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ORIGINAL SCIENTIFIC PAPER

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Identification of Years with Extreme Vegetation State in Central Europe Based on Remote Sensing and Meteorological Data

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ABSTRACT

Background and Purpose: Determination of an extreme year from the aspect of the vegetation activity using only meteorological data might be ambiguous and not adequate. Furthermore, in some ecosystems, e.g. forests, the response is not instantly visible, but the effects of the meteorological anomaly can be seen in the following year. The aim of the present paper is to select and characterize typical and anomalous years using satellite-based remote sensing data and meteorological observations during the recent years of 2000-2014 for Central Europe, based on the response of the vegetation.

Materials and Methods: In the present study vegetation characteristics were described using remotely sensed official products of the MODerate resolution Imaging Spectroradiometer (MODIS), namely NDVI, EVI, FPAR, LAI, GPP, and NPP, with 8-day temporal and 500 meter spatial resolution for the period of 2000-2014. The corresponding mean temperature and precipitation data (on the same grid) were derived from the Open Database for Climate Change Related Impact Studies in Central Europe (FORESEE) daily meteorological dataset. Land cover specific anomalies of the meteorological and vegetation characteristics were created and averaged on a country-scale, where the distinction between the main land cover types was based on the synergetic use of MODIS land cover and Coordination of Information on the Environment (CORINE) Land Cover 2012 datasets.

Results: It has been demonstrated that the anomaly detection based solely on basic meteorological variables is ambiguous since the strength of the anomaly depends on the selected integration time period. In contrast, the effect-based approach exploiting the available, state-of-the-art remote sensing based vegetation indices is a promising tool for the characterization of the anomalous behaviour of the different land cover types. The selection of extreme years was performed in an explicit way using percentile analysis on pixel level.

Conclusions: Plant status in terms of both positive and negative anomalies shows strong land cover dependency in Central Europe. This is most likely due to the differences in heat and drought resistance of the vegetation, and species composition. The selection of country-specific extreme years can serve as a basis for forthcoming research.

Keywords: remote sensing, anomalous vegetation conditions, phenology, MODIS

INTRODUCTION

Variability is one fundamental feature of the Earth's climate system [1, 2]. Climate fluctuations result in considerable interannual variability of the meteorological parameters like temperature, precipitation, cloud cover, radiation and others. Climate change research typically calculates meteorological parameters in annual basis to track global changes and patterns [3]. Percentiles as the measures of annual deviations from the long term mean are also used to quantify expected return-time of extreme weather events [2].

Meteorological parameters exhibit strong intra-annual variability as well with extreme events like heatwaves, drought spells, flash floods, extreme cold periods etc. In meteorology, quantification of the extreme events has long tradition [1, 4, 5]. Climate indices are calculated typically from daily meteorological records to estimate e.g. strength of heatwaves, number of days with extreme precipitation, length of dry periods etc. [1, 6, 7].

Plant processes and productivity have strong economic impacts due to its direct relationship with crop yield, wood production, animal welfare, fodder quantity and quality, ecosystem services, etc. [8]. Thus, quantifying plant production and understanding the processes behind variability of plant status on annual scale is of high importance [9, 10].

Studies focusing on ecosystem processes have problems with the existing climate indices and annual means due to the complex interactions between meteorological parameters and the vegetation state [11]. Intra-annual variability of the meteorological parameters might exert strong impact on plant growth and productivity [12]. Actual vegetation state is the result of beneficial and negative effects from the past. In other words, vegetation status is the integrator of all effects from soil water status, temperature, variability of radiation, etc. Therefore extreme indices and annual means are not directly applicable to study plant growth and explain its interannual variability.

One logical way to study the impact of climate variability on plant processes is the effect-based approach, where the plant response is characterized first, then the meteorological cause of the effect is sought (see e.g. [13, 14]). Due to economic and political reasons these studies should practically focus on the country scale (see e.g. [15]). However, quantification of plant status on large spatial scales is not straightforward due to the small spatial representativeness and amount of observation based, *in situ* data (e.g. biomass data, phenology observations, leaf area index measurements, eddy covariance data, crop census data, etc.).

Remote sensing (RS) provides a very convenient solution to this problem. Data obtained from sensors on board Earth Observing satellites like the Moderate resolution Imaging Spectroradiometer (MODIS) provides unique information [16] which can be linked to plant status via vegetation indices like Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI) [17], Leaf Area Index (LAI), Fraction of Photosynthetically Active Radiation (FPAR) [18] or modelled plant production like Gross Primary Production (GPP), and the Net Primary Production (NPP) [19]. They are produced at convenient spatial scale (with finest 250 m – 1 km), and today already comprise an exceptional 17-years-long data record.

The spatial resolution of the MODIS Collection 6 products for NDVI, EVI, LAI, FPAR, GPP, and NPP is 500 m or finer (for NDVI and LAI with 250 m resolution) which is sufficiently small to isolate large number of pixels that contain a single land cover (LC) type. This enables that the analysis of plant behaviour can be studied for each land cover type separately, which is needed due to the substantially different dependence of plant functional types on the environmental conditions [20]. However, the classification of pixels into LC categories is not trivial due to land use change and land cover classification errors. For best results, other sources of land cover type are needed, like national/regional forest management maps, agriculture land use monitoring systems for payment of subsidies (e.g. in EU countries), or CORINE Land Cover database [21]. Here we propose a novel method that would enable selection and identification of the anomalous years based on RS data and RS-derived products (NFVI, EVI, LAI, FPAR, GPP, and NPP) according to different land cover types and spatial coverage. This method overcomes the issues that are related with the study of the meteorological anomalies alone. Based on the area for which the method is implemented, it could help to assess differences at spatial and temporal scale for a given LC within the area of interest. It can be applied at a national level to study the behaviour of each LC type as well as to assess the magnitude of the anomaly that has occurred in terms of "repeat time".

In the present paper country averages are studied to get robust results and to support future research. At smaller spatial scales climate is not necessarily the dominant driver of plant development and vigour. For example forest production can be adversely affected due to pathogens or insects [11]. Cropland management clearly affects plant status at smaller scales; for example winter wheat is typically harvested in the region by June-July which affects overall greenness. Management practices like fertilization, harvest and irrigation, and also soil type clearly modulate the effect of meteorological conditions in grasslands and croplands. Country averages by land cover types are expected to be driven by climate fluctuations and provide robust and clear signal about the overall productivity in the given country (see e.g. [15, 22] for such approaches).

The aim of the paper is to present a method to select years that can be characterized as anomalous based on observed plant status and greenness. Using multiple vegetation indices we also test the similarity/dissimilarity of the different vegetation metrics in terms of their usability to detect anomalous plant status. To get robust and easily interpretable results we used country-means. Bosnia and Herzegovina, Croatia and Hungary (and in Supplement Czech Republic, Slovakia and Slovenia) were selected to represent Mediterranean, continental and alpine climates. The reason behind such choice is the relatively small geographical extent and the fact that extreme weather events typically affect large areas and sometimes the whole country [23]. Countries with transitional economies are particularly vulnerable to climate extremes [10]. It means that understanding the cause-effect relationships might support the prevention of adverse effects on plant state and this can support economic growth and human welfare.

MATERIALS AND METHODS

Study Area

The target area of this study is the broader region of the Carpathian Basin, determined by the coverage of the applied meteorological dataset (see below). Bosnia and Herzegovina, Croatia and Hungary were selected to represent Mediterranean and continental climate as well, with high biodiversity and variability in the meteorological conditions. Results for Czech Republic, Slovakia and Slovenia are presented in the Supplemental Material. The reason behind chosen countries is the spatial domain of the applied meteorological database, covering fully only the selected countries.

Meteorological Database

To investigate the effects of weather variability on the vegetation activity and greenness, we used the FORESEE database [24]. This freely available meteorological database contains observed and projected daily maximum/minimum temperature and precipitation fields for Central Europe on a regular grid with a spatial resolution of 1/6° × 1/6°, covering the years between 1951 and 2100. For the 1951-2014 period, FORESEE provides observation-based interpolated meteorological fields for the wide region of the Carpathian Basin.

In order to match the temporal and spatial resolution of the applied remote sensing datasets and of the FORESEE, 8-day mean temperature values and precipitation sums were calculated on the finer grid of the MODIS products based on the methodology of Kern et al. [25]. Country averaged mean and anomaly values were calculated for the above mentioned six countries within the study area.

Mean temperature and precipitation fields (respectively) calculated for the entire domain area of the FORESEE database are presented in Figure 1 and 2 for the study period of 2000-2014. Yearly anomaly fields, shown in Figure 3-6, are illustrations of years which might be considered as extreme from the meteorological perspective. Figure 3 and 4 show the anomaly maps of temperature and precipitation (respectively) for 2011, while Figure 5 and 6 shows the anomaly maps of temperature and precipitation (respectively) for 2014 (note that the temperature and precipitation anomaly maps have different legends).

Vegetation Related MODIS Products

In the present study we used the latest version (Collection 6) MODIS NDVI, EVI, FPAR, LAI, GPP, and NPP with 500 × 500 m spatial resolution, as part of the MOD13A1, MOD15A2H, MOD17A2H and MOD17A3H official products [26, 27] derived from the measurements of MODIS sensor on board satellite Terra. The longest possible datasets (covering the period of 2000-2014) were chosen to match the availability of the MODIS products and the temporal coverage of the applied meteorological dataset.

Quality filtering of each dataset was performed using the quality flag information included in the datasets, based on the method described by Kern *et al.* [25]. Besides this, to filter out unrealistic sudden increases and decreases in the state of the vegetation the so called Best Index Slope Extraction (BISE) method [28] was applied afterwards on pixel level for NDVI and EVI data [25]. While FPAR, LAI and GPP has the same 8-day temporal resolution, NDVI and EVI are 16-day composite products, therefore temporal resampling based on the Julian date information included in the MOD13 datasets was also necessary to create NDVI and EVI dataset with the same 8-day temporal resolution [25].

It has to be noted that although most of the MODIS products are state-of-the-art, standardized, well documented data sets, the quality of the model based products is expected to be lower and that affects their applicability [19]. Most notably, MODIS annual NPP products suffers from a major error (with large unexpected positive bias for the first four years (2000-2003) as it is presented in Figure 7 and should not be used in the FORESEE domain. Therefore, the anomaly values from the yearly NPP products were calculated relative to the period of 2004-2014.

Methods and Metrics for Defining Anomalous Years

From the quality (and in the case of MOD13A1 data BISE-filtered) 8-day temporal resolution datasets country averaged multiannual means and yearly anomaly values were calculated for the whole vegetated area of the selected countries within the Carpathian Basin. Land cover specific country averaged values were also derived for broadleaf and coniferous forests, croplands and grasslands. The yearly anomalies were calculated without the first 40 and last 40 days of the year to avoid any misleading result originating from the effect of snow cover. Using the derived yearly anomaly values, relative anomaly values were calculated by dividing the yearly anomaly values by the maximum of the absolute anomaly values during the investigated 2000-2014 period.

To analyse the spatial distribution of the yearly anomaly fields, we calculated the 0.5, 2, 9, 25, 50, 75, 91, 98 and 99.5 percentiles values of all yearly mean anomaly values for all land cover specific pixels separately within a given country. The selected percentiles define thresholds for the classification of anomalies into the following 10 categories:

<0.5p	most extreme negative anomaly,
0.5p – 2p	extremely negative anomaly,
2p – 9p	strong negative anomaly,
9p – 25p	negative anomaly,
25p – 50p	} normal range
50p – 75p	
75p – 91p	positive anomaly,
91p – 98p	strong positive anomaly,
98p – 99.5p	extremely positive anomaly,
>99.5p	most extreme positive anomaly.

The derived percentile values are appropriate to des-cribe the total distribution of the anomaly values of a given land cover type (within a given country) during the study period of 2000-2014. Based on the proposed categorization we calculated for every year separately the number of the pixels (as the percentage for a given LC type) within all the created percentile ranges. Note that there might be situations when e.g. strong positive anomaly was not occurring in the entire time period for a given LC type at all. In this study the maximum anomaly is used independent of its magnitude.

The advantages of the proposed categorization is the following: (1) the method we applied is the same for all LC types, but it yields LC specific results; (2) it enables the identification of areas within the selected geographical area (e.g. country), where mean anomaly is more positive or more negative with respect to the country average, indicating that

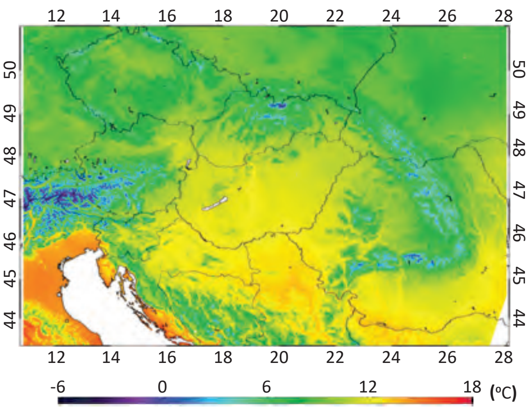

FIGURE 1. Mean annual temperature (°C) during 2000-2014

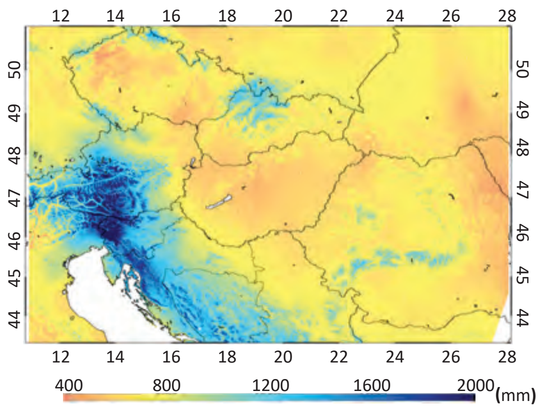

FIGURE 2. Mean annual precipitation (mm) during 2000-2014

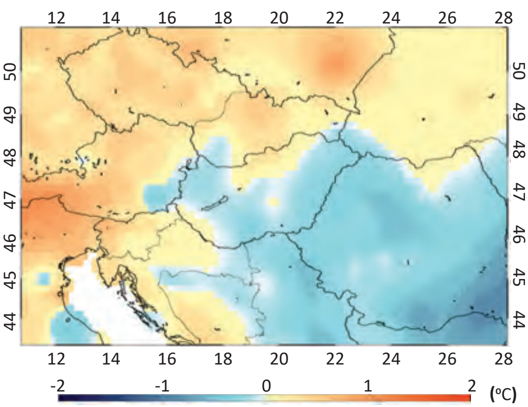

FIGURE 3. Temperature anomaly (°C) in 2011

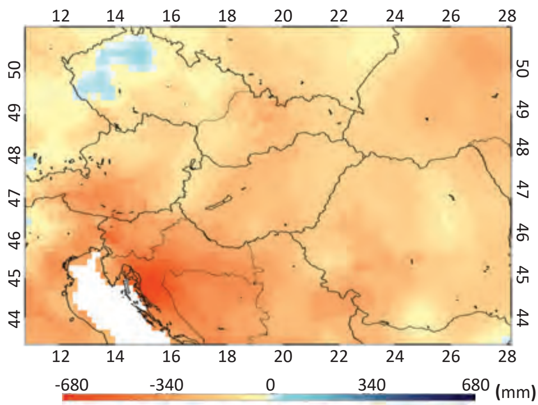

FIGURE 4. Precipitation anomaly (mm) in 2011

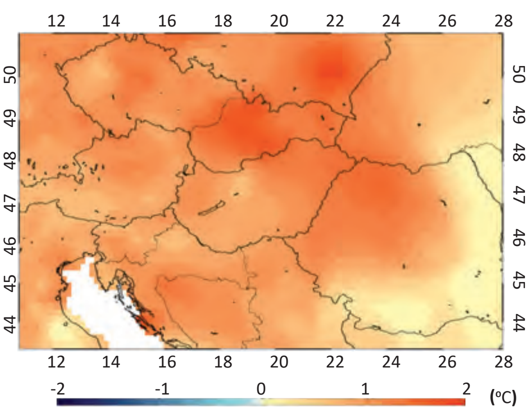

FIGURE 5. Temperature anomaly (°C) in 2014

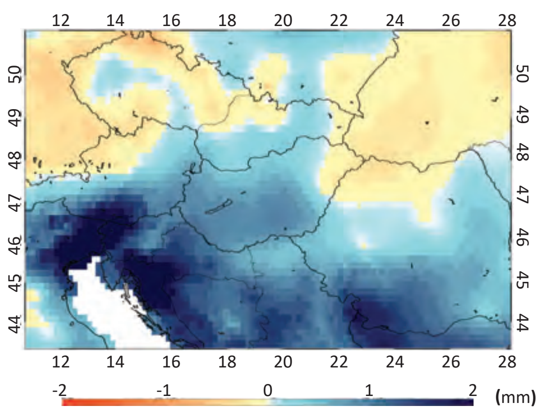

FIGURE 6. Precipitation anomaly (mm) in 2014

some areas are more/less productive, more/less prone or more/less sensitive to meteorological anomalies (where a special attention should be paid to croplands due to the possible yearly crop type change); (3) it is appropriate to be done for any other vegetation related characteristics.

In this paper we propose the following classification of the years, which is based on the percentage of the area showing positive and negative anomalies of a given vegetation characteristics (NDVI, EVI, FPAR, LAI, GPP, and NPP). Using the yearly anomaly fields of given vegetation

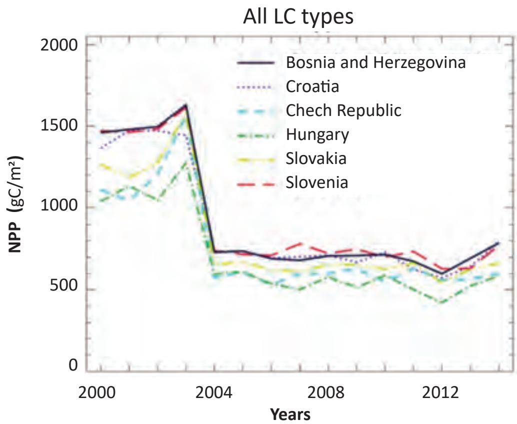

FIGURE 7. Country-averaged annual mean MODIS NPP values for the investigated countries in Central Europe (note that due to technical issues the first 4 years (2000-2003) are not applicable for further processing)

characteristic, for a specific land cover type, the chosen year can be graded based on the thresholds presented in Table 1. It should be noted that the grade for a given year at a given location depends on the selected reference period (e.g. MODIS era, in our case 2000-2014) and the area representing a domain (e.g. region, country or a continent).

Synergy of the MODIS and CORINE Land Cover Databases

In order to study the response of the various vegetation types to meteorological anomalies we distinguished the main land cover types based on the synergistic use of two land cover datasets. The so called MCD12 land cover products based on MODIS observations [29] and the CORINE 2012 database [30] were used to identify pixels with high probability of being broadleaf forests, coniferous forests, croplands and grasslands.

From the five types of land cover classification contained in the MCD12Q1 product [31] we used the Type-1 (International Geosphere Biosphere Programme - IGBP) to identify croplands and grasslands and the Type-3 (MODIS-derived LAI/fPAR scheme) classifications for broadleaf and coniferous forests. The categories of the land cover classification for the used MODIS pixels are given in the translation matrix between the different LC schemes (Table 2). The reason behind the usage of Type-3 for forests was that the widely used Type-1 IGBP land cover classification suffers from well-documented errors [32, 33] with 75% overall accuracy [31] including misclassification of the mixed forest types as well [34]. We found that the misclassification is especially evident for the lowland forests along rivers, for example like the Gemenc forest by the Danube in Hungary, or the river Spačva basin in eastern Croatia, extending also to Vojvodina in Serbia. According to

TABLE 1. Thresholds to the selection of the anomalous years based on the percentage of the affected area

Grade for the year	Share of the area showing very negative and extremely negative anomaly		Share of the area showing very positive and extremely positive anomaly
Extremely bad	>50%	&	<10%
Bad	25% - 50%	&	<15%
Average	<25%	&	<25%
Good	<15%	&	25% - 50%
Extremely good	<10%	&	>50%
Ambiguous	does not meet any of the above criteria		

TABLE 2. Translation matrix between the different land cover classification schemes

LC classification in this paper	MODIS (Type* of MODIS LC classification)	CORINE Land Cover Type (CLC code)
Broadleaf Forests	Deciduous Broadleaf Forest (3)	Broad-leaved forest (311)
	Evergreen Broadleaf Forest (3)	
Coniferous Forests	Evergreen Needleleaf Forest (3)	Coniferous forest (312)
	Deciduous Needleleaf Forest (3)	
Grasslands	Grasslands (1)	Pastures (231)
		Natural grasslands (321)
Croplands	Croplands (1)	Non irrigated arable land (211)
		Permanently irrigated arable land (212)
		Rice fields (213)
		Annual croplands associated with permanent croplands (241)
		Complex cultivation pattern (242)

* Type 1 - IGBP global vegetation classification scheme; Type 3 - MODIS-derived LAI/FPAR scheme [29]

MODIS Type-1 land cover classification both forests have been categorized as mixed forest, while they are broadleaf forests in reality. In fact Spačva forest with its area of 40 kHa size is the largest complex of pedunculate oak forest in Europe [35]. In contrast to this, the Type-3 classification doesn't have mixed forests category, resulting in all forested pixels categorized as either broadleaf or coniferous category. We have to note that in Type-3 classification croplands and grasslands are categorized together as "Grasses/Cereal crops", therefore Type-3 classification cannot be used to discriminate croplands and grasslands.

