2012 respectively. They have been converted to reflectance, orthorectified using ASTER GDEM Version 2, atmospherically corrected with QUick Atmospheric Correction (QUAC) algorithm in ENVI and subset to the area of interest [8]. A cosine topographic correction was applied to improve the LU/LC classification output due to the mountainous relief of the reserve [9]. For this purpose as for cartography of the classification outputs ASTER GDEM Version 2 was used [10]. A mask was prepared in order to mask out the area outside the biosphere reserve. The classification scheme used for LU/LC classification is CORINE (2000) Level 3 [11]. As an extension to CORINE Level 3 additional thematic classes have been used in order to represent the diversity of the LU/LC of the study area. These classes are accordingly: ‘Outbreak’, ‘Burnt area’, and ‘Unclassified’. Supervised MLC, with a probability threshold of $p=0.05$, has been used to discriminate between the LU/LC classes. Supervised NN and SVM classifiers were also used to test which of the classification outputs will provide the best results for the thematic change detection. Two ground truth images created by random sampling with 229 pixels and 219 pixels each, for 2007 and 2012 thematic classifications respectively, have been used for the accuracy assessment of thematic classification outputs. The thematic classification images were used as an input for the thematic change detection. In order to
perform thematic change detection on the classification outputs, the images were co-registered using Moravec operator in ENVI with following parameters: number of tie points 25 and minimum correlation 0.70. Finally the thematic change image was smoothed with a kernel of $3 \times 3$ pixels and the isolated regions were aggregated with a factor of 9. In order to precise the analysis of the dynamics of the most changed ‘Outbreak’ LU/LC class an additional thematic supervised classification was done on a Landsat 5 TM image from 23 September 2011. This was done using field spectroradiometry data collected using ASD Hand Held Field Spec (HH FS) by applying SAM and SID classifiers to the image. The SAM is a deterministic (hard) whereas the SID is a probabilistic (soft) classifier [12, 13]. The field collected spectra in four sampling sites during the summer and autumn of 2011 was assembled into an ENVI spectral library. The ASD HH FS data was pre-processed into reflectance using the ViewSpec 6 software. Then an averaging of the four sample sites was done for the dead spruce trees, stressed ones (which were visibly affected by the *Ips typographus* L. but still lively) and healthy ones. The so defined three sub-classes within the ‘Outbreak’ LU/LC class were used for detailing the status of the forest prior to the wildfire event in 2012. The cartographic representations of the results were prepared in ArcGIS/ArcInfo 9.2 academic license software.

2. Results and discussions
The results from the LU/LC classifications for the 2007 and 2012 are presented on figure 1.

![Figure 1. LU/LC classifications of (a) Landsat 5 TM (26 July 2007) and (b) Landsat ETM+ (1 September 2012) satellite images.](image)

From the comparison of figure 1(a) and figure 1(b) it is evident that for the five year period, i.e. between the two image acquisitions, the most noticeable changes took place in the class ‘Outbreak’. This class has been expanded in the outermost direction due to the European spruce bark beetle infestation and degraded due to the wildfire of June 2012 and the encroachment of the natural grasslands in place of the dead coniferous vegetation. The separability between classes is a measure of how good classes are discriminated in the spectral space. According to Jeffries-Matusita and Transformed Divergence tests, it is most evident between ‘321 Natural grassland’ and ‘Outbreak’, ‘332 Bare rock’ and ‘331 Broad-leaved forest’, and ‘Outbreak’ and ‘331 Broad-leaved forest’ (2.0 Jeffries-Matusita and Transformed Divergence). The numerical results from the accuracy assessments
of the NN LU/LC classification of Landsat 5 TM and SVM LU/LC classification of Landsat 7 ETM+ image are presented in table 1 and table 2. The NN and SVM LU/LC classification outputs have been chosen amongst the three supervised classifications due to their highest overall and thematic accuracy, and Kappa coefficient. From table 1, see row ‘Total’, is evident that the pixels of ground truth image coincide with the designated pair of classes in 218 out of 229 of the cases (95.20% accuracy; Kappa 0.9382). The most accurately classified classes are: ‘332 Bare rock’, ‘321 Natural grassland’ and ‘331 Broad-leaved forest’, which again may be attributed to the better separability between classes in this season of the year.

