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DETECTION AND MAPPING OF CONIFEROUS FORESTS IN WESTERN BULGARIA DAMAGED BY BIOTIC AND ABIOTIC FACTORS IN THE FRAME OF THE 'CORINE LAND COVER 2018' PROJECT

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Abstract

Two forest sub-regions at the western border of the country were selected as a study area because a lot of coniferous forest stands were damaged by biotic and abiotic factors in the last several years. Using the methodology, software and images of the CORINE Land Cover 2018 Project, a computer-assisted interpretation of the multitemporal satellite and aerial digital images was performed. False color compositions were used, including NIR and SWIR spectral bands. All coniferous forests in the study area (larger than 5 ha) damaged in the period 2012 – 2018 were detected and mapped. The obtained results were compared with terrestrial data from the annual reports of Forest Protection Station Sofia (FPS 2018), which are by years, by the affected areas and by the factors for the damages. The comparison proved the appropriateness of the approach and its advantages became obvious, compared to traditional ground observations, including in terms of accuracy, time and money.

Key words: bark beetle, computer assisted photo interpretation, CORINE Land Cover methodology, damaged coniferous forests, detection and mapping.

Introduction

As a consequence of climate change in Europe, an increase in average annual temperatures and the frequency of extreme weather events is expected. This will lead to deterioration in the health of forest ecosystems. According to the data of the Executive Forest Agency in Bulgaria in recent years, the amount of wood obtained from salvage cuttings was significantly increased.

The poor health condition of the Bulgarian forests is due to both biotic and abiotic stressors. As the most significant factors can be mentioned the bark beetle attacks on coniferous trees, windthrows and windsnaps, snow uproots and snow breakages etc.

As a first step in the development of a strategy that aims to control the spread of bark beetle is the monitoring and mapping of the population dynamics of these pests. On the other hand, the new outbreaks of bark beetle damage are difficult to identify with terrestrial means, as well as expensive and time-consuming (Lindner et al. 2010).

The monitoring of forest ecosystems using remote sensing techniques has improved significantly in recent years, and existing technologies are suitable for use in many aspects of forest management (Lefski et al. 2001, Wang et al. 2004).

For detecting and mapping of bark beetle attacks remote sensing methods take into account the physiological and visual effects on the forest canopy leading to changes of the spectral reflectance in the red edge and near IR spectral bands. Three stages are known which take into account the color change of the leaves as a result of the attacks (Niemann and Visintini 2005). The first is the so-called 'green stage', in which there are no visible signs of a change in the color of the leaves and occurs during the colonization of the host, when the first generation hatches.

Generally, the 'red' and 'gray' stages occur within one to three years of the mass attack. During these stages, the crown initially gradually becomes reddish-brown in color, and in the 'gray stage' progressive defoliation occurs. It is possible to observe some overlap in the evolution of the 'red' stage and the beginning of the 'gray' stage, all the trees being dead.

The detection of 'red' and 'gray' stages by remote sensing techniques has been investigated over the last 30 years (Niemann and Visintini 2005), mainly aerial photographs and visual interpretation being used.

Also, change detection techniques (Collins and Woodcock 1996) and tasseled cap transformation was applied to Landsat imagery (Price and Jakubauskas 1998, Skakun et al. 2003) providing good results in the monitoring of forest disturbances and mortality as a result of insect attacks. The study by Franklin et al. (2003) is based on the automatic detection algorithm for damage during the 'red' stage instead of visual interpretation.

COPERNICUS is the Earth observation programme which provides accurate, timely and easily accessible information to improve the management of the environment, understand and mitigate the effects of climate change and ensure civil security. COPERNICUS is the new name for the Global Monitoring for Environment and Security programme, previously known as GMES. It is headed by the European Commission (EC) in partnership with the European Space Agency (ESA) (Anonymous 2017a).

The objective of the Copernicus Land Monitoring Service is to provide land-cover information to users in the field of environmental and other terrestrial applications.

The Land Monitoring Service started its activities in 2011 as part of the GMES Initial Operations (GIO).

The current service is articulated in three components (Anonymous 2017b):

- A global component;
- A Pan-European component;
- A local component.

The CORINE Project is a part of the Pan-European component - producing land-cover and land-change maps at continental scale as well as geophysical and vegetation parameters for seasonal and annual change monitoring. CORINE Land Cover 2018 (CLC2018) is the fifth CORINE Land Cover inventory. Brief history of CLC is presented in Table 1.