From the yearly MCD12Q1 land cover datasets with 500 m × 500 m spatial resolution covering the period of 2001-2013 we selected the pixels (hereafter called *stable LC pixels*) which had no land cover change during the entire period. The usage of the temporal stability selection criteria excluded pixels which underwent any kind of land cover change during the investigated period, either actual, or resulting from the error in classification. Implementation of such a strict rule resulted with dropping significant number of the pixels. The percentage of stable LC pixels was only ~56% of the whole study area based on Type-1 classification. Specifically, 32%, 34%, 53%, 69%, and 28% of the pixels remained for the categories of broadleaf forests, coniferous forests, mixed forests, croplands, and grasslands, respectively. Based on Type-3 classification the percentages of stable LC pixels in the whole study were 48% and 42% for broadleaf and coniferous forests, respectively. The percentages were calculated relatively to the mean number of the pixels during the 13 years of the total dataset.

In order to increase the reliability of the applied LC categorization we used the CORINE land cover dataset as a reference LC dataset for the year 2012. The accuracy of CORINE is 87.0 ± 0.7% [21], which is significantly better than the 75% accuracy of MODIS [31]. Using GIS software [QGIS 2.16], we intersected the vector-based CORINE layer with the grid of the MODIS pixels at 500 m × 500 m spatial resolution and obtained the share of every of the 44 CORINE land cover types present within each of the MODIS grid-cells (i.e. pixel). Due to differences in land cover categorization between MODIS and CORINE, we used translation matrix (Table 2) to unify the classification. Based on the area share information of CORINE we selected so called CLC2012 pure pixels for deciduous forests, coniferous forests, croplands and grasslands, which contained at least 90% area share from the given LC type (Table 2, column 1). In the case of croplands and grasslands the 90% threshold was applied for the sum of the area shares of the different CLC categories (separately for croplands and grasslands) listed in Table 2 (column 3).

Using the derived set of MODIS stable pixels and CORINE pure pixels we selected "reliable" pixels which were classified by both land cover database to the same vegetation type of broadleaf forests, coniferous forests, croplands and grasslands. Figure 8 shows the location of the remaining reliable pixels of the main land cover types based on MODIS IGBP (MCD12 Type-1), LAI/FPAR scheme (MCD12 Type-3) classifications and CLC2012 database. This land cover map shows the location of the pixels which were finally used in the present study as reliable pixels, being constant during the study period and having probably right classification. Based on the information of the CORINE database regarding the percentage values of the presence of a given land cover type the mean percentage for the selected broadleaf forests, coniferous forests, croplands and grasslands pixel was 99.0%, 99.0%, 99.3% and 98.2%, respectively. The problem of using the MODIS Type-1 classification for forests is illustrated in Figure 9. The presented map shows the location of the pixels which are classified as broadleaf forests and coniferous based on the MODIS Type-3 and CORINE classifications, but not based on MODIS Type-1 classification. The number of the forested pixels (in the study area) which are not represented well in Type-1 classification is considerable: 59.5% and 66.3% for broadleaf and coniferous forests, respectively, relatively to the number of the derived reliable broadleaf and

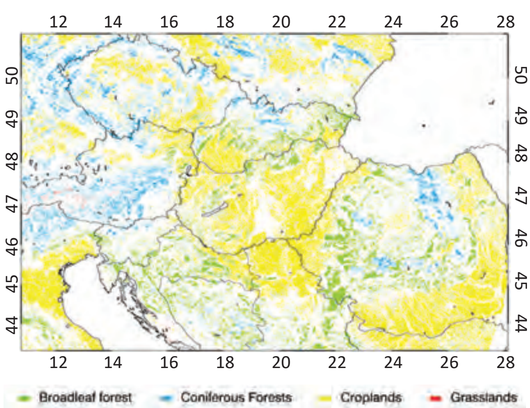

FIGURE 8. Reliable pixels of the main land cover types based on MODIS IGBP (MCD12 Type-1) and LAI/FPAR scheme (MCD12 Type-3) classifications and CLC12 database

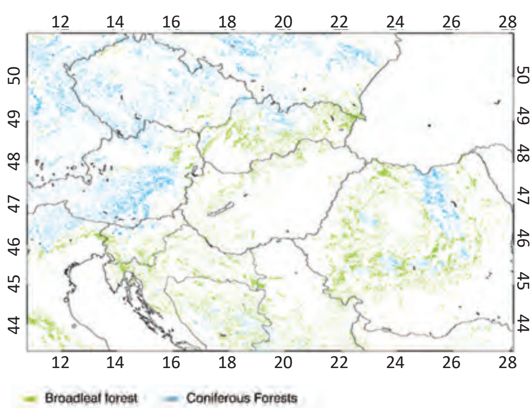

FIGURE 9. Location of the broadleaf and coniferous forests pixels according to both the MODIS Type-3 and CORINE classifications which are classified by MODIS Type-1 classification in some other LC category

coniferous pixels, which were selected finally to our further investigations.

After the synergetic use of the two MODIS datasets with CORINE dataset the number of the selected pixels was 6.3% for broadleaf, 3.1% for coniferous forest, 17.1% for cropland and 0.1% for grassland pixels relative to the all vegetated pixels in the whole domain. It means, with the final pixel selection we were taking into account 26.6% of the whole domain in a total value. The country specific pixel numbers are presented in Table 3.

RESULTS AND DISCUSSION

Problems with the Selection of Extreme Years Based Solely on Meteorological Data

In order to study the dependence of the strength of meteorological anomalies on the selected integration time period, first we present country averaged mean temperature and precipitation anomalies in Figure 10 (left and right side images, respectively) during 2000-2014 for Bosnia and Herzegovina, Croatia and Hungary (and in Figure S1 in the Supplementary Material for Czech Republic, Slovakia and Slovenia).

While the columns show whole year anomalies in Figure 10, the curves indicate periods with various length (starting at different date and all ending with 7th of October within the year), representing gradually only the predominant part of the growing season. 7th of October was used as the end of the integration period as we can hypothesize that meteorology in the dormant season affects plant state to a lesser extent. The beginning was varied with ~2 weeks periods and ranging from 1st January to 26th June.

The figure shows that even if there is an extreme temperature or precipitation anomaly for a given year, it does not necessarily mean that the vegetation was exposed to similar meteorological anomalies during the growing season. A good example is 2003, when the country-averaged annual temperature anomaly was negative in the presented countries (especially for Hungary), but a strong, mostly positive anomaly was detectable for the growing season. On the contrary, year 2004 or 2005 (with similar negative annual temperature anomalies) showed only negative temperature anomalies during the shorter time periods until the end of the growing season. In terms of annual temperature anomaly year 2007 was very similar to year 2000 for all three selected countries, but with much higher intra-annual variability, on average having cooler than usual period in summer and early autumn. On the contrary, in 2012 (with annual temperature anomaly similar to the one in 2007) the summer-early autumn period was characterized with the highest positive anomaly during the year, when the mean temperature of the countries was continuously higher than the average. Finally, year 2014 is worth mentioning as well. Though it had the largest annual anomaly, its temporal evolution was not consistent. Precipitation showed similar features, however the intra-annual variability was much lower. It is important to mention the two consecutive years of 2010 and 2011, which was characterized by very strong positive (2010) and then negative precipitation anomaly (2011) all over the Carpathian-Basin.

These results illustrate the problems in defining temperature and precipitation anomalies as they strongly depend on the selected integration period. In other words, we cannot unambiguously select extreme years based on the yearly (or monthly/seasonal) mean meteorological conditions that can be related with e.g. vegetation state, crop yield, forest productivity, outbreak of insects or other phenomena. To find the extreme years in plant greenness and describe the response of the vegetation greenness, it is more straightforward to study anomalous behaviour of the plant state (or other phenomena that is related with ongoing climate anomalies).

Selection of Anomalous Years Based on the Overall Impact on Vegetation

Yearly relative anomalies of the vegetation related characteristics (such as NDVI, EVI, FPAR, LAI, GPP, and NPP) during 2000-2014 are presented in Figure 11 for croplands and grasslands. Figure 12 shows the same for broadleaf and coniferous forests for Bosnia and Herzegovina, Croatia and Hungary (Figure S2 and S3 in the Supplementary Material illustrate results for the Czech Republic, Slovakia and Slovenia). The yearly, land cover specific anomalies of the meteorological variables (temperature and precipitation) are also presented in Figure 11 and 12.

Based on the results, the relative anomalies for the different vegetation characteristics could be described as quite consistent for croplands and grasslands, showing the same direction of relative anomaly in most of the cases. It is also notable that GPP and NPP show opposite character for

TABLE 3. Number of the pixels at 500 m × 500 m spatial resolution which complied with the selection criteria separately to the main LC types and countries (selection criteria: MODIS LC type for a given pixel did not change during 2001-2013 and its LC classification with 90% share corresponds to that of CORINE 2012 - see Table 2)

Country	Broadleaf Forests	Coniferous Forests	Grasslands	Croplands
Bosnia and Herzegovina	26 252	2 825	200	2 039
Croatia	35 302	421	1 067	21 928
Czech Republic*	2 855	24 925	2	48 869
Hungary	21 699	58	16	137 246
Slovakia*	26 369	6 218	13	38 027
Slovenia*	7 178	1 922	4	1 479

* Figures and additional information for these counties are in the Supplement.

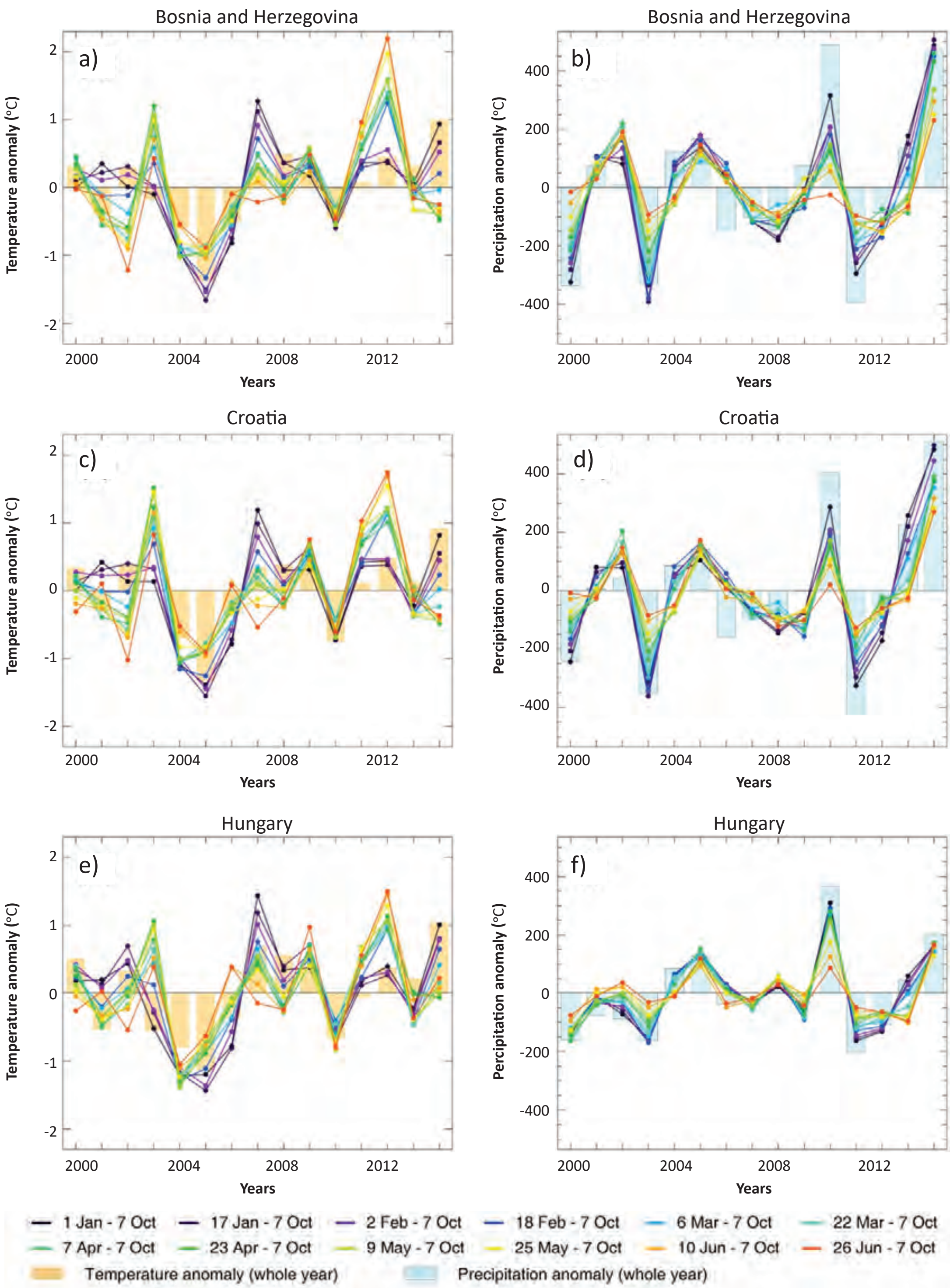

FIGURE 10. Temperature (left side images) and precipitation (right side images) anomalies of time periods with different length within the years during 2000-2014 based on the FORESEE database for Bosnia and Herzegovina, Croatia and Hungary (curves represent the selected time periods ending in 7th October, while columns indicate anomalies for the entire year)

some years compared to other indexes. (Anomalies of NPP for the year 2000-2003 are not shown; see section 2.4. in the Materials and Methods for the explanation).

For a given land cover type in some area (country) within the reference period 2000-2014, the calculated relative anomalies facilitate straightforward comparison between years, as well as between different land cover types within the same year. For example, we can select years when croplands and grasslands were both anomalous (like 2000, 2003 and 2012 with negative anomalies, or 2010 and 2014 with positive anomalies), but in some years (such as 2001 and 2004) croplands and grasslands showed different response to the environmental conditions. These differences might be related to land cover type specific features, species distribution and human disturbances (harvest, fertilization), and maybe other factors like soil water holding capacity, etc. Additionally, croplands in some countries cover C4 plants with higher drought resistance, which might affect the results. Also, croplands and grasslands might exhibit different critical time periods when the ongoing weather affects their productivity [36]. Clearly, it is not only the yearly anomalies of the meteorological parameters that affect the plant status, but the within-year temporal pattern of the meteorological elements. Note that the number of pixels (see Table 3) was low for grasslands in all countries except Bosnia and Herzegovina and Croatia, which can affect the reliability of the results for grasslands in those countries.

While in the case of croplands and grasslands the vegetation related characteristics are mostly consistent, forests reveal different behaviour (Figure 12). As it is obvious from the figure, in the case of forests the different characteristics are not showing similarity for the anomalies, as it was found for croplands and grasslands. It is especially true for GPP and NPP, which are in fact models and not indices that are derived directly from the reflectance data [19]. It means that GPP and NPP results must be treated with caution. For example, in 2012 the reason behind the large disagreement between the mean anomaly of NDVI, EVI, LAI and FPAR, and the mean behaviour of GPP and NPP might be related with the extreme meteorological conditions during the growing season, causing significant drought in the Carpathian-Basin and a consequently simulated lower productivity by the GPP-model. In addition, forests with typically deeper root zone do not react in the same way to changing meteorological conditions as the shallow-rooted croplands and grasslands [16]. Forest productivity depends on the available soil water content in the topsoil to a lesser extent, because deeper groundwater supplies can be accessible to trees. Trees store a relatively large amount of non-structural carbohydrate – which is the product of the previous year – to mitigate negative effect of shortage in nutrients and photosynthetic carbon uptake. Therefore they are likely to be less affected by the shorter term weather anomalies, but showing stronger exposure to the longer term changes. Based on the observed results, we could not select the same years as anomalous years for herbaceous vegetation, which were highlighted in the case of croplands and grassland over the studied countries. The role of the carbohydrate reserves seems to be important which might impose lagged effect [13]. This can be recognised in 2013 as the effect of the previous, extreme year (evident in strong negative anomaly for croplands, see Figure 11) which has contributed to a negative anomaly in broadleaf forests (see Figure 12).

Co-variation between the meteorological and vegetation anomalies does exist and it can give us some basic information at the annual scale. However, the main aim of the present study was not to execute in-depth analysis of cause-effect of environmental variables on the detectable plant state anomalies, but to select anomalous years. In order to quantify their co-variance Pearson's r values (correlation coefficients) were calculated and compared. The correlation coefficients between the yearly anomalies of the vegetation characteristics and the yearly meteorological anomalies were calculated for the different plant types separately. Table 4 present the correlation coefficients calculated between the NDVI anomalies and the temperature and precipitation anomalies, where the statistically significant ($P<0.05$) values are indicated. In the case of temperature, the calculated r values show the strongest correlation for forests (especially with broadleaf forests), while in the case of precipitation the largest correlation is present for croplands and grasslands. Both the direction and the strength of the correlation depend strongly on the land cover type, indicating complex relationship between the vegetation and meteorological conditions. It also implies that large scale and land cover specific studies should not be made together, but separately and at finer temporal and spatial scale.

Selection of Anomalous Years Based on the Magnitude and Spatial Extent of NDVI Anomalies

The investigation of the country averaged mean yearly anomaly does not provide information about its spatial distribution. Therefore, pixel-level investigations were performed using percentiles analysis for the area of a given land cover type affected with severe anomaly (see Section 2.4 in the Materials and Methods). Here we present the results based only on the NDVI, while the results for all other metrics are provided in the Supplementary material (S6, S8, S10, S12).

Different land cover types react with varying intensity to meteorological anomalies as it can be inferred by careful inspection of Figure 13. It shows that, for example, broadleaf forests (top left) maintain rather stable mean annual NDVI and the corresponding anomalies are in the range of +/- 0.05 of the mean in 99% of the cases. Coniferous forests (Figure 13, top right), on the other hand, show higher variability of the mean NDVI compared to broadleaf forests, but the magnitude is still lower than for grasslands (Figure 13, bottom right), and considerably lower than in the case of croplands (Figure 13, bottom left).

Differences between countries exist, but they are rather small, with increasing discrepancies toward the extremes (2p and less or 98p and more). However, this could be the result of relatively small number of pixels with extreme values and should be interpreted with caution. This is particularly the case for grasslands, where the number of pixels was large enough only for Bosnia and Herzegovina and

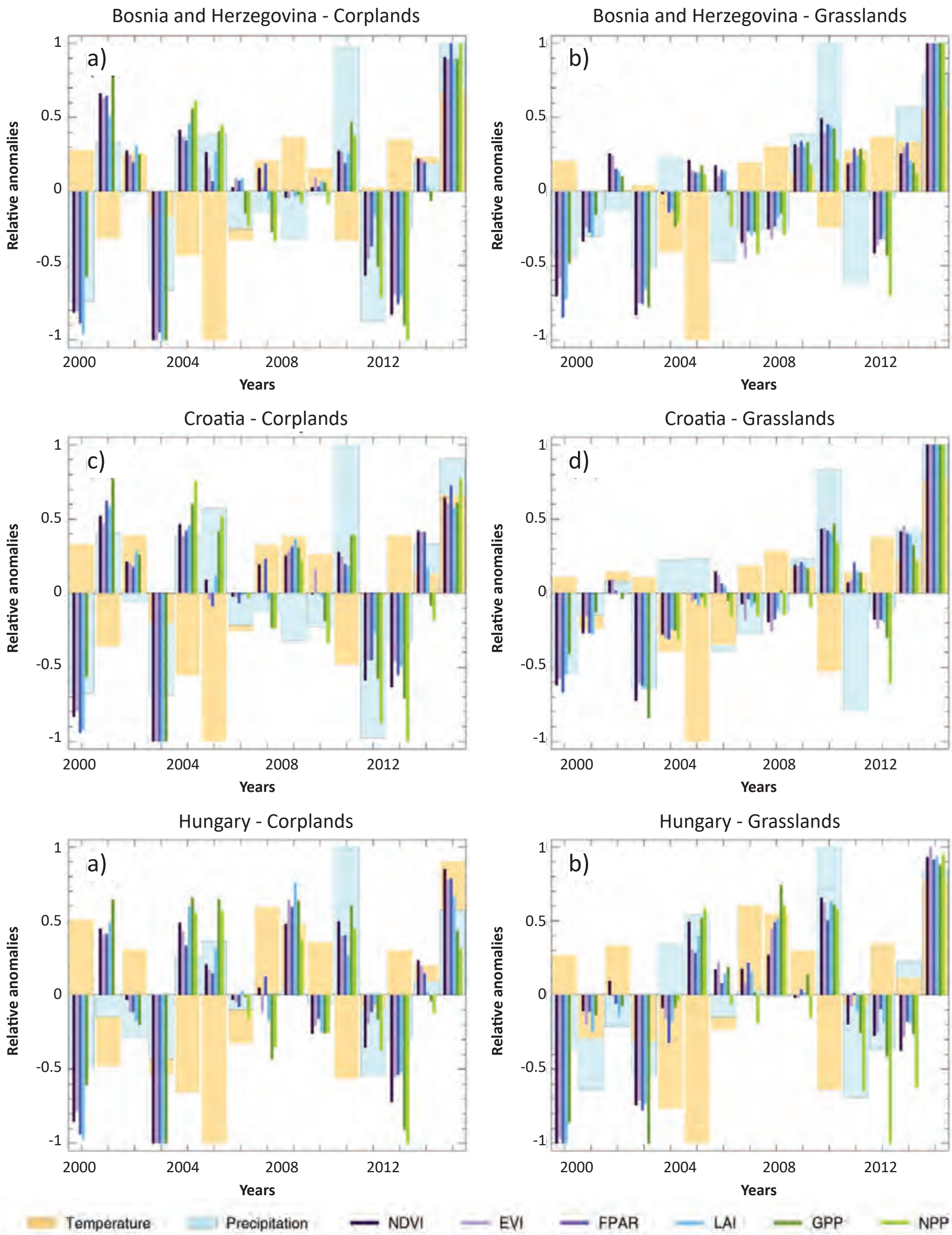

FIGURE 11. Yearly relative anomalies of the vegetation related characteristics (such as NDVI, EVI, FPAR, LAI, GPP and NPP) and of the meteorological variables (temperature and precipitation) during 2000-2014 for croplands and grasslands of Bosnia and Herzegovina, Croatia and Hungary