Table 1. Accuracy assessment of LU/LC NN classification of Landsat 5 TM image (26 July 2007).

| Class               | 332 Bare rock | 321 Natural grassland | 312 Coniferous forest | Outbreak | 331 Broad-leaved forest | Ground Truth (Pixels) |
|---------------------|---------------|------------------------|-----------------------|----------|-------------------------|-----------------------|
|                     | pixels | %      | pixels | %      | pixels | %      | pixels | %      | pixels | %      | pixels | %      | pixels | %      | 218/229 | 100    |
| Unclassified        | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |         |        |
| 332 Bare rock       | 30     | 100    | 0      | 0      | 0      | 0      | 1.37   | 0      | 0      | 30     | 13.10  | 0      | 0      |         |        |
| 321 Natural grassland| 0      | 0      | 49     | 100    | 0      | 0      | 0      | 0      | 0      | 49     | 21.40  | 0      | 0      |         |        |
| 312 Coniferous forest| 0      | 0      | 0      | 0      | 43     | 91.49  | 7      | 9.59   | 0      | 50     | 21.83  | 0      | 0      |         |        |
| Outbreaka           | 0      | 0      | 0      | 0      | 4      | 8.51   | 66     | 90.41  | 0      | 70     | 30.57  | 0      | 0      |         |        |
| 331 Broad-leaved forest | 0  | 0      | 0      | 0      | 0      | 0      | 30     | 100    | 100    | 218/229| 100    | 0      | 0      |         |        |
| Total               | 30     | 100    | 49     | 100    | 47     | 100    | 73     | 100    | 30     | 100    | 218/229| 100    | 0      |         |        |

aDead coniferous forest

Table 2. Accuracy assessment of LU/LC SVM classification of Landsat 7 ETM+ image (01 September 2012).

| Class               | 332 Bare rock | 321 Natural grassland | 312 Coniferous forest | Outbreak | 331 Broad-leaved forest | Burned area | Ground Truth (Pixels) |
|---------------------|---------------|------------------------|-----------------------|----------|-------------------------|-------------|-----------------------|
|                     | pixels | %      | pixels | %      | pixels | %      | pixels | %      | pixels | %      | pixels | %      | pixels | %      | 218/219 | 100    |
| Unclassified        | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |         |        |
| 332 Bare rock       | 53     | 100    | 0      | 0      | 4.26   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 53      | 24.20  |
| 321 Natural grassland| 0      | 0      | 47     | 100    | 0      | 0      | 1      | 5.56   | 0      | 0      | 0      | 0      | 0      | 0      | 48      | 21.92  |
| 312 Coniferous forest| 0      | 0      | 0      | 58     | 100    | 0      | 11.11  | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 58      | 26.48  |
| Outbreaka           | 0      | 0      | 0      | 0      | 1.72   | 17     | 94.44  | 0      | 0      | 0      | 0      | 0      | 17     | 0      | 17      | 7.76   |
| 331 Broad-leaved forest | 0  | 0      | 0      | 0      | 0      | 0      | 24     | 100    | 0      | 0      | 0      | 24     | 100    | 0      | 24      | 10.96  |
| Burned area         | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| Total               | 53     | 100    | 47     | 100    | 58     | 100    | 19     | 100    | 24     | 100    | 19     | 100    | 218/219| 100    | 0      |        |

aDead coniferous forest

From the row ‘Total’ in table 2 it is evident that the pixels of ground truth image coincide with the designated pair of classes in 218 out of 219 cases. This accounts for 99.54% overall accuracy and a
Kappa coefficient of 0.9943. The least accurately classified class is ‘Outbreak’, though; it features 94.44% thematic accuracy. The separability test, according to Jeffries-Matusita and Transformed Divergence tests, for the training sites of Landsat 7 ETM+ image, is most evident between ‘321 Natural grassland’ and ‘Outbreak’, ‘312 Coniferous forest’ and ‘321 Natural grassland’; and ‘Burned area’ with ‘331 Broad-leaved forest’, ‘312 Coniferous forest’ and ‘321 Natural grassland’ (2.0 Jeffries-Matusita and Transformed Divergence).