The main characteristics of CLC2012 and CLC2018 are summarized in Table 2.

Table 1. CORINE Land Cover inventories in Europe (Büttner and Kosztra 2017).

Name	Start year	End year
CLC1990	1986	1999
CLC2000	2001	2006
CLC2006	2007	2010
CLC2012	2013	2015
CLC2018	2017	2018

Table 2. Main characteristics of CLC2012 and CLC2018.

Characteristic	CLC2012	CLC2018
Satellite data used dominantly	IRS, SPOT-4/5 and RapidEye	Sentinel-2 and Landsat-8 for gap filling
Time consistency	2011–2012	2017–2018
Geometric accuracy satellite images	≤ 25 m	≤ 10 m (Sentinel-2)
CLC mapping minimum mapped unit	25 ha	25 ha
CLC mapping minimum width	100 m	100 m
Geometric accuracy	better than 100 m	better than 100 m
Thematic accuracy	≥ 85 % (probably achieved)	≥ 85 %
Change mapping	boundary displacement min. 100 m; all changes > 5 ha must be mapped	boundary displacement min. 100 m; all changes > 5 ha must be mapped
Production time	3 years	1.5 years
Documentation	standard metadata	standard metadata
Access to the data	free access for all kind of users	free access for all kind of users

CORINE Land Cover Methodology

The method applied for the creating the CLC database is computer assisted visual interpretation. This is a method of recognizing, identifying and assessing of objects recorded in aerial or satellite images, which is based on analysis of interpretation elements of the recorded landscape objects (Kosztra et al. 2017). The standard CLC nomenclature includes 44 land cover classes. These are grouped in a three-level hierarchy. The five main (level-one) categories are: 1) artificial surfaces, 2) agricultural areas, 3) forests and semi-natural areas, 4) wetlands, 5) water bodies (Heymann et al. 1994).

Raw satellite images first have to be pre-processed and enhanced to a geometrically correct document in national projection.

CORINE Land Cover Changes (CLC Changes) are mapped first in the 2nd CLC inventory, CLC2000. It was a policy requirement to map changes smaller than the 25 ha, minimum mapped unit (MMU) size of CLC. Starting from CLC2006, mapping CLC Changes has been standardised: all CLC changes larger than

5 ha have to be mapped.

CLC Change$_{2012-2018}$ is the primary product of the CLC2018 Project. The aim is to produce European coverage of real land cover changes that are:

• larger than 5 ha;
• wider than 100 m;
• occurred between 2012 and 2018;
• detectable on satellite images, regardless of their position.

CLC2018 Satellite Images

To map CLC changes between 2012 and 2018 two sets of satellite images should be used: the ones used to derive CLC2012 (IMAGE2012) as well as the ones depicting the 2018 status (IMAGE2018).

IMAGE2012

Two coverages of pan-European multi-temporal ortho-rectified satellite imagery covering all 39 participating countries with 12 nautical miles' sea buffer was provided by ESA for the period of 2011-2012, with all spectral bands and cloud masking. The main parameters of IMAGE2012 satellite imagery are shown in Table 3 (Büttner and Kosztra 2017).

Table 3. The main parameters of IMAGE2012 satellite imagery.

Parameter	IRS LISS-III	RapidEye	SPOT-4 and SPOT-5
Swath width (km)	141	20	60–80 (depending on looking angle)
Number of bands	4	5	4
Spectral bands	Green, Red, NIR, SWIR	Blue, Green, Red, Red-edge, NIR	Green, Red, NIR, SWIR
Ground sampling distance (m)	23.5	6.5	20 and 10
Bit depth	7	12	8
Delivered resolution (m)	20	20	20
Projection	national	national	national

IMAGE2018

Sentinel-2 mission is a European earth polar-orbiting satellite constellation (Sentinel-2A and 2B) designed to feed the Copernicus system with continuous and operational high-resolution imagery for the global and sustained monitoring of Earth land and coastal areas (Anonymous 2017c).

The Sentinel-2 system is based on the concurrent operations of two identical satellites flying on a single orbit plane but phased at 180º, each hosting a Multi-Spectral Instrument (MSI) covering from the visible to the shortwave infrared spectral range and delivering high spatial resolution imagery at global scale and with a high revisit frequency (Table 4) (Gatti and Naud 2017).