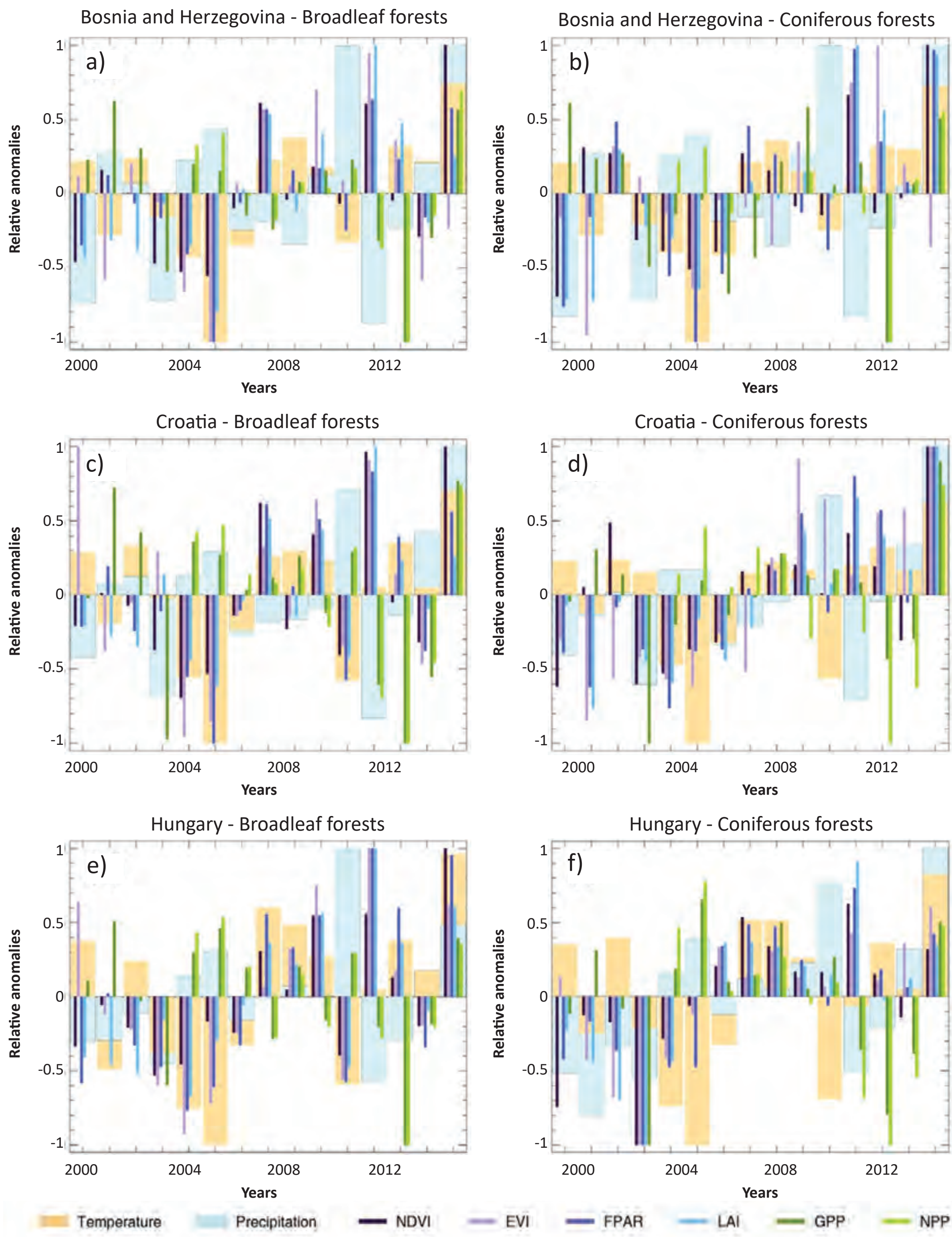

FIGURE 12. Yearly relative anomalies of the vegetation related characteristics (such as NDVI, EVI, FPAR, LAI, GPP and NPP) and of the meteorological variables (temperature and precipitation) during 2000-2014 for broadleaf and coniferous forests of Bosnia and Herzegovina, Croatia and Hungary

Croatia (see Table 3). We would also like to point out the differences among countries in the case of the croplands, and in particular to Slovenia. It can be seen that the high values for the anomalies in NDVI are occurring in Slovenia less frequently than e.g. in Slovakia or in Czech Republic. The reason behind this could be climate (relatively large amount of precipitation in Slovenia - see Figure 2) but also it could be due to the differences in crop type or cultivation method. Somewhat similar behaviour can be observed also for the coniferous forests in Hungary, where the observed magnitude of their positive anomaly is apparently lower than for coniferous forests in the other countries. However, here the caution is needed, because it could be an artefact due to the modest number of available pixels and this would require further investigation. In any case, these results corroborate the logic of country level analysis, where the considered area is large enough to reduce the effects of random noise (caused e.g. by species or management differences), but small enough to retain the information on the exiting differences among the countries. The relatively uniform distance between the values of the mean anomalies for the shown percentiles (Figure 13) indicates that the choice of the percentiles, representing the border between the classes of anomalies (see Section 2.4 in the Materials and Methods for the list) has been made properly.

In an effort to identify specific years that can be characterized as extremes according to a given RS characteristic, we performed a land cover and country specific analysis. The results for Bosnia and Herzegovina, Croatia and Hungary based on NDVI are given in Figures 14-16 and Table 5 while the results for other countries and other RS characteristics are available in the Supplementary

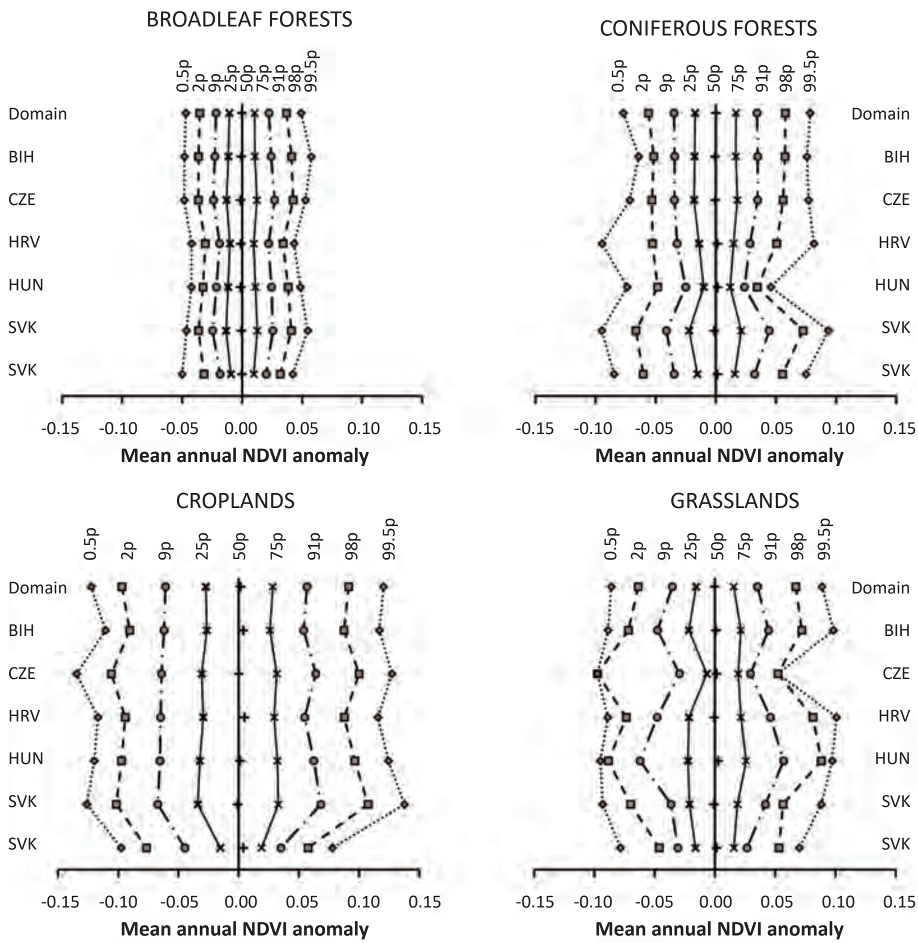

FIGURE 13. Categorization of mean annual NDVI anomalies according to the land cover for the selected countries and for the whole FORESEE domain (numbers at the top are percentiles (p; left of 0.5p - most extreme negative anomaly; 0.5p - 2p - extremely negative anomaly; 2p - 9p - very negative anomaly; 9p - 25p - negative anomaly; 25p - 75p - normal range; 50p - median; 75p - 91p positive anomaly; 91p - 98p very positive anomaly; 98p-99.5p extremely positive anomaly normal; right of 99.5p - most extreme positive anomaly); BIH - Bosnia and Herzegovina, CZE - Czech Republic; HRV- Croatia; HUN - Hungary; SVK - Slovakia; SVN - Slovenia).

TABLE 4. Correlation coefficients (r) between the yearly NDVI and meteorological (temperature and precipitation) anomalies for the main land cover type in the case of the different countries (note, for Czech Republic and Slovenia the number of the selected grassland pixels were less than 5 (Table 2))

Country	Broadleaf Forests		Coniferous Forests		Croplands		Grasslands	
	temp.	prec.	temp.	prec.	temp.	prec.	temp.	prec.
Bosnia and Herzegovina	**0.58***	0.18	**0.58***	0.24	-0.11	**0.83***	-0.02	**0.70***
Croatia	**0.63***	-0.10	**0.53***	0.00	-0.07	0.44	0.20	0.11
Czech Republic	**0.75***	-0.06	**0.60***	0.40	0.35	**0.79***	0.21	**0.76***
Hungary	**0.66***	-0.00	0.24	0.38	-0.03	**0.76***	0.00	**0.73***
Slovakia	**0.74***	-0.19	**0.54***	-0.26	0.19	**0.60***	0.52*	-0.43
Slovenia	**0.69***	-0.19	0.47	-0.30	0.03	**0.71***	0.35	0.44

* Statistically significant values (P < 0.05)

materials (Figures S7, S9, S11, S13 and Tables S2-S5). Distribution of shares of NDVI anomalies by categories according to the land cover and years (Figures 14-16) clearly shows the dominant effects of meteorological conditions. However, the responses of various land cover types differ significantly. What immediately strikes the attention is the fact that croplands and grasslands have almost unanimous agreement on which year was the worst (2003) and which one was the best (2014). However, year 2003 cannot be classified as extreme for croplands and grasslands in all countries, although they are relatively close geographically (e.g. compare Hungary and Croatia). When we focus on forests, the situation is rather clear regarding the best year (2014 was the best for all forest type and in all countries except for coniferous forest of Hungary and Slovenia). Here the case of Slovenia is somewhat easier to interpret. Namely, in January-February 2014 large part of Slovenia and part of Croatia was experiencing severe case of freezing rain that caused extensive damage to forests of the affected region [37, 38].

Regarding the negative extreme in the case of forests, the situation is more complex. Unlike for croplands and grasslands, year 2003 was not the worst in all cases except for broadleaf forests in Hungary and coniferous forests in Hungary and Croatia. Interestingly, year 2004 and 2005 are indicated as worst or second worst years for forests in different countries. This could imply that the negative effects of year 2003 (which was in fact an extremely warm and dry year all over Europe [39] on forest ecosystems were not immediately visible, but the consequences of the unfavourable weather was “remembered” by the ecosystem and manifested itself in the following years. This “dampening” effect of the negative anomalies in the case of forests is very important. It shows how difficult is to make straightforward conclusions based only on the current observation without taking into account the events of the past.

Table 6 shows the summary of country-specific extreme years for the different land cover types and different vegetation indices (based on the approach given in Table 1). Note that NPP is not used here due to problems with the temporal coverage of the dataset (see Section 2.3). The table shows that for herbaceous vegetation and for coniferous forests in Central Europe year 2003 is undoubtedly the most important year that affected vegetation status adversely. Besides year 2003, year 2000 is also notable. Meteorological conditions during those years need deeper evaluation. In contrast, for broadleaf forests year 2005 and 2012 might be notable, but as it was mentioned earlier, there is no clear evidence for unanimous selection of extremely unfavourable year in terms of overall forest development status. Considering above-average plant performance year 2014 is clearly noticeable for herbaceous vegetation and coniferous forests (to a lesser extent). For broadleaf forests the situation is similar to the bad year case, namely there is no unambiguous single good year. 2009, 2011 and 2014 might be studied in some countries to gain deeper understanding of the cause of the positive anomalies. The presented results corroborate that the different vegetation characteristics provide relatively consistent results in terms of anomalous plant behaviour.

CONCLUDING REMARKS

In this study we do not attempt to discriminate the different RS-based indices, which means that the indices are not ranked or qualified in any way. NDVI, EVI, LAI and FAPAR are all related to plant greenness and leaf development status, which is in turn related to photosynthetic capacity and plant productivity. GPP and NPP are based on a series of model assumptions and they provide measures that are directly related to productivity. Therefore, we assume that they all serve as proxies of plant processes, and as such we can expect from them to respond to the climate fluctuations. The selection of the relatively large number of indices was done due to their different complexity in their algorithm and assumptions which were used during their calculations.

For example, NDVI and EVI are indices obtained directly from reflectances provided by the polar orbiting MODIS instrument, which can already be related to the potential plant productivity. On the other hand, FPAR and LAI (which are also obtained from remotely sensed data) are also related to plant productivity and plant development status, but unlike the former two, FPAR and LAI are calculated taking into account the biome type derived from the land cover information [18]. Thus they embedded additional information but possibly additional errors as well (either random due to e.g. misclassification of the pixel, or bias due to the possible bias in biome

TABLE 5. Overview of the best and worst years and the degrees (percentage of the pixels) of the NDVI anomaly with respect to different land cover categories and countries

LC	Country	Worst year	2nd worst year	Best year	2nd best year
		(Share of pixels with **very negative** anomaly or worse)		(Share of pixels with **very positive** anomaly or better)	
Broadleaf forests	BIH	2005 (26.7%)	2004 (25.7%)	2014 (61.5%)+	2007 (28.0%)
	CZE	2010 (25.4%)	2004 (24.1%)	2014 (68.1%)+	2011 (26.8%)
	HRV	2004 (31.5%)	2005 (19.0%)	2014 (50.3%)+	2011 (44.4%)
	HUN	2003 (28.0%)	2004 (22.7%)	2014 (69.2%)+	2009 (24.6%)
	SVK	2010 (28.6%)	2000 (23.8%)	2014 (65.5%)+	2011 (15.4%)
	SVN	2004 (35.3%)	2013 (19.8%)	2014 (47.1%)	2011 (39.2%)
Coniferous forests	BIH	2000 (43.6%)	2005 (27.3%)	2014 (67.6%)+	2011 (32.6%)
	CZE	2006 (38.0%)	2004 (22.7%)	2014 (48.8%)	2011 (26.0%)
	HRV	2003 (26.8%)	2000 (24.7%)	2014 (42.8%)	2002 (17.1%)
	HUN	2003 (51.7%)$	2000 (25.9%)	2011 (32.8%)	2006 (19.0%)
	SVK	2006 (28.6%)	2000 (22.5%)	2014 (45.4%)	2011 (34.4%)
	SVN	2004 (35.4%)	2013 (27.8%)	2002 (38.7%)	2001 (24.8%)
Croplands	BIH	2003 (46.7%)	2000 (35.7%)	2014 (52.8%)+	2001 (36.2%)
	CZE	2003 (70.8%)$	2006 (12.9%)	2014 (40.9%)	2013 (23.3%)
	HRV	2003 (50.2%)$	2000 (37.1%)	2014 (31.7%)	2001 (23.6%)
	HUN	2003 (46.5%)	2000 (36.8%)	2014 (37.9%)	2004 (18.8%)
	SVK	2003 (47.5%)	2000 (31.8%)	2014 (46.2%)	2001 (17.0%)
	SVN	2003 (74.0%)$	2000 (34.8%)	2014 (38.4%)	2001 (15.4%)
Grasslands	BIH	2003 (56.0%)$	2000 (42.0%)	2014 (79.5%)+	2010 (25.0%)
	CZE	#	#	#	#
	HRV	2003 (51.3%)$	2000 (41.5%)	2014 (79.7%)+	2013 (19.8%)
	HUN	2000 (81.3%)$	2003 (56.3%)	2014 (68.8%)+	2010 (43.8%)
	SVK	#	#	#	#
	SVN	#	#	#	#

BIH - Bosnia and Herzegovina, CZE - Czech Republic; HRV- Croatia; HUN - Hungary; SVK - Slovakia; SVN - Slovenia; # - insufficient number of pixels; $ - extremely bad year; + - extremely good year

TABLE 6. Summary of country-specific extreme years for the different land cover types and different vegetation indices (based on the approach given in Table 1). Note that NPP is not used here due to problems with the temporal coverage of the dataset (see Section 2.3).

Land cover	NDVI	EVI	FPAR	LAI	GPP
	Extremely BAD years (very negative and extremely negative anomaly)				
Broadleaf	none	none	2005 (BIH, HRV)	none	2012 (SVN, SVK)
Coniferous	2003 (HUN)	2003 (HUN)	2003 (HUN)	none	2003 (HRV, HUN)
Cropland	2003 (CZE, HRV, SVN)	2003 (BIH, CZE, HRV, HUN, SVN)	2003 (CZE, HRV, HUN, SVN)	2003 (BIH, CZE, HRV, SVN)	2003 (HRV, HUN, SVN)
Grassland	2003 (BIH, HRV, HUN)	2000 (HUN), 2003 (BIH)	2000 (BIH, HUN)	2000 (BIH, HUN)	2003 (BIH, HRV, HUN)
	Extremely GOOD years (very positive and extremely positive anomaly)				
Broadleaf	2014 (BIH, CZE, HRV, HUN, SVK)	none	2011 (SVN)	2011 (BIH, HRV, SVN)	2009 (CZE) 2014 (BIH, HRV)
Coniferous	2014 (BIH)	2013 (CZE)	2014 (CZE)	none	2014 (BIH, HRV)
Cropland	2014 (BIH)	2014 (BIH)	2014 (BIH)	none	2001 (HRV), 2014 (BIH)
Grassland	2014 (BIH, HRV, HU)	2010 (HUN), 2014 (BIH, HRV, HUN)	2010 (HUN), 2014 (BIH, HRV, HUN)	2014 (BIH, HRV, HUN)	2014 (BIH, HRV, HUN)

BIH - Bosnia and Herzegovina, CZE - Czech Republic; HRV- Croatia; HUN - Hungary; SVK - Slovakia; SVN - Slovenia

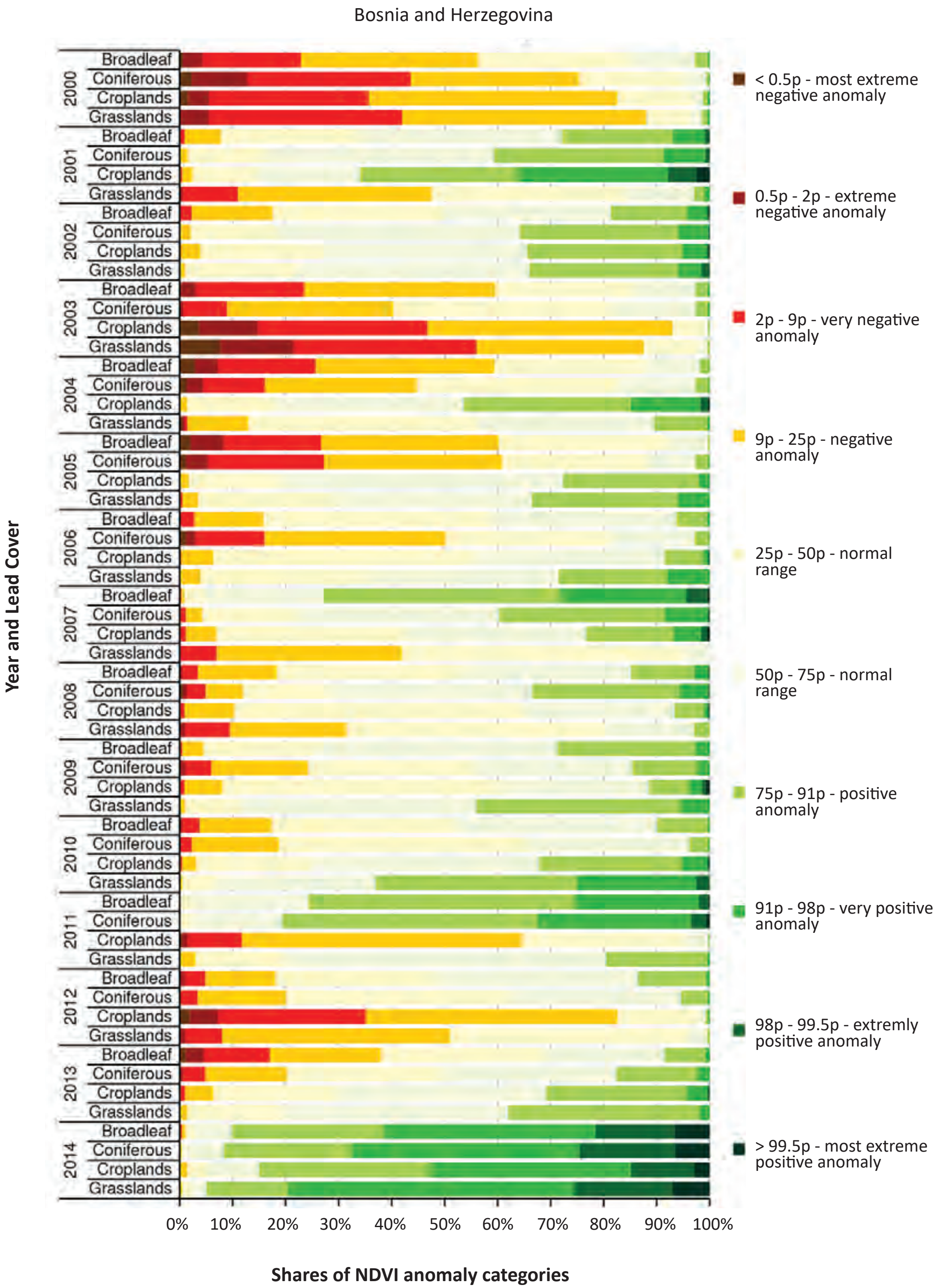

FIGURE 14. Distribution of shares of NDVI anomalies by categories according to the land cover and years for Bosnia and Herzegovina.