For the thematic change detection of LU/LC based on the Landsat 5 TM data is selected the classification output from NN classification due to its higher thematic accuracy compared to the improved classification result of MLC in terms of overall accuracy and Kappa. The SVM classification result of LU/LC based on Landsat 7 ETM+ data is undoubtedly the best amongst the other classification outputs in terms of thematic and overall accuracy. The total classified area in both image extracts is 14.62 km². The break down for the LU/LC classes is presented in table 3.

Table 3. Total area (km²) and relative percentage (%) of the LU/LC classes’ area from Landsat TM (26 July 2007) and Landsat ETM+ (01 September 2012) images.

| LU/LC class          | Landsat 5 / TM (26 July 2007) | Landsat 7 / ETM+ (01 September 2012) |
|----------------------|-------------------------------|-------------------------------------|
|                      | Area (km²)                    | Percent (%)                         | Area (km²) | Percent (%) |
| Unclassified         | 4.56                          | 31.22                               | 0.00       | 0.00        |
| 332 Bare rock        | 1.13                          | 7.70                                | 1.02       | 6.97        |
| 321 Natural grassland| 3.46                          | 23.70                               | 3.93       | 26.91       |
| 312 Coniferous forest| 2.79                          | 19.11                               | 7.29       | 49.86       |
| Outbreak²            | 2.26                          | 15.47                               | 1.17       | 7.98        |
| 331 Broad-leaved forest| 0.41                        | 2.80                                | 0.47       | 3.21        |
| Burnt area           | -                             | -                                   | 0.74       | 5.07        |
| Total                | 14.62                         | 100.00                              | 14.62      | 100.00      |

²Dead coniferous forest

The results in table 3 show an increase of ‘331 Broad-leaved forest’ class with about 0.4%. This change can be attributed to either misclassification of the class with other classes as for the relative increase in the class, as well as seasonality changes. Parts of the young sprouts of broadleaf vegetation, which have appeared after the fallout of the dead coniferous stands, have been devastated by the wildfire in 2012, which total area within the reserve is estimated to 0.72 km². The ‘312 Coniferous forest’ and ‘Outbreak’ LU/LC classes match an increase in their relative proportion. This can be explained with misclassification of the first class with the ‘Unclassified’, and a relative decrease of the latter one due to the bark beetle infestation and wildfire in 2012. The result from the thematic change detection performed on the LU/LC classification outputs is presented on figure 2.
Figure 2. Map of LU/LC thematic change between 2007 and 2012.
The figure represents visually the thematic change of the LU/LC classes which error matrix of total change is presented in table 4.

Table 4. Change detection matrix of total LU/LC change between 2007 and 2012 in percentages and (km²).