The multispectral imager Sentinel-2 is the most advanced of its kind – in fact it is the first optical Earth observation mission to include four bands in the 'red edge', which provide key information on vegetation state. Spectral bands of Sentinel-2 are compared with bands of main satellite sensors used in previous CLC projects in Table 5 (Büttner and Kosztra 2017).

Table 4. The main parameters of IMAGE2018 satellite imagery.

Parameter	Sentinel-2 Multispectral Imager (MSI)
Swath width (km)	290
Number of bands	13 (altogether) 4 in VIS 6 in NIR 3 in SWIR
Ground sampling distance (m)	10 – bands 2, 3, 4 (VIS) and band 8 (NIR) 20 – bands 5, 6, 7, 8a (NIR) and bands 11, 12 (SWIR) 60 – band 1 (VIS), band 9 (NIR) and band 10 (SWIR)
Bit depth (recording)	12
Repeat cycle at the Equator (days)	10 (with 1 satellite) 5 (with 2 satellites)
Data access	free, full and open access
Delivered resolution (m)	10/20/60 (depending on band)

Table 5. Comparison of spectral bands of satellite sensors.

No	Sentinel-2 MSI	Landsat-7 ETM	IRS LISS-III	SPOT-4 HRV	Remark
1.	0.433–0.453				VIS band. Main use: atmospheric correction (aerosols)
2.	0.458–0.523	0.45–0.52 (TM1)			VIS: blue band
3.	0.543–0.578	0.53–0.61 (TM2)	0.52–0.59 (MS1)	0.50–0.59 (XI1)	VIS: green band
4.	0.650–0.681	0.63–0.69 (TM3)	0.62–0.68 (MS2)	0.61–0.68 (XI2)	VIS: red band
5.	0.698–0.713				NIR: vegetation red edge band
6.	0.733–0.748				NIR: vegetation red edge band
7.	0.773–0.793				NIR: vegetation red edge band
8.	0.735–0.950	0.75–0.90 (TM4)	0.77–0.86 (MS3)	0.78–0.89 (XI3)	NIR band
8a.	0.855–0.875				NIR: vegetation red edge band
9.	0.935–0.955				NIR band. Main use: atmospheric correction (water vapor)
10.	1.365–1.395				SWIR band. Main use: atmospheric correction (cirrus clouds)
11.	1.565–1.655	1.55–1.75 (TM5)	1.55–1.70 (MS4)	1.58–1.70 (XI4)	SWIR band
12.	2.100–2.280	2.09–2.35 (TM7)			SWIR band

The recommended standard image band combinations in order to provide similar colours on screen for interpretation are shown in Table 6.

Table 6. Recommended standard colour band combinations.

Colour	IRS	SPOT-4,5	RapidEye	Sentinel-2
Red (R)	band 3 (NIR)	band 3 (NIR)	band 5 (NIR)	band 8 (NIR)
Green (G)	band 4 (SWIR)	band 4 (SWIR)	band 3 (Red)	band 11 (SWIR)
Blue (B)	band 2 (Red)	band 2 (Red)	band 2 (Green)	band 4 (Red)

CORINE Land Cover Software

CLC2018 Support Package is a significantly modified and improved version of CLC2012 Support Pack-age. The CLC2018 software has been developed for the Government Office of the Capital City Budapest (BFKH), legal successor of the Institute of Geodesy, Cartography and Remote Sensing (FÖMI). BFKH as consortium member of European Topic Centre Urban, Land and Soil Systems (ETC/ULS) provides assistance for the implementation of European CLC2018 project managed by the European Environment Agency (EEA) within the framework of COPERNICUS Earth Observation Programme (Taracsák 2017).

GIS software packages in general are designed primarily for viewing GIS databases, with tools for creating maps, menus for handling databases and with graphical editing tools. If the software has editing functions too, these are general tools, not specialized for any individual task. In the contrary CLC2018 Support Package offers a specialized, problem-oriented software tool, which significantly facilitates the updating, change detection, quality control and correction of CORINE Land Cover databases by means of computer-assisted visual photointerpretation. Consequently, this software is not applicable for creating, viewing or editing GIS databases in general. For these purposes one can use any common commercial (e.g. ESRI ArcGIS) or free (e.g. Quantum GIS) software.