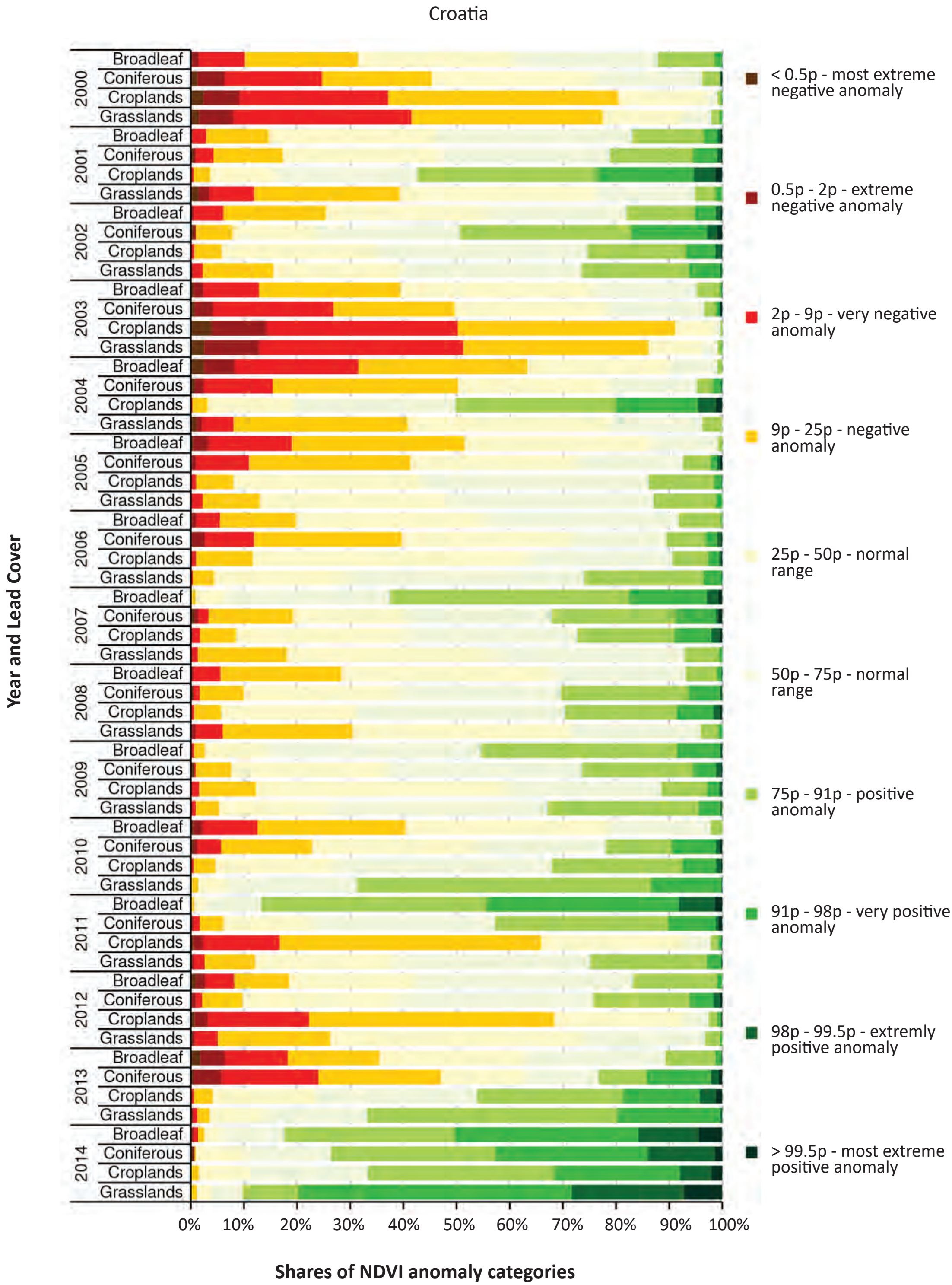

FIGURE 15. Distribution of shares of NDVI anomalies by categories according to the land cover and years for Croatia.

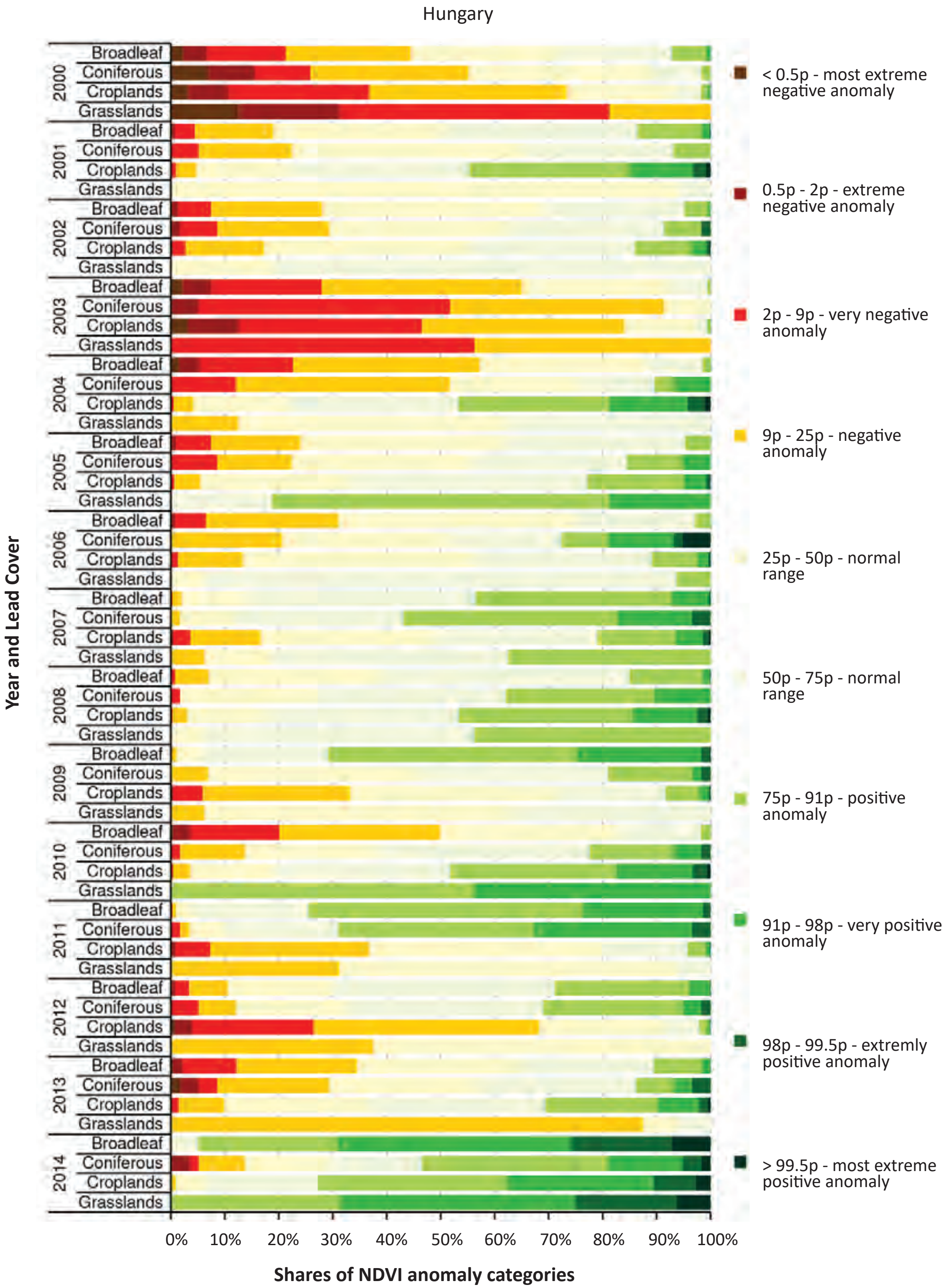

FIGURE 16. Distribution of shares of NDVI anomalies by categories according to the land cover and years for Hungary.

parameters used in FPAR and LAI calculation). Finally, MOD17 products, namely GPP and NPP, are likewise not independent from FPAR [19] but they also carry additional information (and probably additional errors) due to the meteorology information used for their calculation.

Considering the above, it is clear that all of the indices or metrics potentially have advantages and setbacks and it is difficult to select the best one. Therefore, in our work we decided to investigate all and treat them as an ensemble, similarly to the ensemble technique used in numerical weather prediction.

The selection of land cover specific anomalous years highlighted that plant response to unusual climate conditions strongly depend on the land cover type. Intra-species differences also exist but in this study this was not addressed. The advantage of the country-mean studies is the robustness which was demonstrated earlier in other studies [15, 22]. Using country means the spatial differences are most likely diminished to some extent, and in fact regions with considerably higher anomalous behaviour might exist within the countries that might require further studies.

We need to mention that in the present approach anomalies were defined for the entire growing season. It is clear that the growing season (from start of season to cessation) might be split into different time periods that needs further investigation. These anomalies associated with smaller temporal scale might provide additional information on the nature of anomalies and their meteorological driver.

The presented results might provide invaluable information for researchers associated with plant production (ecologists, agronomists, foresters, etc.). As ecosystem services are closely tied to plant productivity [8], stakeholders might also find the presented information useful. With the availability of additional years, the time series should be extended and thus the trend in the strength of the anomalies might be estimated.

The present study highlighted the difficulties related with the selection of appropriate time periods and climate indices to define extreme weather from the point of view of ecosystems. The effect-based approach relying on RS data resolves this difficulty as the observed anomalies act as integrators of the past environmental conditions thus they are good indicators of unusual conditions. Explicit selection of anomalous years indicated that the unusual plant state is not independent of the plant functional type. It is also clear that large differences exist between herbaceous and woody vegetation, where the latter is also associated with legacy effect from the previous year [40]. This legacy effect is one major issue which needs further research. In any case, legacy effect (which is well documented) alone questions the pure meteorological approach for the selection of anomalous years, as climate anomalies in the last year might exert stronger impact on the current plant growth than the present year. We propose to further refine the effect-based approach separately for the different land cover types to better understand the main drivers of plant growth in Central Europe and also worldwide.

Acknowledgements

We thank NASA, for producing and distributing the MOD13 NDVI data. Earth Observing System Data and Information System (EOSDIS) 2009, Earth Observing System ClearingHouse (ECHO) / Reverb Version 10.91.5 [online application], Greenbelt, MD: EOSDIS, Goddard Space Flight Center (GSFC) National Aeronautics and Space Administration (NASA), URL: https://wist.echo.nasa.gov/api/. CORINE Land Cover (CLC) 2012 Database is the property of European Commission - Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG-GROW) and European Environment Agency is data custodian. The CLC database has full, open and free access in line with the Copernicus delegated regulation (EU) No 1159/2013 of 12 July 2013, supplementing Regulation (EU) No 911/2010 of the European Parliament and licensing conditions for GMES users and defining criteria for restricting access to GMES dedicated data and GMES service information. The research has been supported by the Hungarian Scientific Research Fund (OTKA PD-111920 and K-104816), the Croatian Science Foundation (HRZZ UIP-11-2013-2492) and the Széchenyi 2020 programme, the European Regional Development Fund and the Hungarian Government (GINOP-2.3.2-15-2016-00028).

Supplementary materials

Supplementary material 1. (http://www.seefor.eu/supp_material/kern_et_al_1.pdf)

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Current Status and Perspectives of Forestry Entrepreneurship in Croatia

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ABSTRACT

Background and Purpose: The relevance and importance of forestry entrepreneurship is constantly increasing, especially in countries with high transition dynamics in forestry sector. In Croatia, forestry entrepreneurs have in short time become an indispensable part in the performing of harvesting and other types of forestry operations. This paper presents the current status and perspectives of forestry entrepreneurship in Croatia.

Materials and Methods: Based on the analysis of the available data from various sources (normative state acts, Forestry Chamber's official registries, databases and documents, state forestry company business reports etc.), this paper provides an overview of the legal and institutional framework for the activities of private entrepreneurs in Croatian forestry with particular attention to licensing forestry contractors and the role of the Croatian Chamber of Forest and Wood Technology Engineers (Forestry Chamber).

Results and Conclusions: The paper explains the activities, tasks, organization structure and formal bodies of the Forestry Chamber. The licensing model is also presented together with the formal criteria and minimum conditions which forestry entrepreneurs have to fulfill in order to acquire a license for forest work operations. Structural characteristics and the profile of forestry entrepreneurs is given by the number, size and type of business, the type of forest operations for which they are licensed, and the volume of work that they are performing for Croatian Forests Ltd, the state forest company. Finally, the paper includes some reflections on the perspectives and possibilities for improving the status of entrepreneurship in Croatian forestry.

Keywords: forestry entrepreneurship, contractors, licensing, forest work operations, Forestry Chamber, Croatia

INTRODUCTION

Due to the development of forestry technologies at the end of the 20th century and structural changes within the sector (market transition, private restitution, etc.) a significant decrease in the number of employees and work machinery occurred in state-owned forestry companies. This period had also been characterized by the development of new business segments, such as the appearance and development of private contractors in forest harvesting [1-8]. The same scenario happened in Croatia with private contractors in the field of forestry operations during the 1990s. Research conducted in that period showed that in the beginning the first forest entrepreneurs were not adequately organized or qualified [2, 9, 10]. Conclusions from these papers showed that the newly introduced market mechanisms alone had not contributed to the profiling and selection of the best and most fitting forestry entrepreneurs. It also pointed out the necessity for developing a licensing model which would filter the existing forestry contractors and ensure quality in performing forest work operations [11].

Today private entrepreneurs play an important role in global forestry and also in Croatian forestry [12-19]. In Croatia they perform a significant amount of forest operations and provide various services (felling, hauling and skidding, transport, etc.) for their employers, mainly for Croatian Forests Ltd, the state forest management company. They have all also undergone a licensing process established in the meanwhile. The process of licensing has been given, as a special authority, to the Croatian Chamber of Forestry and Wood Technology Engineers.

This paper presents the current status of forestry entrepreneurship in Croatia. It provides an overview of the legal and institutional framework for the activities of private entrepreneurs in Croatian forestry with particular attention to licensing and the role of the Croatian Chamber of Forest and Wood Technology Engineers (Forestry Chamber). The paper explains the activities, tasks, organization structure and formal bodies of the Forestry Chamber. The licensing model is also presented together with the formal criteria and minimum conditions which forestry entrepreneurs have to fulfill in order to acquire a license for forest work operations. Structural characteristics and the profile of forestry entrepreneurs is given by the number, size and type of businesses, the type of forest operations for which they are licensed, and the volume of work that they are performing for the state company Croatian Forests Ltd. Finally, the paper includes some reflections on the perspectives and possibilities for improving the status of entrepreneurship in Croatian forestry.

MATERIAL AND METHODS

All data presented in this paper have been gathered from the Forestry Chamber's databases and official documents, as well as normative state acts and Croatian Forests Ltd. business reports. Organization and tasks of the Forestry Chamber are given based on the adopted regulations [20, 21], while the licensing model and structure of entrepreneurships (the number, size and type of licensed businesses) are defined according to respective legal documents and Forestry Chamber's public registries [22-25]. The scale of contractors' engagement in the state forestry is established by analyzing yearly business reports of the state forest company [26]. This includes overview of the volume of harvesting work (felling, skidding, forwarding and log transportation) that contractors are performing for the Croatian Forests Ltd. Analysed data are expressed in relative and absolute terms in the presented tables and graphs.

Forest Resources in Croatia

Total area encompassed by the General Forest Management Plan of the Republic of Croatia [27] covers 2.69 million (mill) ha, or 47% of country's land surface. The majority of forests are owned by the state (78% or 2.11 mill ha), while only 22% (or 581,770 ha) is privately owned. Almost all of the state owned forests are managed by Croatian Forests Ltd., state forest management company (2.02 mill ha), while the rest (0.09 mill ha) is managed by other public institutions (Ministry of Defense, public institutions designated for the management of national parks and others).

Total growing stock of all forests is 398 mill m^3, where 302 mill m^3 is located in state forests managed by Croatian Forests Ltd., about 78 mill m^3 is located in private forests, and 17 mill m^3 in state forests managed by other public institutions.

Annual increment is 10.5 mill m^3 (Croatian Forests Ltd. - 8 mill m^3; private forests - 2.1 mill m^3; other state forests - 0.4 mill m^3). Annual felling amounts to 6.56 mill m^3, out of which 5.8 mill m^3 is located in state-owned forests managed by Croatian Forests Ltd., 0.7 mill m^3 is located in private forests, and 0.06 mill m^3 is located in other state-owned forests [27].

Basic principles of forest management in Croatia relate to balanced and multiple use of forests and to sustainability of their economical, ecological and social functions.

RESULTS

Croatian Chamber of Forest and Wood Technology Engineers

Croatian Chamber of Forest and Wood Technology Engineers, founded in 2006, is an autonomous and independent professional organization that performs the following tasks as entrusted public authorities:

- Keeps the registry of licensed engineers of Forestry and Wood Technology (Registry of authorised engineers);
- Issues, renews and revokes licenses (approvals) to legal and natural entities for conducting work operations in the field of forestry, hunting and wood technology;
- Determines the registration and membership fees for the Chamber;
- Determines professional obligations of the Chamber members and their performance in accordance with the code of professional ethics;
- Conducts professional exams for authorized engineers, according to a special regulation on the content and manner of taking professional exams passed by the Ministry in charge of forestry, hunting and wood technology;
- Performs other tasks that are by special laws established as a public authority of the Chamber.

Through its sections and committees (Figure 1), the Chamber also performs the following:

- Promotes the development of the profession and cares about professional training of members;
- Encourages the adoption of regulations that establish public authorities of the Chamber in accordance with the criteria of European and international practice;
- Represents the interests of its members;
- Provides expert opinions in the preparation of regulations in the field of forestry, hunting and wood technology;
- Organizes professional development of its members;
- Issues the Chamber's newsletter and other professional publications;
- Performs other duties in accordance with the law, the statute and other regulations of the Chamber.

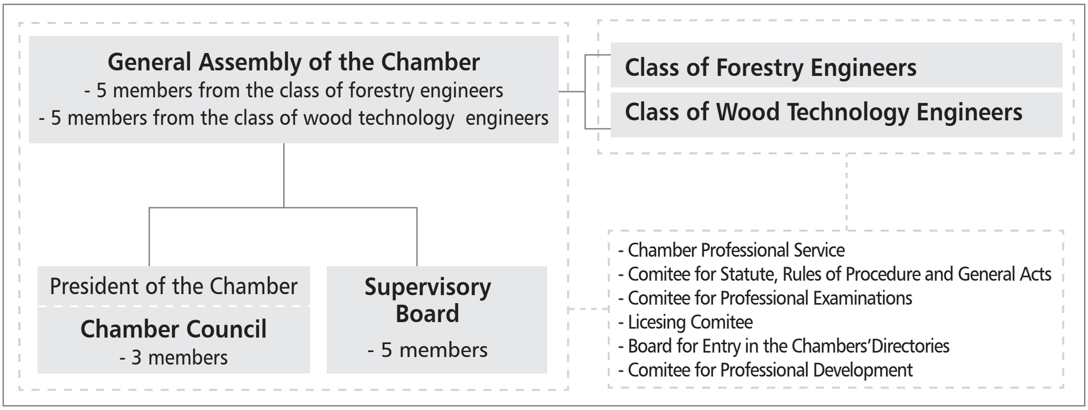

FIGURE 1. Organization of the Croatian Chamber of Forest and Wood Technology Engineers

The governing bodies of the Chamber are: General Assembly of the Chamber, Chamber Council, Supervisory Board and President of the Chamber (Figure 1). General Assembly is the highest governing body of the Chamber and it consists of elected representatives of two professional classes (the class of forestry engineers and the class of wood technology engineers). Chamber Council is the executive body of the Chamber and it consists of the Chamber President and presidents of two professional classes. Supervisory Board has a president and four members appointed and dismissed by the General Assembly. President of the Chamber is also the president of the Chamber Council and he or she is elected and dismissed by members of the General Assembly.

The Chamber today has 1198 active members. There are 1159 members from the class of forestry engineers and 39 members from the class of wood technology engineers.

Licensing Model for Forest Entrepreneurs in Croatia

The Law on Forests [28] prescribes that forest operations can be performed only by registered and licensed contractors, and professional activities by authorized engineers. Exceptionally, some less risky forest operations (work with simple manual tools related to habitat preparation, thinning, planting, reforestation) private forest owners can do on their own (or with the help from their household members and neighbors with no financial compensation).