| Class Changes       | 2007 | 2012 |
|---------------------|------|------|
|                     | Percent (%) | Area (km²) | Percent (%) | Area (km²) | Percent (%) | Area (km²) | Percent (%) | Area (km²) | Percent (%) | Area (km²) | Percent (%) | Area (km²) |
| Unclassified        | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| Wildfire scar       | 4.96  | 0.06  | 0.05  | 0.13  | 0.03  | 0.01  | 28.82  | 0.65  | 100  | 0.74  | 100  | 0.74  |
| 312 Coniferous forest | 8.15 | 0.09  | 6.05  | 21.75 | 2.1   | 9.23  | 12.70  | 0.29  | 37.39 | 2.73  | 100  | 7.29  |
| 331 Broad-leaved forest | 8.15 | 0.09  | 6.05  | 21.75 | 2.1   | 9.23  | 12.70  | 0.29  | 37.39 | 2.73  | 100  | 7.29  |
| 332 Bare rock       | 71.70 | 0.81  | 5.64  | 0.2   | 0     | 0     | 0.72   | 0.02  | 100  | 1.02  | 100  | 1.02  |
| 321 Natural grassland | 12.23 | 0.14  | 86.83 | 3.01  | 10.79 | 0.3   | 7.03   | 0.03  | 20.22 | 0.46  | 100  | 3.93  |
| Outbreaka           | 2.96  | 0.03  | 0.91  | 0.03  | 9.12  | 0.25  | 0      | 0      | 37.46 | 0.85  | 100  | 1.17  |
| Class Total         | 100   | 1.13  | 100   | 3.46  | 100   | 2.79  | 100    | 0.41  | 100  | 2.26  | 0    | 0     |
| Class Changes       | 28.29 | 0.32  | 13.17 | 0.46  | 24.87 | 0.69  | 16.26  | 0.07  | 62.54 | 1.41  | 0    | 0     |
| Image Difference    | -9.51 | -0.11 | 13.54 | 0.47  | 160.89| 4.49  | 14.73  | 0.06  | -48.41| -1.09 | 0    | 0     |

Due to the errors in LU/LC classification and the ‘Unclassified’ class present in 2007 image, there are substantial changes in LU/LC structure. Nevertheless, two most evident changes took place between both dates which are mainly due to the insect infestation and the wildfire of June 2012. The most changed LU/LC classes in terms of the area they occupy from 2007 to 2012 in descending order are: ‘Outbreak’, ‘332 Bare rock’, ‘312 Coniferous forest’, and ‘331 Broad-leaved forest’. The change in the class area has decreased in the first two classes, whereas the latter two have been increasing.

*aDead coniferous forest
...their relative percentage. This may be attributed to the wildfire of 2012, which burnt most of the ‘Outbreak’ LU/LC class area. Contrarily, the increase of the relative percentage of the area of the coniferous and deciduous vegetation can be explained with the recovery of the coniferous since 2007 and encroachment of deciduous species as well as to misclassification between LU/LC classes. Finally, an additional step was undertaken towards revealing the status of the most affected by the pest infestation trees within the ‘Outbreak’ LL/LC class. The pre-processed and stored in a spectral library spectra was resampled to the first four bands of Landsat 5 TM image acquired on 23 September 2011 (few days before the ASD HH FS measurements). Even though the SAM and SID algorithms are proven to deliver high accuracy with airborne and space borne spectrometry data the loss of information due to spectral resampling was preferred in order to conform with the results for 2007 and 2012 derived from Landsat radiometers, figure 3.

**Figure 3.** Map of the ‘Outbreak’ class and ‘Dead spruce’ sub-class for 2007, 2011, and 2012 with an inset of the ASD HH FS spectral plots.

Therefore, a complete coincidence among the sub-classes (dead, stressed and healthy spruce) and the ‘Outbreak’ class was not observed at some places due to the fact that the dead coniferous trees appear ‘greener’ on the Landsat 5 TM pixels. This can be explained with to the lush grass that is growing below them swiftly encroaching the new sunlit spaces left after tree mortality. The SID classifier mapped better than SAM the variations within the ‘Outbreak’ class. Depending on the method used for the SID, i.e. either by Maximum or Minimum Value, the no classified areas are more or less distinctive. The best results were achieved using the Maximum Value of $p=0.1$, where the stressed groups of trees appear interspersed or within the dead coniferous forest sub-class. This corresponds well to the real situation observed in the reserve. The total area classified as ‘dead spruce’ for 2011 was 0.511 km$^2$ and the ‘Stressed spruce’ was 0.8 ha. It is here to mention that SID classifier underperformed in a way due to the following reasons: 1) the Norway spruce is represented by 7 varieties while only the affected by the pests were spectrally sampled; 2) the TPC of the spruce forest differs from place to place. By using a $p=0.1$ for the SID each pixel is classified with 95% probability. Therefore only 100 percent TPC spruce stands were classified. The results are interesting not only for the fact that these were the densest spruce stands in 2011 but also that the three sub-classes did exist interspersed – an evidence for the pattern of the pest infestation.