InterChange program provides a tool for the revision of CLC2012 database and supports the interpretation of land cover changes in order to create the CLC-Change$_{2012–2018}$ database. The program provides a convenient and easy-to-use interface for editing polygons in CLC2012 and CLC-Change databases, for viewing and modification of polygons' data and for finding and correction of errors generated during interpretation and editing. InterChange program was designed especially for revision of existing land cover databases and interpretation of land cover changes. It is unsuitable for primary interpretation of satellite images and for building up an independent land cover database (Taracsák 2017).

The Bark Beetle Problem in Bulgaria

Reducing the afforested area due to biotic and abiotic factors can lead to significant environmental and economic consequences. Biotic damage is mainly due to species of the family Scolitidae and in particular to the pine engraver beetle (*Ips acuminatus* Gyll.), which primarily attacks Scots pine (*Pinus sylvestris* L.).

Bark beetles are secondary pests. They exist naturally in nature and usually they do not create any problem. Normally, bark beetles attack almost dying old trees and play a very important role in the destruction of wood. They start to create a problem as a secondary pest when there is a significant amount of potential food – potential hosts, as the trees are in a weakened state. Exactly such are the artificial pine forests, created outside their natural habitat. In the 60s and 70s of the last century about 1 million hectares of artificial plantations were created in Bulgaria mainly of Scots pine and Austrian pine and at that not in the high mountain region, but in the middle mountain region and below it at an altitude of about 700 meters. They were created on very inappropriate dry places with less rainfall, and when these trees reached over 40 years of age and the respective size, they needed more nutrients and water, which were not available. The stands were already very dense because the lack of access to them hindered logging.

Bark beetles started to be a problem in the country because in 2014 and 2015 there were wet snow and fallen trees, and the beetles most often attack dead, fallen trees that are much weakened. In the large mass of fallen wood they rapidly multiplied (one family of the insect create a generation of 60 small larvae). Then they transfer to the already weakened trees. Normally this pest makes two generations during the year. The development of this pest is such that its maximum probably was reached in 2017. Compared to the 53,000 cubic meters of contaminated wood in 2012, only for the first 6 months of 2017 dead trees already amount to 400,000 cubic meters of wood. The peak of the damages almost coincides with the second time horizon (the first being 2012) of the CORINE Land Cover 2018 project.

Study Area

The damages of coniferous forests due to both biotic and abiotic stressors are greatest in southern and southwestern Bulgaria, where forest officials have adopted logging plans to tackle the pest infestation. Almost all of the damaged forest stands fall into 3 forest sub-regions of Bulgaria. These are (Fig. 1) Kraishte-Ihtiman (a sub-region of the Moesian forest region), Osogovo (a sub-region of the Thracian forest region) and Ardino (a sub-region of the Sothern border forest region).

This study is carried out within the CORINE Land Cover 2018 project and concerns the first two adjacent forest sub-regions located right next to the western border of the country.

Results and Discussion

Using the methodology, software and images of the CORINE Land Cover 2018 Project described above, a computer-assisted interpretation of the multitemporal satellite and aerial digital images was performed. False color compositions were used, including NIR and SWIR spectral bands (Table 5). All coniferous forests in the study area (larger than 5 ha) damaged in the period 2012–2018 have been detected and mapped. As far as pure coniferous forests attacked by bark beetle are concerned, depending on which of the above-mentioned 3 stages they are at, the color of the crowns in the left window (healthy trees – 2012) changes from dark brown through light brown to light gray green in the right window (already attacked trees – 2018) (Fig. 2). If the trees are already fallen or cut the dark

Fig. 1. A map of the forest regions and sub-regions of Bulgaria (by EFA 2011).

brown from the left window changes to light green if the grass cover is seen or to light red-brown in the presence of deciduous understory, as is the colour of broadleaved forests.

According to the CORINE Land Cover Project nomenclature, this is a change in land cover from class 3.1.2 Coniferous forest to class 3.2.4 Transitional woodland/shrub (Fig. 2). In the same way areas with damaged conifers greater than 5 hectares, which are parts of polygons of mixed coniferous-deciduous forests – class 3.1.3 Mixed forests, are also detected and mapped. Because only real changes are given under the technology of the project, here the source code 3.1.3 is changed and the change is given again as 3.1.2 Coniferous forest to 3.2.4 Transitional woodland/shrub.

Altogether for both sub-regions, 716 polygons with damaged forests were delineated with a total area of 17,896 ha.