The process of licensing forestry contractors is prescribed by the "Ordinance on issuing, renewal and revocation of the license for forestry, game management and wood processing operations". The Ordinance states expert and formal/general criteria which a forestry contractor has to present to the licensing committee: These include:

1. Evidence of legal personality, i.e. of its registration for performing forestry operations (excerpt from the court, professional or trade registry);
2. Evidence of the required number of employees (confirmation by the Croatian Pension Insurance Institute):
   a. Proof on the number of workers,
   b. Copy of the contract with authorised forestry engineer;
3. Evidence of procured machinery, equipment, measuring instruments and tools for performing certain type or stage of work for which a license is required (inventory list of fixed assets or a statement by the responsible person under the financial or penal responsibility, certified by a public notary);
4. Evidence of the professional qualifications of workers and certificates for:
   a. Operators of work machinery and tools,
   b. Forestry engineers authorised for the respective category of work (inclusion in the Registry of authorised engineers);
5. Evidence of certified functionality of machinery, equipment, measuring devices and tools needed for performing certain types and stages of forest work;
6. Documents from which annual costs and revenues of the entrepreneur for the previous year can be seen;
7. Other conditions prescribed by special legislative acts, depending on the type of license.

Types of forestry activities (in accordance with the "Ordinance on types of forestry operations, minimum conditions for their implementation and works that could be undertaken by forest owners independently" for which the entrepreneurs can request a license (single - for all work stages, or partial – for specific work stages) from the Chamber are presented in Table 1.

The Preparation stage includes:

- designing, planning and making surveys and studies,
- evaluation, analysis, assessment, observation and monitoring of the situation,
- selection of procedures, equipment, facilities, resources, materials, techniques and technologies of work,
- education and consultation.

The Performance stage includes direct execution of work.

The Supervision stage includes:

- control of quality and quantity of the conducted operations, procedures, equipment, facilities, resources, materials, applied techniques and technologies,
- control of quality and transport of forest products,
- making audits and reports
- issuance of certificates and other verifications of conformity with the prescribed standards and regulations.

TABLE 1. The categories and stages of forest work for which Chamber issues a license

	Category of forest work *	Preparation	Performance	Supervision
1.	Development of forest management plans, game management plans and programs for management of forest seed objects		✓	
2.	Silvicultural work, forest reproduction material	✓	✓	✓
3.	Protection of forests against harmful organisms, fires and natural disasters	✓	✓	✓
4.	Harvesting operations	✓	✓	✓
5.	Construction and maintenance of forest infrastructure	✓	✓	✓
6.	Urban forestry	✓	✓	✓
7.	Forest ecology and preservation of biodiversity		✓	
8.	Tree marking	✓	✓	✓
9.	Management of private forests		✓	

*For activities 1, 7 and 9 a single license is issued, and for other types of activities a partial license can be issued (for preparation, for performing and for supervising the activity)

Stated forestry activities (Table 1) may be performed only by contractors who meet the minimum requirements for carrying out forest work and who have passed the licensing procedure (applied for license with all necessary documents and received a positive evaluation of the Chamber's licensing committee). Minimum requirements for performing forest operations include meeting the prescribed conditions of professional and technical proficiency. Professional requirements are met if all employees of the contractor (the licensee) are employed on a full-time basis in their positions. Technical requirements are met if the contractor (license holder) has the machinery, equipment, devices and tools necessary for technologically appropriate execution of work. This includes safety and protection equipment for workers and all persons who are permanently or temporarily located at the site.

Minimum requirements are defined separately for every category (and stage) of forest work. Table 2 shows the minimum requirements for contractors engaged in harvesting operations as the most common license category.

Licenses for forest contractors are issued for a period of five years. Upon the end of license validity, contractor can make a request for license renewal. The request is, same as the first issuing of license, submitted to the Committee of the Chamber, together with the documented proofs about the fulfillment of respective conditions.

Forestry Entrepreneurs - Structure and Characteristics

The process of licensing of private entrepreneurs in Croatian forestry began in October 2007. Until today 940 licenses have been issued (the state on 25th April 2016). Among them 356 licenses (37.9%) are active and 584 (62.1%) have been revoked for different reasons (Table 3).

Out of 356 active licenses, i.e. companies that possess complete or partial license for at least one of the nine types of forestry operations, 220 of them (61.8% of all active companies) are registered as sole proprietorships. Around 112 active license holders (31.5%) are registered as limited companies (Ltd). Public institutions and other types of organizations (joint-stock company, limited partnership, family farm, cooperative) account for 24 (6.7%) active licenses (Figure 2).

Territorial distribution of the contractors, according to the company's headquarters, shows that the majority of

TABLE 2. Minimal requirements for contractors engaged in 'harvesting operations'

Harvesting operations	Requirements
Preparation	• 1 authorised forestry engineer (per every 10,000 m^3 of gross volume)
Performance	• For the production of up to 8000 m^3 of net volume per year – 1 forestry technician; • For the production level of 8000 to 30,000 m^3 of net volume per year – 1 authorized forestry engineer and 1 forestry technician; • For each production increase of 30,000 m^3 of net volume per year – number of employees increases for one authorized forestry engineer and one forestry technician; - Minimum of 2 workers per working group - Specific work machinery, tools and equipment - Attests for work machinery and tools - Evidence of the technical condition and working order of machines and tools - Evidence of professional qualifications for workers handling working tools (only for chain saw, power tools and machinery) - Evidence of workers' qualifications for safe forest work (only for work with chain saw, power tools and machinery) *Animal extraction does not require employment of authorised forestry engineer or forestry technician, regardless of the level of production.
Supervision	1 authorised forestry engineer (per every 20,000 m^3 of gross volume)

entrepreneurs are located in central Croatia, Gorski Kotar and Lika region, i.e. in the hilly-mountainous part of Croatia. A somewhat smaller number of contractors are situated in Slavonia and northern Croatia, while in Istria and Dalmatia there are just a few contracting businesses. Individually, the highest number of active entrepreneurs is in Primorje-Gorski Kotar County (12.9%), Lika-Senj County (12.4%) and Karlovac County (11%) (Figure 3). Different concentration of contractors in some areas is the result of the quantity and type of forest work for which employers (mainly Croatian Forests Ltd.) hire them. Complexity of working conditions and the tradition of engagement in forestry are also important influence factors [10]. It should be noted that two license holders are from Slovenia and two from Austria.

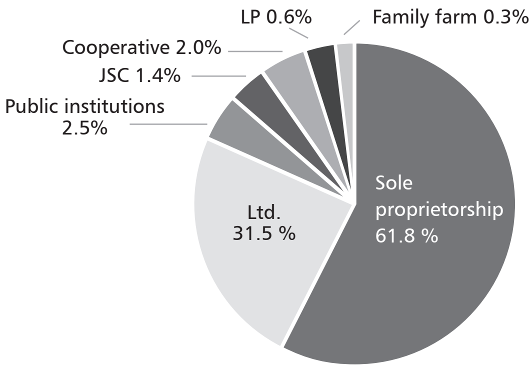

FIGURE 2. Types of businesses licensed for conducting forest operations (the state on 25th April 2016)

Considering the number of entrepreneurs licensed for certain forestry activities, the largest share is made up of contractors with license (complete or partial) for harvesting operations (84.6% of all active companies) (Figure 4). Considerable proportion of companies are also licensed for activities related to silviculture, forest seed and seedlings (53.4% of active companies), where majority of licenses refers to silvicultural operations (171 licenses) and very rarely to operations concerning forest seeds and seedlings. Entrepreneurs licensed for other forest activities are also scarce with a slightly higher number of licenses recorded for construction and maintenance of forest infrastructure (18.3%) and tree marking (13.2%) (Figure 4).

The number and type of services that forestry contractors provide is usually limited to one type of forestry activity. Only three organizations (0.8%) possess licenses in all 9 categories of forest work, according to the "Ordinance on types of forestry operations, minimum conditions for their implementation and works that could be undertaken by forest owners independently" [22]. Three companies possess licenses for 8 different types of forest work, and two companies have licenses for 7 different forestry activities. The majority of entrepreneurs possesses a license only in one category of forest work (161 companies, i.e. 45.2%), or perhaps in two different categories (124 companies, i.e. 34.8%). The most frequent combinations of licenses, i.e. the number and type of forestry activities for whose implementation entrepreneurs have been licensed, are shown in Table 4.

Considering that harvesting operations represent the most common license category, the structure of contractors

FIGURE 3. The distribution of forestry entrepreneurs by counties

TABLE 3. Revoked licenses for conducting forest operations

Reason for revoking the license	N	%
Renewal, change or extension of license	216	37.0
Not complying with the requirements prescribed by the Ordinance on issuance of licenses	208	35.6
Expired license	89	15.2
Termination of business, request for license withdrawal or canceling license application	59	10.1
Other reasons	12	2.1

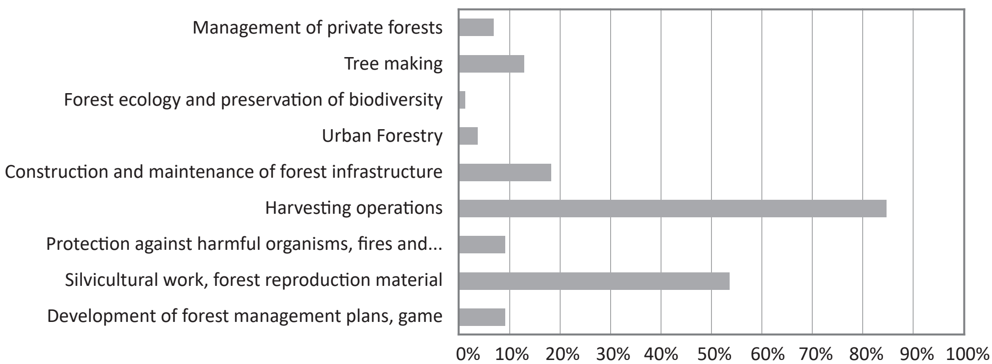

FIGURE 4. The share and number of active license holders by the type of forest activities (the state on 25th April 2016)

engaged in harvesting activities has been analyzed in more detail (Table 5). Complete license (for Preparation, Performance and Supervision stage) is owned by 11 companies. All other companies possess partial licenses, mostly for the Performance stage of harvesting operations (284 licenses altogether). Partial license for Preparation and Supervision stages (without Performance stage) is owned by 16 companies, and only one company possesses a license solely for Supervision stage.

The highest proportion of contractors, in all three stages, meets only the minimum requirements prescribed by the "Ordinance on types of forestry operations, minimum conditions for their implementation and works that could be undertaken by forest owners independently". Accordingly they possess licenses for the lowest volume of harvesting activities. These are:

- 17 companies (63.0%) in Preparation stage licensed for up to 10,000 m^3 of gross volume,
- 222 companies (78.2%) in Performance stage licensed for up to 8000 m^3 of net volume per year,
- 18 companies (64.3%) in Supervision stage licensed for up to 20,000 m^3 of gross volume.

Even though forestry contractors in Croatia predominantly represent small, modestly equipped businesses, which is evident from the number of licenses for the lowest volume harvesting activities, during the past few years they have conducted a significant share of harvesting operations in state forestry (Figure 5-7).

On average, each year forestry contractors perform around 26% of all felling activities in state forests. Their

TABLE 4. The number and type of services (activities) for which forestry contractors simultaneously possess a license (state on 25th April 2016)

Forest work	Number of companies	
	N	%
2) Silvicultural work, forest reproduction material, and 4) Harvesting operations	115	32.3
4) Harvesting operations	113	31.7
5) Construction and maintenance of forest infrastructure	27	7.6
1) Development of forest management and hunting plans	16	4.5
2) Silvicultural work, forest reproduction material, 4) Harvesting operations, and 5) Construction and maintenance of forest infrastructure	14	3.9
2) Silvicultural work, forest reproduction material, 4) Harvesting operations, and 8) Tree marking	9	2.5
1) Development of forest management and hunting plans, 2) Silvicultural work, forest reproduction material, 3) Protection of forests, 4) Harvesting operations, 8) Tree marking, and 9) Management of private forests	6	1.7
Other 27 different combinations	56	15.7

TABLE 5. The structure of forestry entrepreneurs licensed for harvesting operations (the state on 25th April 2016)

Stage	Volume of work		Number of companies	
			N	%
Preparation	Up to 10,000 m^3 of gross volume	17	27	7.96
	Up to 20,000 m^3 of gross volume	5		
	Up to 50,000 m^3 of gross volume	1		
	Without limitations	4		
Performance	Up to 8000 m^3 of net volume per year	222	284	83.82
	Up to 30,000 m^3 of net volume per year	17		
	Up to 60,000 m^3 of net volume per year	1		
	Up to 120,000 m^3 of net volume per year	2		
	Up to 180,000 m^3 of net volume per year	1		
	Without limitations	41		
Supervision	Up to 20,000 m^3 of gross volume	18	28	8.26
	Up to 40,000 m^3 of gross volume	5		
	Up to 100,000 m^3 of gross volume	1		
	Without limitations	4		
	Licenses altogether		339	100.00

share in skidding and forwarding has been notable for longer time now, and in the last five years it amounted to 40.6%. In log transportation 81.9% of removal is done by forestry contractors [26]. In private forests the activity of contractors is not documented, so there is no exact data about their operations there.

DISCUSSION AND CONCLUSSIONS

Private entrepreneurs in forestry today play an important role in all forms of forest ownership and management regimes, both on the European and global scale. In Croatia, they have in short time become an indispensable part in performing harvesting and other types of forestry operations. The biggest user of their services is Croatian Forests Ltd, the state forest management company, for which forestry contractors every year on average conduct 26% of felling, 41% of skidding and 82% of log transportation. The volume of work that they perform in private forests is significantly smaller, due to poor management of private forests and the possibility for forest owners to perform part of the work (less risky forestry operations) on their own.

Forestry entrepreneurs have undergone a licensing process established in 2007 with the foundation of the Croatian Chamber of Forest and Wood Technology Engineers and the adoption of necessary regulations ("Ordinance on types of forestry operations, minimum conditions for their implementation and works that could be undertaken by forest owners independently"; "Ordinance on issuing, renewal and revocation of the license for forestry, game management and wood processing operations") [22, 23]. The process of licensing forestry entrepreneurs is an important element of entrepreneurial frame in every activity, and in the field

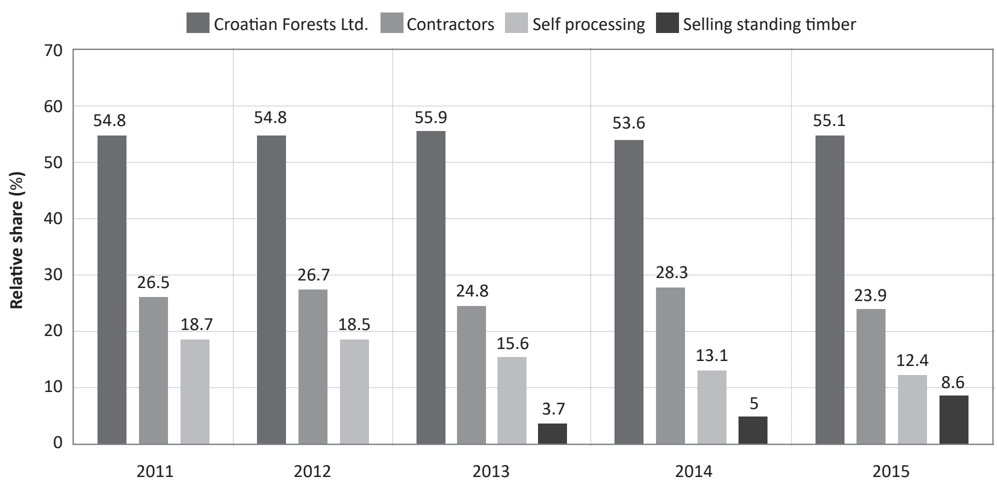

FIGURE 5. The share of contractors in felling activities by years

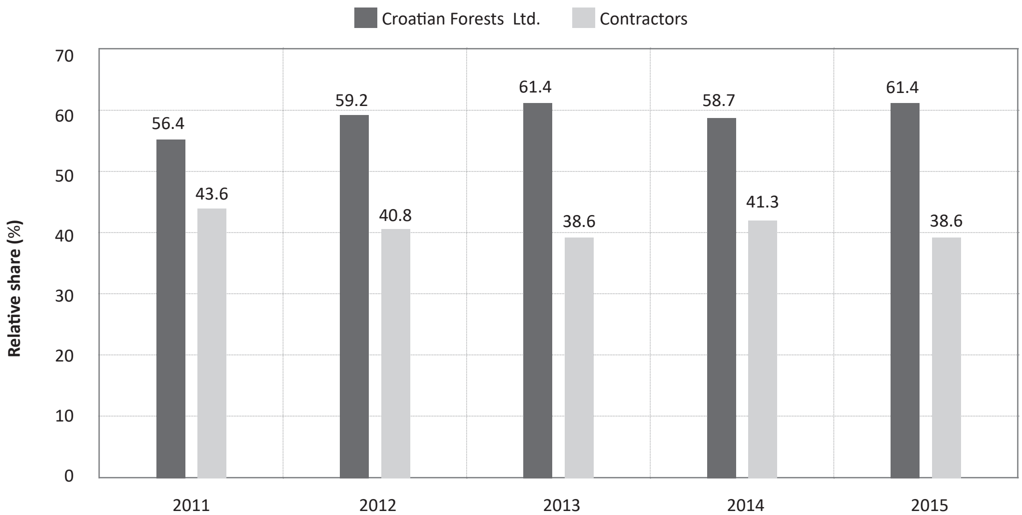

FIGURE 6. The share of contractors in skidding and forwarding activities by years

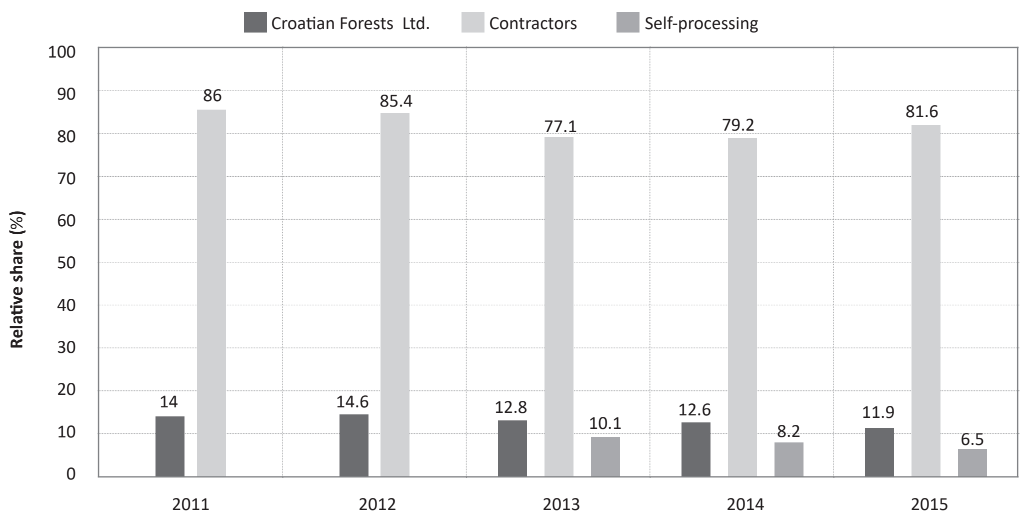

FIGURE 7. The share of contractors in log transportation by years

of forestry it also represents an unconditional contingency of sustainable forest management. The licensing process puts an emphasis on the inclusion of private entrepreneurs in the sustainable forest management through a process of certification of their quantitative and qualitative characteristics.

The foundation of the Chamber as an institution with public authority and implementation of the licensing process have certainly improved the status of forestry entrepreneurship in Croatia, but in the meanwhile, new challenges and problems have arisen. Some of the open issues related to the Chamber, licensing, authorized engineers and the like are the following:

- the issue of the operational supervision and control of the contractors' performance and quality of work - the Chamber doesn't have developed instruments for it,
- the set limit for employing authorized forestry engineers in Performance stage of harvesting operations (30,000 m^3 of net volume per year) receives many critics from contractors which suggests a need for reevaluation,
- the problem of issuing certificates (official signet) to authorized forestry engineers on their own behalf, or as so far, on the behalf of the company that employs them,
- the Chamber is given the task of issuing tree marking hammer to contractors (with adequate license) – acquired authority which needs to be regulated in respective acts of the Chamber,
- equal representation of two professional classes (forestry engineers and wood technology engineers) in governing bodies of the Chamber (General Assembly), i.e. in decision making, despite the different number of members,
- the issue of certifying forestry engineers for operations concerning urban forestry, landscaping and horticultural

activities, and the relation with the Croatian Chamber of Architects which authorises ‘landscape architects’.

All these, and some other issues require adequate attention and solutions that will further enhance the situation of forestry entrepreneurship in Croatia. One of the important influencing factors is certainly the common European labor market and free flow of labor force, as a promising opportunity for expanding entrepreneurs’ activities. In addition, based on the findings on the current state and development of entrepreneurship, the perspectives of Croatian forestry entrepreneurs also depend upon:

- Restructuring of the state forest management company, with which many diversified entrepreneurial opportunities should be created;
- Continual development and strengthening of the system and the criteria for licensing forestry entrepreneurs;
- Intensity and strictness of the implementation of measures related to education, training, occupational health and safety of forestry workers employed in private forestry sector;
- Development of entrepreneurial spirit in existing and future forestry businesses, through education and information dissemination, i.e. the promotion of models for transfer of (tacit) knowledge;
- State financial policy related to the promotion of national entrepreneurial activities through subventions, tax deductions, credit arrangements and other incentives, all with the goal of raising the level of technical, technological, professional, personnel and other competencies of forestry entrepreneurs.