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3. Conclusions
From classification outputs and accuracy assessments it is evident that the lowest production and users’ accuracies are attributed mainly to mixing up the classes in spectral space for both images from 2007 and 2012. Nevertheless, almost all of the thematic accuracies feature more than 90% accuracy whereas other peak at 100. The thematic accuracies from all the LU/LC supervised classifications are higher than 85%, which also accounts for their utilization for area assessment. It was found out also, that the relative increase of the ‘312 Coniferous forest’, ‘331 Broad-leaved forest’ classes is due to deciduous species encroachment and coniferous forest recovery since the demise of the insect outbreak, while the decrease of the ‘Outbreak’ and ‘332 Bare rock’ classes is mainly due to the wildfire which took place in June 2012. Its burnt area was estimated to 0.72 km².

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References
[1] Space GMES − Observing our planet for a safer world http://ec.europa.eu/enterprise/policies/space/gmes/ [Date accessed 11/6/2012]
[2] UNESCO-MAB Biosphere Reserve Directory, Bistrichko Branichté http://www.unesco.org/mabdb/br/brdir/directory/biores.asp?mode=all&code=BUL+03 [Date accessed 1/7/2012]
[3] Panayotov M, Kulakowski D, Laranjeiro D S and Bebi P 2011 Wind disturbances shape old Norway spruce-dominated forest in Bulgaria Forest Ecology and Management 262 470–81
[4] Georgiev G 1995 People’s Parks and Natural Reserves in Bulgaria. (Sofia: Prosveta) (In Bulg.)
[5] Filchev L 2012 An assessment of European spruce bark beetle infestation using Worldview-2 satellite data Proc. of European SCGIS Conf.: “Best practices: Application of GIS technologies for conservation of natural and cultural heritage sites” (Sofia, 21–23 May 2012, Bulgaria) pp 9–16
[6] Gikov A and Pironkova Z 2005 Using geoinformation technologies for assessment of tornado damages in forest areas Proc. of Sci. Conf. with Int. Participation “Space, Ecology, Safety” (SES 2005), (Varna, 10–13 June 2005), pp 269–74 (In Bulg.)
[7] Panayotov M and Georgiev D 2013 Dynamics in the Ips typographus outbreak following the 2001 windthrow in Bistrishko braniste reserve Silva Balcanica (in press)
[8] ENVI Atmospheric Correction Module: QUAC and FLAASH User’s Guide, Version 4.7, 20AC47DOC, August, 2009 ITT Visual Information Solutions
[9] Füreder P 2010 Topographic correction of satellite images for improved LULC classification in alpine areas Grazer Schriften der Geographie und Raumforschung 45 187–94
[10] Advanced spaceborne thermal emission and reflection radiometer (ASTER), Global digital elevation model (GDEM) version 2, NASA USGS ERSDAC METI, 2011, p 11
[11] CORINE Land Cover nomenclature. http://www.igeo.pt/gdr/pdf/CLC2006_nomenclature_addendum.pdf [Date accessed 11/6/2012]
[12] Kruse F A, Lefkoff A B, Boardman J B, Heidebrecht K B, Shapiro A T, Barloon P J, and Goetz, A F H 1993 The Spectral Image Processing System (SIPS) - Interactive Visualization and Analysis of Imaging spectrometer Data Remote Sensing of the Environment 44 145–163
[13] Du H, Chang C-I, Ren H, D’Amico F M, Jensen J O 2004 New Hyperspectral Discrimination Measure for Spectral Characterization Optical Engineering 43 1777–86