The obtained results are compared with data from the annual reports of Forest Protection Station Sofia (FPS 2018), which are by years, by the affected areas and by the factors for the damages (Table 7).

From these terrestrial data can be seen that the dynamics of the areas affected by bark beetle show a continuous increase over the period under review, with a maximum of 3,242.9 ha in 2017. The share of the bark beetle area compared to the total area of the damaged stands is 51.1 %.

The areas of damaged by caused abiotic factors are the largest for the stressors ice breakage, followed by snow breakage and the snow uproot – 33.3 %, the maximum value being in 2016. The areas affected by windsnap and windthrow are 9.5 %, the maximum being in 2016.

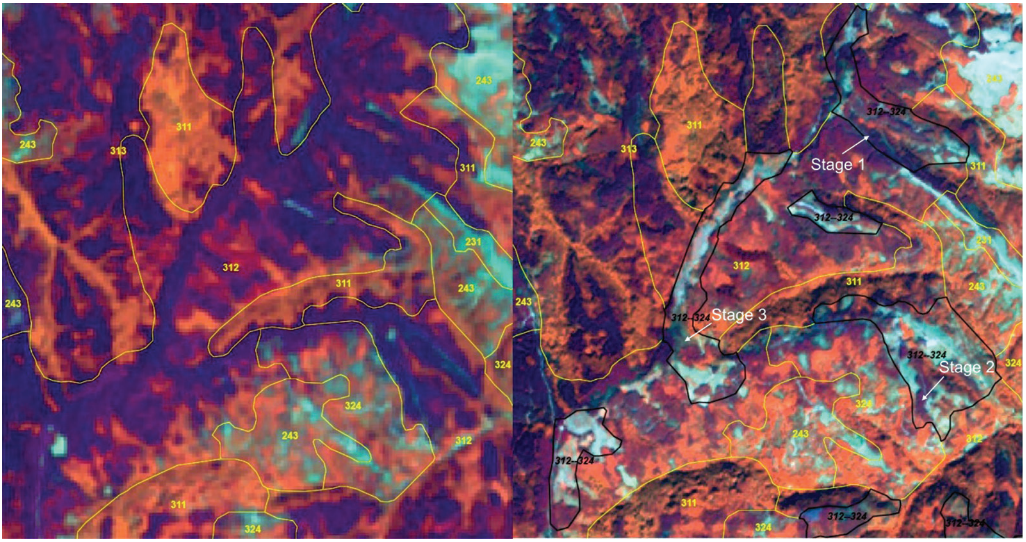

Fig. 2. Detection and mapping of damaged coniferous forests: left window – image 2011; right window – image 2017 – change polygons (black contours).

Table 7. Terrestrial data for the annual distribution of affected areas by stressors.

Stressor	Years							Sum
	2012	2013	2014	2015	2016	2017	2018*	
	Area, ha							
Windthrow	16.5	122.7	1	0.7	46.2	71.2		258.3
Windsnap	4.9	64.7		9.5	54.1	13.3		146.5
Windthrow & windsnap	0.1	243.4	157.1	277	486.8	103.1	44.7	1,312.2
Bark beetle	817.5	279.7	726.5	963.7	2,448.6	3,242.95	789.9	9,268.8
Ice breakage	86.5	12.1		568.4	614.4	357.2	13.2	1,651.8
Snow uproot	14.5	3		0.6	14.1	29.9	7.5	69.6
Snow breakage	403.3	177.2	7.6	17.2	50.1	59.6	13.8	728.8
Snow uproot & breakage	152.2	189.6	82	880.1	1908.7	318.8	47.3	3,578.7
Defoliation of Scots pine	44.8	89.7	168.6	19.4	18.8	14.4	7.6	363.3
Defoliation of pine	11.3	164.2	230.3	91.2	79.5	169.2	1.1	746.8
Total area	1,551.6	1,346.3	1,373.1	2,827.8	5,721.3	4,379.6	925.1	18,124.8

Note: *data for 2018 are up to June.

Conclusions

The comparison between terrestrial data (18,124.8 ha damaged forests) and the results obtained by the CORINE technology (17,896 ha damaged forests) shows that the difference is only 228.8 ha (1.3 %) due to limitation of 5 ha minimum area of mapped changes in the latter case.

From the presented results, it can be concluded that the CORINE technology has a number of advantages compared to traditional ground observations, including in terms of accuracy, time and money.

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