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Forest Soil Pollution with Heavy Metals (Pb, Zn, Cd, and Cu) in the Area of the "French Mines" on the Medvednica Mountain, Republic of Croatia

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ABSTRACT

Background and Purpose: This paper deals with the results of the investigation of the selected heavy metal contents in forest soil in the region of an abandoned mine. The analysis of the forest ecosystem soil on the Medvednica Mountain was conducted in the region of the so-called "French Mines" (FM). The elements selected for analyses were cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn) because of their toxicological characteristics.
Material and Methods: In the investigated area - five entrances of the FM - composite topsoil samples (0–5 cm) were taken. Those samples were compared to the control samples which were taken outside the area affected by mines. The soil samples were analysed for the following parameters: pH, particle size distribution, organic C content and pseudo-total mass fractions of the selected heavy metals. The heavy metals were determined by atomic emission spectrometry with inductively coupled plasma (ICP-MS).
Results and Conclusion: The results reveal that the soil is locally polluted, i.e. the highest mass fraction values of these four heavy metals were found in the area of the FM. Average pseudo-total fraction of Cd in the analysed topsoil samples was in the range of 0.17–4.41 $mg \cdot kg^{-1}$ (median: 0.97 $mg \cdot kg^{-1}$). Cu was found in the range of 4.54–1260 $mg \cdot kg^{-1}$ (median: 45.7 $mg \cdot kg^{-1}$). In the case of Zn, mass fraction values were found in the range of 36.8–865 $mg \cdot kg^{-1}$ (median: 137 $mg \cdot kg^{-1}$). Finally, average values of the pseudo-total fraction of Pb were found in the range of 58.4–12000 $mg \cdot kg^{-1}$ (median: 238 $mg \cdot kg^{-1}$). The results reveal that mining activities leave consequences on soil for a long time.

Keywords: heavy metals, soil pollution, forest soil, mining sites, Medvednica Mt.

INTRODUCTION

There are many various environmentally hazardous substances, but researchers around the world are especially interested in heavy metals. Heavy metals are naturally occurring elements that have a high atomic weight and a density at least 5 times greater than that of water [1]. From a biological point of view, Nieboer and Richardson [2] have classified heavy metals into three groups: (i) elements essential to some organisms (V, Cr, Mn, Fe, Co, Zn, and Mo), (ii) elements necessary for growth and development of plants (Mn, Fe, Cu, Zn, Mo, and Ni), and (iii) phytotoxic elements (Cd, Hg, and Pb). World Health Organization (WHO) has classified As, Cd, Hg, and Pb among 10 groups of hazardous chemicals. Those are elements which have toxicological characteristics. Moreover, when their concentrations increase, Mn, Co, Ni, Cu, Zn, Se, Ag, Sb, and especially Cr and Ti are also considered toxic [3].

Since the pollution of soil by heavy metals is one of the possible causes of a decrease in forest ecosystem vitality and degradation of the whole habitat, there is a significant scientific interest in research of the connection of heavy metal concentration values in the environment to their degradation effect [4]. In higher concentrations heavy metals show negative influence on the environment, especially in the context of their inclusion into the biological cycle of matter [5]. Plants uptake heavy metals from soil, often as micronutrients, thus introducing them to the food chain. This way heavy metals become ready for re-distribution and dissemination in the environment [6, 7].

Several authors have already been doing research on heavy metals in the soils in the Republic of Croatia [8-15]. Generally, mass fraction values of Fe, Mn, Zn, Cu, Cr, Ni, Pb, and Cd have been determined in the surface horizon (0–5 and 5–15 cm).

The influence of mining activities on soil pollution by heavy metals is presented in a certain number of papers [16-20]. In the area of the Zrinski Mines, situated near the FM on the Medvednica Mt., there is pollution by heavy metals, primary by Hg, but also Cd and Pb [21-23]. The presence of the lead-zinc ore in Bistranska gora has been investigated in the late 18th century and in the early 19th century. During that time Count Henri Carion started to exploit this ore in pursuit of galena, with the intention of obtaining silver. However, the quantity of the found ore was too low to continue the exploitation and the mines were abandoned [24].

The hypothesis for this research was possible pollution of forest soil by heavy metals as a consequence of mining activities which were finished around 200 years ago. Therefore, the main goal of this work is to determine the extent of contamination in the forest ecosystem on the Medvednica Mt. in the area of FM. These results will give an insight into the potential ecological hazards of mining activities.

MATERIAL AND METHODS

The research area is situated on the northern slopes of Medvednica Mt., nearly below the ski lift station in the area of FM (Figure 1). Lithological surface in the area of FM is made of parametamorphites, which originate from sedimentary rocks and were unevenly affected by regional metamorphosis. Among rocks one can distinguish quartz conglomerates and breccia conglomerates, metagraywacke, metasiltstones, recrystallized limestones and dolomites, slates, phyllites, different low-grade metamorphic schists, quartzites and marbles [25]. According to Vrbek [26], dystric cambisol are the dominant soils in the research area. The vegetation of the investigated area belongs by association to the Pannonian beech-fir forests with fescue (*Festuco drymeiae-Abietetum)* [27]. Climate of the area of the community is characterized by average annual temperatures between 6–8˚C and precipitation of 900–1200 mm [28]. Elevation of the area of FM is between 610–720 m. The orientation of the slope position is North-West, with a slope gradient between 12–35˚.

Soil sampling on the mine area were done in two occasions. On the FM sites 1–3 the regular sampling procedure (systematic statistical sample) was applied; on the regular square net 30×30 m 41 samples were taken. On the FM sites 4–5, six samples were taken by randomized sampling. Four control samples (C 1–4) out of the influence area of FM were taken with the purpose of comparison to the FM samples (Figure 1). The control samples have similar characteristics in comparison to the FM samples (similar lithological units and vegetation). The control samples were taken from grid 1×1 km within the project "Trace elements in the soil of the forest ecosystem of Medvednica Mountain". Composite samples (9 sub-samples spaced 1 m apart, and cross-scheduled) were taken from the depth of 0–5 cm by a plastic probe with an inner diameter of 80 mm. For laboratory analyses the samples were dried by air at room temperature, crushed and sieved through sieves of 2 and 0.2 mm holes [29]. The soil samples were analysed for the following parameters: pH [30], particle size distribution [31], soil organic carbon [32], and pseudo-

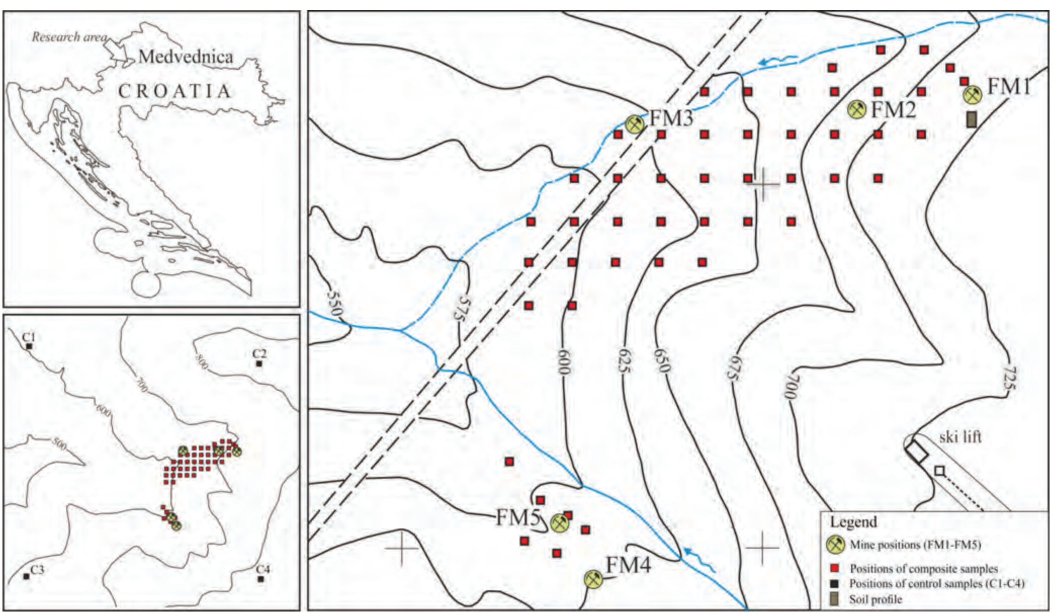

FIGURE 1. Geographical location of the research area with the position of composite samples and soil profile.

total mass fractions of the selected heavy metals (Cd, Cu, Pb, and Zn). The last one was determined by ICP-AES technique in aqua regia digestates of the samples; microwave enhanced digestion procedure of the soil samples was performed [33]. The main parameters of the analysis of the soil digestates by ICP-AES are given in Table 1. The samples were analysed in the laboratory of the Faculty of Forestry of the University of Zagreb.

For all analysed variables the procedures of descriptive statistics (minimum, lower quartile, median, upper quartile, maximum, mean, standard deviation, coefficient of variance, standard error, and asymmetry) were applied. In order to exclude the influence of outliers and extreme values, the median was applied as an average value. The differences between values of the analysed variables using Kruskal-Wallis non-parametric test were tested. I (α) error type of the value of 5% is considered to be statistically significant [34]. The obtained variables for the pedophysiographic characteristics of soil, as well for concentrations of th heavy metals for FM 1–3 (grid 30×30) and FM 4–5 (taken randomly) were compared to the variables determined for the control samples.

The level of contamination for the topsoil was ranked by Brüne-Ellighaus criteria [35] and Croatian Directive on the protection of agricultural land from pollution (hereinafter referred to as Directive) [36]. According to Brüne-Ellighaus criteria [35] the limit values for Cd are 2 mg·kg^{-1}, Cu 100 mg·kg^{-1}, Pb 150 mg·kg^{-1} and Zn 300 mg·kg^{-1}. Since the soil texture class of the FM area is dominantly silt loam, according to Directive [36] maximum allowed concentrations of heavy metals are Cd 1 mg·kg^{-1}, Cu 90 mg·kg^{-1}, Pb 100 mg·kg^{-1} and Zn 150 mg·kg^{-1} (Table 2).

Distribution of the selected heavy metals through the investigated area is shown on prediction maps, which were created by an interpolation technique Inverse Distance Weighting (IDW) in the ArcMap programme. Geochemical maps of each element in the ArcGIS extension of Geostatistical Analyst were generated. In order to make a correct presentation of the element concentration values on

TABLE 1. The main ICP-AES measurement parameters

Parameters	ICP-AES operating conditions
Instrument	Thermo Fischer iCAP6300 Duo
RF power	1150 W
Auxiliary Ar flow	0.5 L·min^{-1}
Sample Ar flow	0.65 L·min^{-1}
Coolant Ar flow	12 L·min^{-1}
Sample introduction system	– auto-sampler CETAC ASX-260 connected by peristaltic pumps – concentric nebulizer with cyclonic spray-chamber
Peristaltic pumps rate	45 rpm
Peristaltic pumps tubes	– sample: orange/white – rinsing: white/white
Flush (take-up) time	45 s
Washing time between samples	60 s
Plasma view	Auto view
Maximum measuring time	– low wavelengths (160-230 nm): 15 s – high wavelengths (230-847): 5 s
Lines measured (nm)	Cd-228.802; Cu-324.754; Pb-220.353; Zn-202.548
Multi-elemental calibration solutions	– 0, 1, 10, and 100 μg/L (in HNO_3,ψ = 1%)
System rinsing solution	Nitric acid, HNO_3, *supra pur*, ψ = 1%

TABLE 2. Criteria for determining pollution degrees according to the Brüne-Ellinghaus scale [35] and the Directive on the protection of agricultural land from pollution [36].

Brüne-Ellinghaus, 1981		Directives on the protection of agricultural land from pollution, 2014	
Pollution degree	% Lv	Pollution degree	PD (%) = HMC/MAC*100
very low	1–5	clean	<25
low	5–10	increased	25–50
medium	10–25	high contamination	50–100
high	25–50	contaminated	100–200
very high	50–100	polluted	>200
above Limit value	>100		

% Lv - limit value; PD - pollution degree; HMC - heavy metal content; MAC - maximum allowed content the sampling sites, the deterministic space interpolation technique Inverse Distance Weighting (IDW) was applied. In the calculation there were minimum 3 to maximum 6 neighbouring points. The calculation range was a circle of a radius of 30 m. Spatial distribution of every particular class in the map was represented as a polygon in a corresponding colour, with blue nuances for low neighbouring to red for high neighbouring [37].

RESULTS

Average values of the analysed variables for topsoil samples (0–5 cm) in the FM area (FM 1–3 and FM 4–5) and control plots (C) are shown in Table 3.

Topsoil reaction in the FM area ranges from 4.89 to 8.09. According to Scheffer and Schachtschabel [38], pH-value in topsoil is in the range from moderately acidic to weakly basic. The pH-values determined in the samples taken in the FM area are statistically higher than the values determined in the samples collected on the control surfaces. The highest median pH-value has been found on FM 1–3 (pH_{H2O}=6.59; pH_{CaCl2}=6.09) and it has statistically higher value in comparison to the control plots (pH_{H2O}=4.91; pH_{CaCl2}=4.41). FM 4–5 have similar pH-values as FM 1–3 (pH_{H2O}=6.40; pH_{CaCl2}=5.89) and they are statistically different to those found for the control samples (pH_{H2O} (H (2, N=51)=10.827; p=0.045); pH_{CaCl2} (H (2, N=51)=9.860; p=0.0072) (Table 3).

Median values found for Cd were 0.70 mg·kg^{-1} (FM 4–5) and 0.97 mg·kg^{-1} (FM 1–3) in the area of FM and these values are higher than those found on the control plots (0.44 mg·kg^{-1}), but the difference is not statistically significant (Figure 2 left, Table 3).

Mass fraction values determined for Pb in topsoil are statistically and significantly different between the samples taken in the FM area and control plots H (2, N=51)=8.411; p=0.0149). The highest median mass fraction value of Pb is found for the sites FM 4–5 (273 mg·kg^{-1}), while on the sites FM 1–3 the median values of Pb are somewhat lower (238 mg·kg^{-1}). The lowest median value was found on the control plots (73.7 mg·kg^{-1}) (Figure 2 right, Table 3).

The determined mass fractions of Cu show similar relations as the ones determined for Pb, but no statistically significant difference between the median value determined in the samples taken on the FM area and control plots was found. The highest median mass fraction value in FM 4–5 (50.5 mg·kg^{-1}), and the lowest ones (26.7 mg·kg^{-1}) on the control plots were found. On the sites FM 1–3, the found median mass fraction value was 45.7 mg·kg^{-1} (Figure 3 left, Table 3).

TABLE 3. Descriptive statistics for the analysed variables pH_{H2O}, pH_{CaCl2}, organic C content, Cd, Cu, Pb, and Zn in the areas of "French Mines" (FM 1–3 and FM 4–5) and control plots (C).

Variable		Unit	N	Minimum	Lower quartile	Median	Upper-quartile	Maximum	Mean	Std. dev.	Coef. var.	Std. error of mean	Skewness	p-values
pH_{H2O}	FM 1-3		41	4.89	6.06	6.59	7.61	8.09	6.74	0.93	13.8	0.14	-0.31	
	FM 4-5		6	5.86	5.90	6.40	6.90	6.94	6.40	0.49	7.62	0.20	0.00	0.0045
	C		4	4.82	4.84	4.91	5.06	5.17	4.95	0.16	3.16	0.08	1.35	
pH_{CaCl2}	FM 1-3		41	4.17	5.38	6.09	7.19	7.41	6.19	0.98	15.9	0.15	-0.39	
	FM 4-5		6	5.27	5.29	5.89	6.49	6.63	5.91	0.60	10.2	0.25	0.08	0.0072
	C		4	4.20	4.28	4.41	4.55	4.64	4.41	0.19	4.20	0.09	0.21	
Org C	FM 1-3		41	36.24	61.82	92.59	112.65	158.47	89.12	29.57	33.18	4.62	0.05	
	FM 4-5	g·kg^{-1}	6	91.18	107.65	115.78	257.41	309.57	166.23	92.80	55.83	37.89	1.06	0.0512
	C		4	65.60	69.20	86.70	102.17	103.74	85.69	19.30	22.53	9.65	-0.10	
Cd	FM 1-3		41	0.17	0.58	0.97	1.55	2.75	1.09	0.70	64.2	0.11	0.75	
	FM 4-5	mg·kg^{-1}	6	0.17	0.17	0.70	2.40	4.41	1.42	1.68	118	0.69	1.43	0.4117
	C		4	0.23	0.27	0.44	0.86	1.15	0.57	0.42	73.7	0.21	1.35	
Pb	FM 1-3		41	58.4	112	238	456	1559	411	444	108	69.4	1.48	
	FM 4-5	mg·kg^{-1}	6	111	184	273	1594	12000	2405	4732	197	1932	2.38	0.0149
	C		4	55.3	64.1	73.7	74.8	75.1	69.5	9.51	13.7	4.75	-1.95	
Cu	FM 1-3		41	4.54	25.1	45.7	64.9	1260	113	216	191	33.7	4.21	
	FM 4-5	mg·kg^{-1}	6	26.8	37.7	50.5	130	798	182	304	167	124	2.37	0.2376
	C		4	16.1	16.6	26.7	36.8	37.2	26.7	11.6	43.6	5.81	0.00	
Zn	FM 1-3		41	36.8	108	137	232	865	200	182	91.2	28.5	2.19	
	FM 4-5	mg·kg^{-1}	6	135.3	140	172	207	473	216	128	59.4	52.4	2.23	0.0983
	C		4	46.3	57.8	91.8	125	136	91.5	41.1	44.9	20.5	-0.02	

Similar patterns for Zn have been found too. Zinc mass fraction values which were determined in the topsoil samples taken in the FM area are not statistically and significantly different to those found on the control plots. On the sites FM 4–5, median mass fraction value is the highest one: 172 mg·kg^{-1}. Somewhat lower value was found on the sites FM 1–3: 137 mg·kg^{-1}, but the difference was not statistically significant. The lowest median mass fraction value was found on the control plots: 91.8 mg·kg^{-1} (Figure 3 right, Table 3).

The median values of the soil organic carbon content ranges from 86.7 g·kg^{-1} on the control plots to 115.78 on the FM 4–5 (Table 3). According to Gračanin and Ilijanić [39], soils on the FM area are very humic and thus influence the binding of Cu [36].

Twenty samples taken from the area FM 1–3 were selected for the particle size distribution analysis with the purpose of the interpretation of 'geochemical analyses' results in the context of Croatian Directive on the protection of agricultural land from pollution [36]. According to the particle size distribution analysis [31], soil texture class ranges from silt loam to silt clay loam [40] (Table 4).

Spatial distribution of the analysed heavy metals (Cd, Cu, Zn, and Pb) for FM (FM 1–3) is shown on the prediction maps. Red nuances indicate the highest concentration of heavy metals, and blue nuances stand for the lowest concentration [37] (Figure 4, 5, 6 and 7).

In the very vicinity of the mine the pedological profile has been opened (Figure 1 and 8). The profile reveals that there is a dystric cambisol (relatively shallow, skeletoidal) on the moderate slope; according to the previous data [26] it is the most present soil type on Medvednica Mt. The soil profile is of A-B-R type. The thickness of the A-horizon ranges from 0 to 17 cm, while for B-horizon it ranges from 17 to 43 cm. In the context of particle size distribution the investigated soil is clay loam. According to Scheffer and Schachtschabel [38], the reaction of soil is very acidic. Using the criteria of Gračanin and Ilijanić [39], this soil is very humic and richly supplied with nitrogen (Table 5).

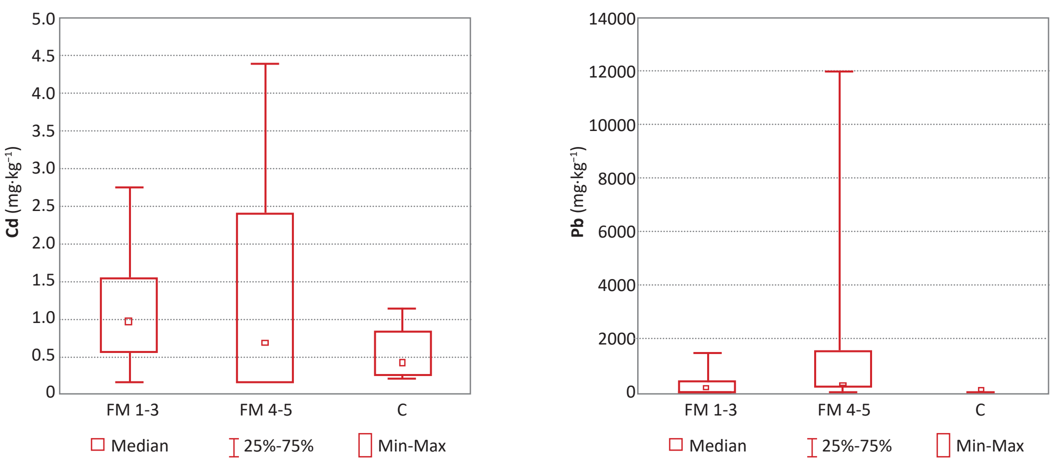

FIGURE 2. Average values and ranges of mass fraction of Cd (left) and Pb (right) on the research area and control plots.

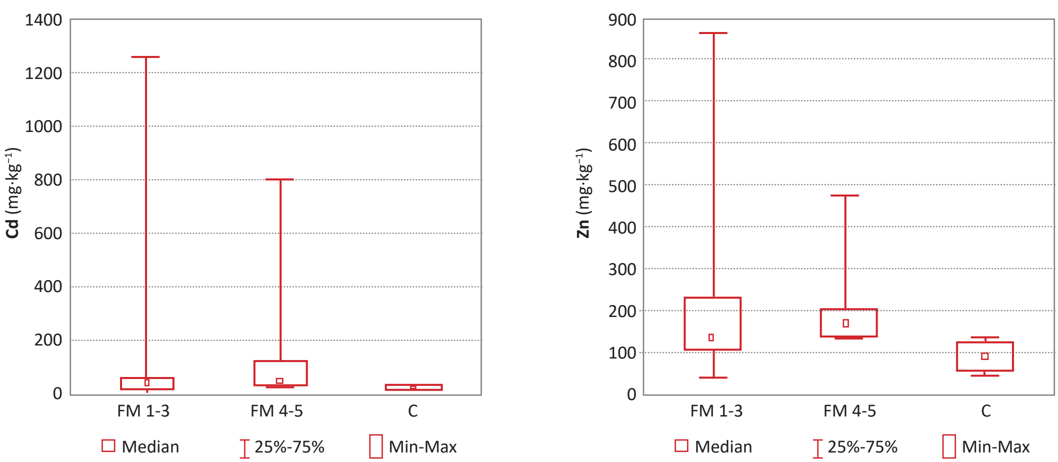

FIGURE 3. Average values and ranges of mass fractions of Cu (left) and Zn (right) on the research area and control plots.

TABLE 4. Descriptive statistics for particle size distribution of soil in the FM 1–3 area.

Variable	Unit	N	Minimum	Lower quartile	Median	Upper quartile	Maximum	Mean	Std. dev.	Coef. var.	Std. error of mean	Skewness
Coarse sand (0.2-2 mm)		20	11.1	16.1	18.2	20.9	31.6	18.7	4.73	25.3	1.06	0.87
Fine sand (0.063-0.2 mm)		20	4.11	5.11	6.19	7.37	11.5	6.40	1.63	25.5	0.36	1.50
Coarse silt (0.063-0.02 mm)	%	20	16.2	19.8	22.6	25.3	37.9	23.2	5.32	22.9	1.19	1.25
Fine silt (0.02-0.002 mm)		20	19.5	30.1	34.0	36.5	44.3	33.0	5.40	16.3	1.21	-0.48
Clay (<0.002 mm)		20	14.3	15.6	18.7	20.0	31.4	18.6	3.71	19.9	0.83	2.13

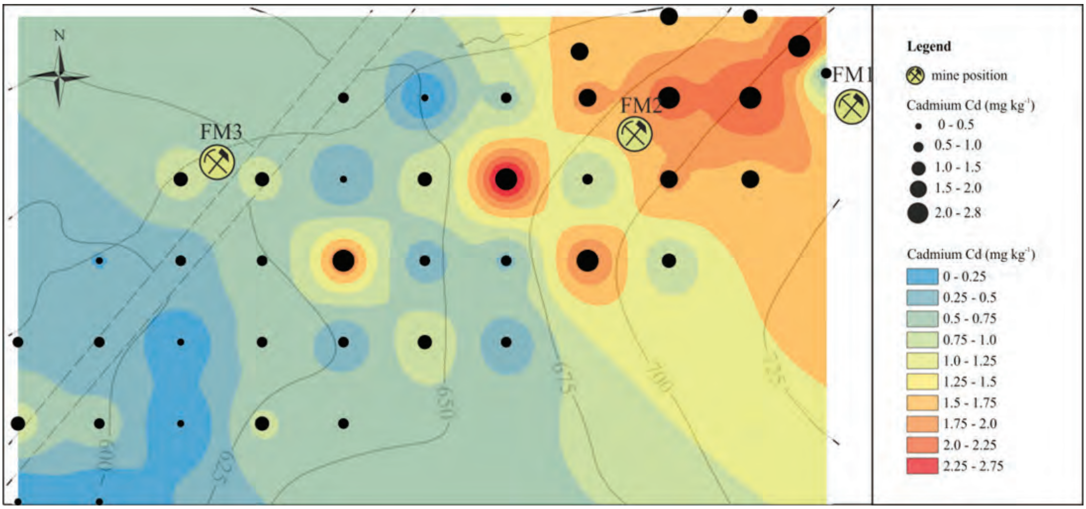

FIGURE 4. Cartographic presentation of the spatial distribution of Cd in the FM 1–3 area.

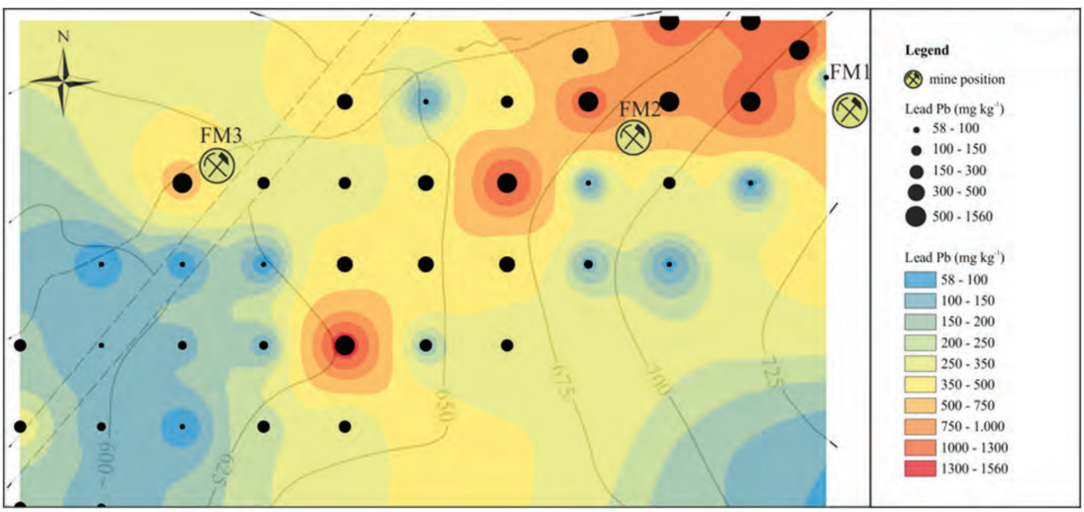

FIGURE 5. Cartographic presentation of the spatial distribution of Pbin the FM 1–3 area.

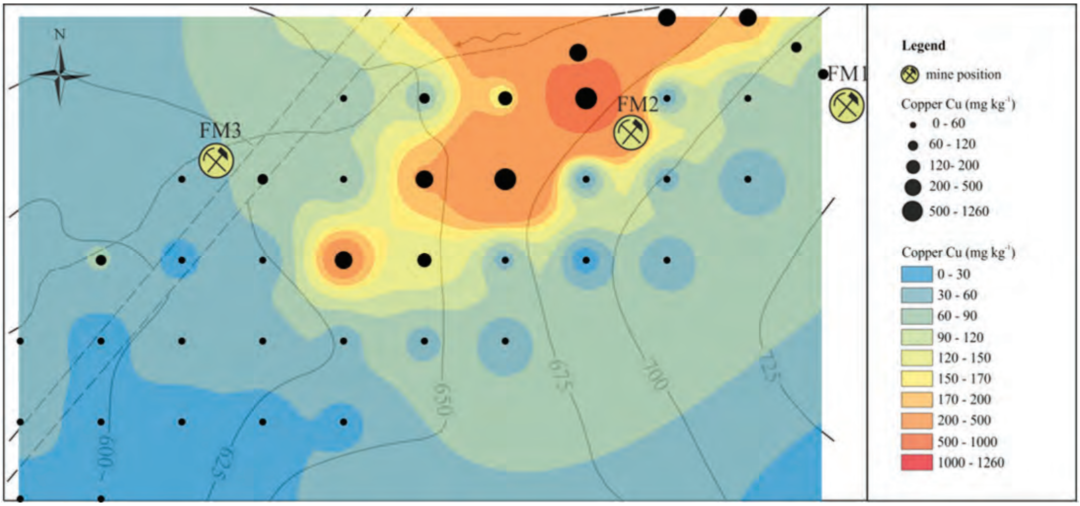

FIGURE 6. Cartographic presentation of the spatial distribution of Cu in the FM 1–3 area.

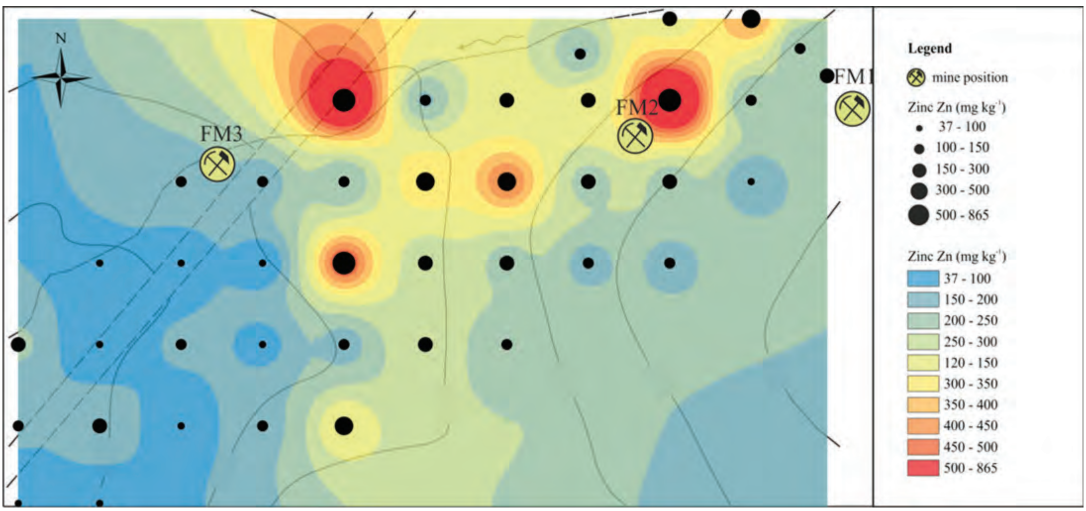

FIGURE 7. Cartographic presentation of the spatial distribution of Zn in the FM 1–3 area.

TABLE 5. Soil properties on the profile in the research area.

Profile	Soil horizon according FAO	Thickness (cm)		Particle size distribution (mm)					Soil texture
		From	To	2.0-0.20	0.20-0.063	0.063-0.020	0.020-0.002	<0.002	
P1	A	0	15-20	23.3	3.1	7.0	31.9	34.7	clay loam
	B	15-20	38-48	25.6	3.6	9.2	34.3	27.2	clay loam
		pH (H_2O)	pH ($CaCl_2$)	C org. g·kg^{-1}	N tot. g·kg^{-1}	Pb mg·kg^{-1}	Cu mg·kg^{-1}	Zn mg·kg^{-1}	Cd mg·kg^{-1}
	A	4.64	4.08	89.73	7.24	58.1	29.8	90.2	0.7
	B	4.92	4.15	46.42	3.23	22.1	35.5	64.6	0.1

FIGURE 8. Soil profile on the research area.

DISCUSSION

The results obtained in this study are in accordance with those in the Geochemical Atlas [37] and with the soil pollution grade according to the Brüne-Ellinghaus criteria [35] (Table 2). Croatian Geochemical Atlas is based on the analyses of composite soil samples which were taken from depth of 0–25 cm, in forest and non-forest areas, and metals by acid mixture (HCl-HF-HNO_3-$HClO_4$) which were extracted. At the same time, the extraction procedure using aqua regia was done and the regression models of correspondence of the two sets of results (namely, total concentrations given in the Geochemical Atlas [37] and the pseudo-total concentration values of the metals from our study) were established. Since in the Republic of Croatia there is no legislation about maximum allowed concentration of the pollutants in forest soils, the results of forest soils studies are usually compared to the guidance prescribed by Croatian Directive on the protection of agricultural land from pollution [36]. Martinović [14] claims that usual natural occurrence of the selected heavy metals in soil is as follows: Cd (<0.5 mg·kg^{-1}), Cu (5–20 mg·kg^{-1}), Pb (<10 mg·kg^{-1}) and Zn (10–50 mg·kg^{-1}). According to the Directive [36], the main "input parameters" for heavy metal determination in soil are pH, particle size distribution and mass fraction of humus.

Median of the pseudo-total mass fraction of Cd in topsoil in the FM area ranges from 0.7 mg·kg^{-1} (FM 4–5) to 0.97 mg·kg^{-1} (FM 1–3).These values are higher than those found on the control plots which amount to 0.44 mg·kg^{-1}. Halamić and Miko [37] claim that the median for Cd in soil in the central part of Croatia is 0.2 mg·kg^{-1}. Cd comes together with zinc in forms of sulphides and carbonates and it is usually present in fraction values that amount to about 1/200 of the values of zinc [37, 41]. Our findings are consistent with such claims. Phytotoxicity of Cd is rarely manifested, but it is well known that Cd is very toxic for humans and animals. The lower tolerance of Cd toward water stress of plantsresults in degradation of the cell wall of the conductive tissue [41]. According to the criteria given by the Directive [36] for silt loam soil (Table 3), we have detected high contamination of soil in the FM area, while according to Brüne-Ellinghaus criteria [35] the studied soil is to be classified as highly polluted with Cd (Table 2).

Median value of the pseudo-total mass fraction of Pb in soil in the area of FM ranges from 238 mg·kg^{-1} (FM 1–3) to 273 mg·kg^{-1} (FM 4–5), while at the control plots a statistically and significantly lower value was found (73.7 mg·kg^{-1}). Global average of Pb in soil is 25 mg·kg^{-1} [42]. Halamić and Miko [37] found that pseudo-total fraction of Pb in the central part of Croatia ranges from 13 to 198 mg·kg^{-1} with median value of 25 mg·kg^{-1}. These values are notably far below those found in our study of soil in the area of FM. Bioavailability of Pb in soil is, on average, less than 1% [43]. Solubility of Pb is highly correlated with pH of soil. Thus, at high pH-values precipitating of Pb in forms of carbonates, hydroxides or phosphates occurs and relatively stable lead-organic complexes can be formed [43]. In the FM area we found that median pH-values are above 6 and that suggests that Pb forms complexes with organic-mineral soil components. When fraction of Pb in soil amounts to more than 100 mg·kg^{-1}, such soil can be toxic for plants. In that context, speciation and bioavailability of lead has an important role. Pb toxicity is manifested as a depression in plant growth. Croatian Directive [36] set upper limit values for pseudo-total lead fraction in various soil types as 50-100 mg·kg^{-1}. In the context of these values, soil in the FM area is polluted with Pb, while if using the Brüne-Ellinghaus criteria [35] the studied soil is above the limit value of pollution (Table 2).

The determined pseudo-total fractions of Cu reveal that in the FM area there is a higher concentration of this metal in soil than in the soil of the control plots, but the difference is not statistically significant. Thus the median value of Cu mass fraction in the FM area ranges from 45.7 mg·kg^{-1} (FM 1–3) to 50.5 mg·kg^{-1} (FM 4–5), while in the soil samples taken on the control plots it is half lower (26.7 mg·kg^{-1}). According to Halamić and Miko [37], the median value of Cu in soil in the central part of Croatia is 16 mg·kg^{-1}, which is lower than the median for the entire Croatian territory, but it is still higher than the value for the whole European continent [44]. Osman [45] claims that when its fraction values in soil exceed 20 mg·kg^{-1} Cu is potentially deleterious for plants. This can be manifested in terms of weak growth of roots and branches, as well as chlorosis and partially necrosis. Soils of the FM area according to the Directive [36] are to be classified as highly contaminated with Cu, while according to Brüne-Ellinghaus criteria [35] one can classify them as soils highly polluted by Cu (Table 2).

The relations similar to those for Cu, have been observed for Zn as well. In the FM 4–5 area the median mass fraction of Zn is the highest one found in the tested areas and amounts to 172 mg·kg^{-1}. In the area FM 1–3 median mass fraction value of Zn is 137 mg·kg^{-1}. On the control plots, Zn is present in the median value of 91.8 mg·kg^{-1}. In the central part of Croatia mass fraction values of Zn fall in the range of 27–362 mg·kg^{-1}, with median value of 61 mg·kg^{-1}. On some individual spots on the mountains Medvednica, Kalnik and Ivanšćica higher fraction values of Zn were found; this is connected to the natural ore occurrences in these mountains [37]. According to Vanmechelen *et al.* [46] the fraction of Zn in organic and mineral horizons is usually below 100 mg·kg^{-1}. National environment quality programmes in Europe consider that the allowable zinc fraction in soil is from 100 to 200 mg·kg^{-1} [47]. Silt loam soils with pH higher than 6, such as those in the FM area, are in the context of findings by Halamić and Miko [37] to be considered as soils contaminated with zinc, while according to Brüne-Ellinghaus criteria [35] one can classify them as soils highly polluted with Zn (Table 2).

On the prediction maps for the area FM 1−3 (Figure 4, 5, 6 and 7) one can notice that the highest fraction values of the selected heavy metals are found in the area of the FM 1 and FM 2, while the lowest one is found for the FM 3. The latter result is explained by fact that the FM 3 has the lowest impact on neighbouring soil, i.e. a minimum quantity of the material (mullock) has been brought out of the mine and out of the main natural slope direction. The contamination follows the natural slope of the terrain and further studies should include a wider area of the mine, respecting the nature of the relief. The determined metals are more concentrated in the vicinities of the mines and the pollution of Medvednica Mt. has a local character. This is an obvious example that mining can locally leave consequences on soil for a long time.

On the occasion of the field work, we did not notice any changes or degradations of the ground vegetation, shrubs and trees. Kabata-Pendias and Mukherjee [43] claim that cadmium, lead, copper and zinc usually accumulate in the roots of the plants with no translocation in the higher parts and thus there are no visible symptoms. Martinović [14] gave an insight into relative indications of the toxic influences of heavy metals on flora, fauna and humans. According to the mentioned reference [14], Cd has the highest toxicological impact on flora, fauna and humans in comparison to the other three analysed elements (Cu, Pb, and Zn). Since for the area described in this paper there is no scientific knowledge about an influence of heavy metals on the flora, fauna and humans, it would be recommended to do a research with the aim of determining their possible depressive act on the vegetation and gene pool.

CONCLUSIONS

On the basis of the results obtained in this study, we conclude as follows:

- Contamination with heavy metals in the research area is strictly local, i.e. related to the openings of the “French Mines”.
- Average pseudo-total fraction of Cd in the analysed topsoil samples was in the range of 0.17–4.41 mg·kg^{-1} (median: 0.97 mg·kg^{-1}). Cu was found in the range of 4.54–1260 mg·kg^{-1} (median: 45.7 mg·kg^{-1}). In the case of Pb, average values of the pseudo-total fraction were found in the range of 58.4–12000 mg·kg^{-1} (median: 238 mg·kg^{-1}), and the pseudo-total fraction values of Zn were found in the range of 36.8–865 mg·kg^{-1} (median: 137 mg·kg^{-1}).
- Our results reveal that mining in the research area had an impact on the local soil quality in terms of pollution with heavy metals, with no visible signs on the vegetation.
- Further research in this area should be focused to the presence of heavy metals in plants, mushrooms, percolated waters and springheads with the aim of determining the possible influence of the described contamination with heavy metals on the wider area, especially in the lower parts of the terrain.

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Spatial Distribution, Genetic Diversity and Food Choice of Box Tree Moth (*Cydalima perspectalis*) in Croatia

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ABSTRACT

Background and Purpose: Box tree moth (*Cydalima perspectalis*: Lepidoptera, Crambidae) is an invasive species rapidly spreading through Europe and making considerable damage to native and planted European box plants (*Buxus* sp.). It has up to three generations per year and has no natural enemies in Europe which helps it to spread rapidly and to become highly invasive in its new range. The aim of this paper is to show i) spatial distribution, ii) number of generations; iii) food choice, and iv) genetic distribution of box tree moth in Croatia.
Materials and Methods: Occurrence data of box tree moth were obtained by field observation and data obtained from the general public. The number of generations of box tree moth was studied by direct observation of life stages on plants. Food choice test was conducted on *Buxus sempervirens*, *Ilex aquifolium*, *Euonymus japonicus* and *Ligustrum vulgare* used as food plants. Haplotype diversity and distribution of box tree moth was done for 5 localities in Croatia and their comparison to the haplotypes from China, Korea and 10 European countries.
Results: Box tree moth has rapidly spread over the whole territory of Croatia in 4 years and it has three generations per year. The larvae showed a clear preference for *B. sempervirens* leaves and the total consumption was 0.5 g/dry weight of box leaves/larva. Three haplotypes were observed and haplotype HT4 was found in 4 out of 5 sampling sites in Croatia. The haplotypes observed in Croatia were present in China, which indicates Chinese origin of Croatian populations.
Conclusions: Suitable European climate, widely available host plants and lack of natural enemies have enabled box tree moth to become highly invasive, to quickly disperse in its new environment and to make devastating damages to ornamental European box plants and hedges.

Keywords: invasive species, *Buxus sempervirens*, haplotypes, total consumption

INTRODUCTION

Increasing trade between continents has facilitated intentional and unintentional movement of insect species beyond their natural range [1, 2]. Trade in live ornamental plants is one of the main pathways of the introduction of non-native arthropods to Europe and among them insect pests [3, 4]. An increasing number of these alien pests originates from Asia [1].

Box tree moth (*Cydalima perspectalis* Walker, 1859; Lepidoptera, Crambidae) (BTM) is one of the recent introductions of non-native (alien) insect pests to Europe [5]. It is native to East Asia [6] and in Europe it was first recorded in the Netherlands and Germany in 2007 [5, 7]. It is assumed that it was introduced to Europe with infested European box plants and since then it has rapidly spread to most European countries and the Caucasus region with further trade of infested plants [6¸ 8].

BTM larvae feed on *Buxus* sp. and cause complete defoliation and plant death [6]. The damage it causes is substantial since European box is widely used as popular ornamental plant in public and private gardens, historical parks, cemeteries and other horticulturally important plantings [6]. Very valuable are unique natural European box populations in Europe and in the Caucasus [9] which are threatened by damages of this highly invasive species [10].

BTM overwinters in larval stage between European box leaves spun together with silk. Larvae need an obligate diapause of 6-8 weeks [11] and they complete their development in late spring after feeding voraciously and totally defoliating European box plants. Pupae are concealed in a cocoon of white webbing among the leaves and twigs. The females lay eggs on the underside of leaves in flat, barely visible egg clusters. Larval development takes 17 to 87 days, depending on the temperature [12]. In central Europe BTM develops two generations per year [11, 13], while three generations per year are reported from southern Germany [7], northern Italy [14], southwest Hungary [15], in comparison to three to five generations found in native China [11, 16].

BTM feeds only on the leaves of *Buxus* sp. [13], but *Euonymus japonicus* Thunb. and *Ilex purpurea* Hassk are mentioned as host plants in Japanese literature [7, 11]. Invasive species can alter their diet by adjusting to new hosts in the introduced region [13, 17], so there is a concern that BTM larvae could feed on European native species (*Ilex aquifolium* L.*, Euonymus latifolius* L.*, E. europaeus* L.*, E. verrucosus* Scop.) that are growing in various continental and sub-Mediterranean forest communities in Croatia where they form important and biologically diverse understorey layer [18].

Only partial data on the occurrence of BTM in Croatia have been published [19] and since then there have been reports of damages from all over Croatia.

A preliminary genetic study on BTM was carried out by Bras et al. [20] to describe the genetic diversity in the native area (Asia) and in some European countries in the introduction area and to disentangle the invasion pathways of BTM introduction into Europe. They analysed a fragment of the mitochondrial genes COI-COII. For the present study, we used a subset of those data with a focus on Croatia, in order to compare the genetic variation in this country with other European countries and Asia.

Although widely present in Croatia, our knowledge about certain aspects of the biology and ecology of BTM has been limited. Therefore, in our research we focused on the following: i) detailed spatial distribution; ii) number of generations; iii) food choice, and iv) genetic distribution of BTM in Croatia.

MATERIALS AND METHODS

Spatial Distribution of Box Tree Moth

Data about the occurrence of BTM in Croatia were obtained by field observation conducted by the authors of this study and by the data obtained from professional nursery growers, other professionals working with plants and the general public (enquiries via the web portal Štetnici Hr and personal enquiries via phone and e-mail) in the years 2013, 2014, 2015 and 2016. For each location where BTM larvae and damages were found and reported, the name of the location, geographic coordinates and the year of the first damages were recorded. Whenever possible, photographic material was requested from the general public to minimise false identification.

Spatial distribution map of BTM occurrence was made using ArcMap 10.1 (ESRI, USA).

The Number of Generations of Box Tree Moth

We researched the biology of BTM in 2014 by direct observations of life stages on European box plants. The plants were located in Zagreb (45°49’12.18”N; 15°59’22.97”E) and Jastrebarsko (45°40’14.87”N; 15°38’41.58”E). The plants were checked every week from April until October. We did not measure the dimensions of larvae in different larval stages, but only observed the presence of larvae, pupae and adults. Adults were observed on plants, street and home lights on the locations of observations.

Food Choice Test of Box Tree Moth

Food choice test was conducted in the entomological laboratory of Croatian Forest Research Institute. BTM larvae were collected in April 2015 in Jastrebarsko (45°40’14.81”N, 15°38’47.91”E). We collected the young overwintering larvae and we tried to choose larvae which were approximately the same size but without determination of exact larval stages. *Buxus sempervirens*, *Ilex aquifolium*, *Euonymus japonicus* and *Ligustrum vulgare* L. were chosen as food plants. *Ilex aquifolium* was chosen because it grows naturally in forests and is protected by Croatian law on nature protection. *Euonymus japonicus* belongs to the same genus as the native *E. latifolius, E. europaeus, E. verrucosus. Euonymus japonicus* was easily available for the test and is an ornamental plant very often grown together with European box. *Euonymus latifolius, E. europaeus* and *E. verrucosus* were not tested since their leaves were not easy to obtain at the time of the test. We assumed that preliminary test on any member of the genus *Euonymus* could show preference of BTM for this plant genus. *Ligustrum vulgare* was tested because we received lots of reports from the general public about damages from BTM larvae on *L. vulgare* and because both *Buxus* and *Ligustrum* are often planted in the same hedge.

We used 50 larvae for each food plant, each larva kept separately in a petri dish. They were kept under laboratory conditions of 20±1 °C with a relative humidity of 65% and a photoperiod of 16h:8h (L:D). Fresh leaves were collected every week from the same plant and kept on twigs in glass jars with water. Leaves of chosen food plants were weighed in a fresh state on a Sartorius BD ED 100 (ATL 224-I) analytical laboratory balance (limit 0.001 g) and then given to larvae. Fresh leaves were added when the larvae consumed them or when they dried out, usually every day or every other day. All leftover leaf material was collected, oven dried at 70°C for 24 hours and weighed.

Total consumption (T_c) was calculated according to Waldbauer [21] using formula: $T_c=[(L_{wg}*(F_w/D_w))–L_{wf}]$ where L_{wg} is the weight of fresh leaves given to larvae and L_{wf} is leftover leaf material, both of them in dry weight/gram (dw/g). To obtain the value of L_{wg} in dry weight/gram, a coefficient F_w/D_w (F_w-fresh weight of leaves, D_w-dry weight of leaves) obtained from 10 leaves (similar in shape and size to the leaves that were given to larvae) was used. To obtain the dry weight of L_{wg} and L_{wf}, they were oven dried at 70°C for 24 hours.

Genetic Distribution

Sampling of material, DNA extractions, PCR amplifications of COI-COII and sequencing were performed following the protocol described in Bras *et al.* [20]. Specimens of BTM were collected in the native area (China and Korea) and in the introduced area (Austria, Belgium, Bulgaria, France, Germany, Hungary, Italy, Serbia, Slovenia and Switzerland) as described in Bras *et al.* [20]. In addition, a total of 18 BTM specimens belonging to 5 localities in Croatia were collected in 2014. Butterflies were collected in Osor and Artatore (Mali Lošinj) and caterpillars were collected on European box plants on three others localities (Zagreb, Vinica, Višnjevac). Haplotype diversity and haplotype distribution were calculated with DNAsp v.5. [22].

RESULTS AND DISCUSSION

Spatial Distribution of Box Tree Moth in Croatia

Data on the occurrence of BTM in Croatia yielded a distribution map (Figure 1) with different layers for each year (2013, 2014, 2015 and 2016). In this graphic depiction it is clearly visible that BTM has in 4 years spread rapidly over whole Croatia. The pest was first recorded in Istria in 2012 [23] and the first outbreak was recorded in the region around Varaždin in 2013 [19] (Figure 1). The pest quickly spread eastwards and southwards in 2014, and by the end of 2016 all the locations we examined showed presence of the moth. The spread was facilitated by the movement of infested plant material since European box plants with presence of larvae were observed in several garden centres in Croatia (Dinka Matošević, personal observation). During our research we have seen and received numerous reports on damages on valuable European box ornamental hedges and plantings in Croatia (e.g. Trsteno Arboretum and Lokrum Island near Dubrovnik). European box is also a part of traditional folk costume in the region of Novi Vinodolski, while old European box plants are an important part of public and private gardens in this region. In 2014 and 2015 all European box in this region has been defoliated by BTM which caused loss of valuable old plants and concern among local citizens.

The Number of Generations of Box Tree Moth in Croatia

On the basis of field observations we can assume that BTM has three generations per year in Croatia (Table 1). In 2014, we observed overwintering larvae feeding until the end of May and the beginning of June, pupae and then adults emerging during June. Young larvae were observed from 5 July 2014 and moths were observed flying from 1 to 15 August. Young larvae were again found on leaves from 15 August and adults were observed again in October 2014.

CLIMEX model [11] shows 3 generations per year for continental Croatia (Marc Kenis pers. comm.); 3 generations have been observed in northern Italy [14] and southwestern Hungary [24], which is comparable to our results. The average monthly air temperature in continental Croatia was in June 2014 in the category very warm with average daily temperatures above 25°C, in August and September 2014 in the category normal and in October 2014 in the category

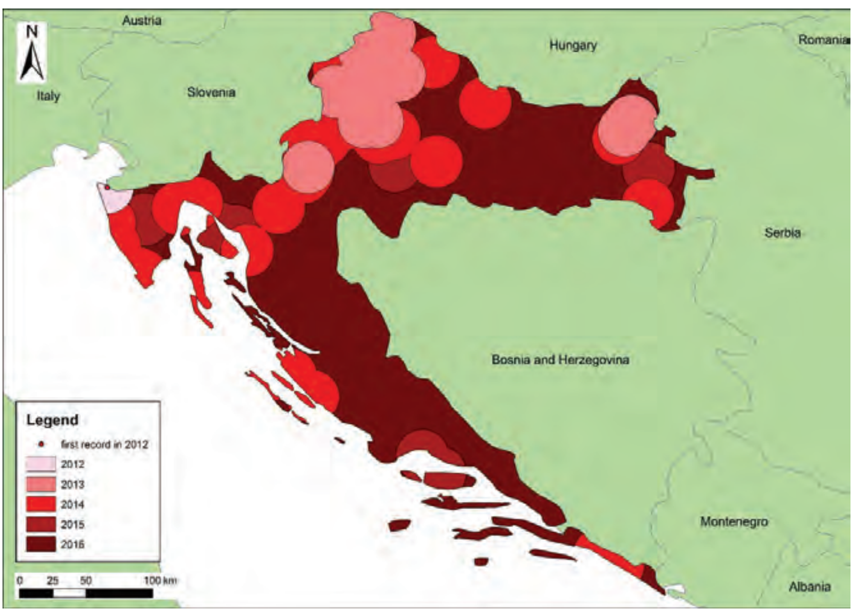

FIGURE 1. The map of yearly spread of box tree moth (*Cydalima perspectalis*) infestations in Croatia. Infestations are visualized with 20 km buffers around confirmed infestation points and coloured according to the year of observation.

very warm [25]. These conditions were favourable for BTM to develop 3 generations per year since larval development takes 23 days at 25°C, and 17 days at 30°C [12] with adults living up to two weeks [6] (Mark Kenis pers. comm.). Very similar occurrence of adults and three generations were recorded in Győr-Bácsa (NW Hungary) in 2014 [24].

Food Choice of Box Tree Moth

BTM larvae showed a clear preference for *B. sempervirens* leaves. The mortality rate of larvae feeding on European box leaves was 5% and the total consumption was 0.5 g/dry weight of box leaves/larva. Larvae successfully pupated and moths emerged.

Larvae did not develop on the other three tested species (*E. japonicus, I. aquifolium and L. vulgare)*. The mortality rate of larvae on these three species was 100% with no feeding or growth recorded.

Our results show that BTM do not feed on *Ilex aquifolium* and *Euonymus japonicus* and therefore we assume that they pose no threat to native and protected *I. aquifolium* growing in Croatian forests. Although we did not make food test on *Euonymus latifolius, E. europaeus*and *E. verrucosus* we can also assume that box tree moth is also not able to feed on our native *Euonymus* species.

Genetic Distribution

In the native area, 6 haplotypes were observed in China [20]. Among them, 4 haplotypes were present in the introduced area but were not homogeneously distributed between countries (Figure 2b).

In Croatia, a total of 3 haplotypes were observed (Table 2). The haplotype HT4 was the most abundant. It was found in 4 sampling localities including Višnjevac where it was the only haplotype observed in the 5 sequenced specimens (H = 0) (Figure 2a). We observed one haplotype in Vinica (HT2), which is the first place where a BTM outbreak was observed in Croatia [19].

The haplotypes observed in Croatia were present in China, which indicates Chinese origin of Croatian populations, and which corresponds to the assumptions of Nacambo *et al.* [11] for the origin of the invasive populations of BTM in Europe. Moreover, Bras *et al.* [20] observed a spatial genetic structuration in the introduced area with the presence of two groups: West Europe (HT1 mostly observed) and Southeast Europe (HT4 mostly observed). Our results (HT4: 13 specimens for 18 sequenced) indicate that Croatia belongs to the south-eastern group. In addition, high genetic diversity (3 out of the 4 haplotypes present in Europe) observed in Croatia may suggest a multiple introduction

TABLE 1. Field observations of the development of box tree moth (*Cydalima perspectalis*) in 2014. The presence of larvae on plants is shown in table as circles, and the presence of adults is shown as a butterfly symbol.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Larvae	○	○	○	○	○	○	○	○	○	○	○	○
Adult						🦋		🦋		🦋		

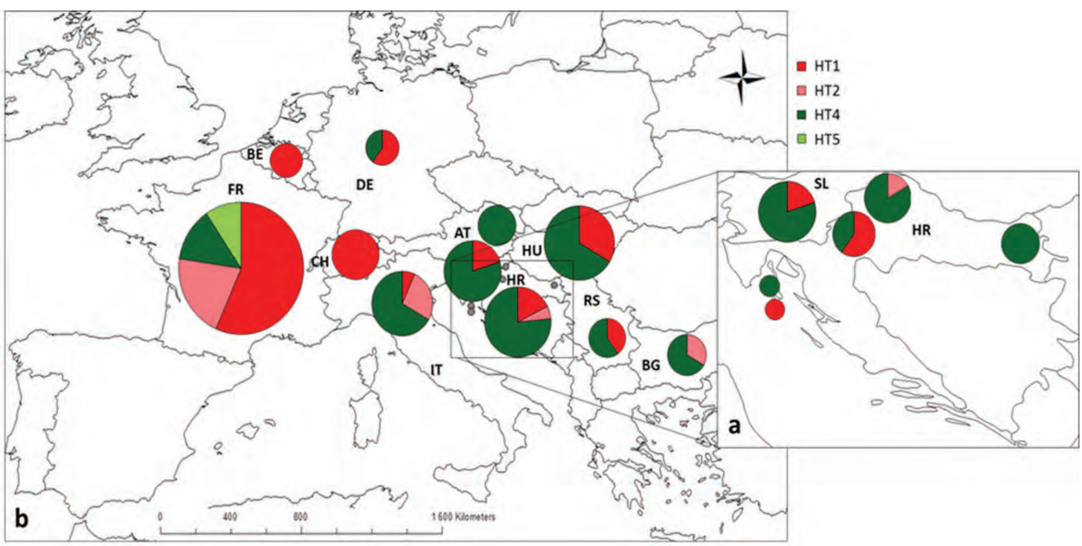

FIGURE 2. Haplotype distribution of box tree moth (*Cydalima perspectalis*) in Europe based on data (a) from the present study on Croatia and (b) Bras et al. [20] for other European countries. Circle size is proportional to the number of individuals. FR: France; DE: Germany; BE: Belgium; CH: Switzerland; IT: Italy; AT: Austria; SL: Slovenia; HR: Croatia; HU: Hungary; RS: Serbia; BG: Bulgaria.

TABLE 2. The list of samples of C. perspectalis from Croatia and haplotype distribution per population (N = Number of individuals per population, H = Haplotype diversity).

Populations	N	Haplotypes	H
Zagreb	5	HT1 (3) ; HT4 (2)	0.60 (± 0.18)
Vinica	6	HT4 (5) ; HT2 (1)	0.33 (± 0.22)
Višnjevac	5	HT4 (5)	0
Osor	1	HT4 (1)	-
Artatore (Mali Lošinj)	1	HT1 (1)	-
Total	18	HT1 (4); HT2 (1); HT4 (13)	0.45 (± 0.12)

event of BTM. Nevertheless, information on the ornamental plant trade in Croatia will help to better understand invasive pathways of BTM.

CONCLUSIONS

BTM is an invasive insect pest that has rapidly spread on the whole territory of Croatia in the period of 4 years causing complete defoliation and death of ornamental European box plants. This rapid dispersal and severe damages are possible by developing three generations per year. BTM shows clear preference for *Buxus sempervirens* only. Croatian haplotypes show a Chinese origin of the species with high probability of multiple introductions by infested plant material. When alien phytophagous insects arrive at a new location, their survival, establishment and spread depend on various factors such as the availability of preferred host plants and the suitability of the local climate [26]. Suitable European climate, widely available host plants and lack of natural enemies [27] have enabled this insect pest to become highly invasive and quickly disperse in its new environment.

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First Record of *Eutypella parasitica* on Maples in Urban Area in Croatia

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ABSTRACT

Background and Purpose: *Eutypella parasitica*, a plant pathogenic fungus attacking maples (*Acer* spp.) was detected for the first time in Croatia in 2007. From 2007 to 2014, it was found only in forests, on several trees in Hum na Sutli, near Slovenian border. In 2015, the presence of *Eutypella parasitica* was monitored for the first time in urban areas.
Materials and Methods: Within the official survey programme, 23 visual surveys were conducted and 24 samples were collected and analysed for the presence of fungi. *E. parasitica* was found in Bundek Park in Zagreb. Typical symptoms of Eutypella canker were detected on two field maples (*Acer campestre*) and two boxelder maples (*Acer negundo*). Twelve isolates were collected from symptomatic trees.
Conclusions: Eleven out of twelve isolates from four trees were confirmed as *E. parasitica* by species-specific polymerase chain reaction. This is the first report of *E. parasitica* in Zagreb, the first record of *E. parasitica* in Croatia outside forests, as well as a record of a new host species in Croatia, boxelder maple (*A. negundo*). Introduction pathway of *E. parasitica* in Zagreb remains unknown.

Keywords: Eutypella canker, survey, *Acer campestre*, *Acer negundo*

INTRODUCTION

Eutypella canker is a disease of maples (*Acer* spp.) caused by the fungus *Eutypella parasitica* R. W. Davidson & R. C. Lorenz [1]. The disease is present in North America and it was not known to occur in Europe until 2005, when it was recorded in Ljubljana, Slovenia [2]. It was subsequently discovered in Austria in forests in 2006 on sycamores (*Acer pseudoplatanus* L.) [3]. In Croatia, *E. parasitica* was found for the first time in 2007 on field maples (*Acer campestre* L.) in Prišlin (Krapina-Zagorje County), near Slovenian border [4]. In 2016, the fungus was reported in Germany [5] and Hungary [6].

Novak Agbaba *et al.* [7] stated that *E. parasitica* is not a quarantine plant pathogen within the European Union, and the damaging potential of this alien fungal species in Europe is largely unknown [7]. Further spread of *E. parasitica* in Croatian forests could damage populations of different valuable maple species, causing economic loss [7]. According to the risk analysis by Ogris *et al.* [8], Croatia is considered to be a state where the risk of *E. parasitica* spread is high. These were the main reasons why *E. parasitica* was an object of official survey programmes, conducted in forests from 2011 to 2015. The review of the current situation of *E. parasitica* in Croatia showed that only two out of 2029 maple trees inspected during four years of survey were found infected with *E. parasitica*, both located in forests around Hum na Sutli [7].

In 2015, the presence of *E. parasitica* was monitored for the first time in urban areas, with the continuation of monitoring activities in forests. The main aim of the monitoring programme in urban areas was to contribute to the knowledge on the presence and distribution of this alien plant pathogen in Croatia.

MATERIALS AND METHODS

Twenty-three visual surveys of maple trees were carried out from the middle of May to the end of October in 2015. Surveys were carried out in parks, alleys, streets and public green areas, where maple trees were visually inspected for the presence of Euytpella canker symptoms. Sycamores, field maples, boxelder maples (*Acer negundo* L.), Norway maples (*Acer platanoides* L.), silver maples (*Acer saccharinum* L.) and Tatarian maples (*Acer tataricum* L.) were the tree species examined. One survey was carried out on maple trees in Poreč (12 trees examined), Virovitica (52 trees examined), Koprivnica (43 trees examined), Desinec (20 trees examined), Osijek (70 trees examined), Beli Manastir (21 trees examined), Novska (24 trees examined), Čakovec (39 trees examined), Varaždin (59 trees examined) and Metković (11 trees examined). Eleven surveys were conducted in different periods in nine districts of the City of Zagreb, with a total of 187 maple trees examined.

Trees were examined for the presence of cankers with similar symptoms to Eutypella canker. When cankers on the main trunk were discovered, bark at the edge of the canker was removed or peeled off to check for the eventual presence of white mycelium fans beneath. The surface of cankers was examined with magnifying lens to determine the eventual presence of black protruding pertihecial necks. Fragments of wood from the edge of necrotic areas or wood fragments with pieces of bark from the cankers were collected for laboratory analysis. If white mycelial mats beneath the cankers were noted, their fragments were cut out and collected as the additional sub-samples. Multiple sub-samples were taken from each tree showing symptoms, and one tree was considered as one sample. Twenty-four samples were collected, 17 from the City of Zagreb, two from Osijek and one each from Desinec, Beli Manastir, Novska, Čakovec and Varaždin.

Laboratory analyses were carried out at the laboratory for mycology of the Institute for Plant Protection, Zagreb. Wood fragments were cut into chips (approximately 5 x 5 mm), surface-sterilized for one minute in 1% NaOCl, rinsed with sterile water, inoculated on potato-dextrose agar (PDA) and incubated at 22°C in darkness. Isolation from mycelial mats was performed by peeling small pieces of mycelia with a needle and placing them directly on PDA. If developed after incubation, sterile white mycelial colonies were sub-cultured in pure cultures from the edge of the advancing growth.

Among the fungi isolated from samples, 12 isolates from four samples resembled descriptions of *E. parasitica* in pure cultures [1, 7, 9]. Polymerase chain reaction (PCR)-based method and species-specific primer pair (EpR/EpF) developed by Piškur *et al.* [10] were used for the identification of isolates. Total DNA from the cultures was extracted from the mycelium ground in liquid nitrogen using Extract-N-Amp® Plant PCR Kit (Sigma-Aldrich) according to the manufacturer's instructions. PCR mixture and PCR conditions were similar to Piškur *et al.* [10]. Isolates which yielded amplification fragments of 341 bp were identified as *E. parasitica*.

All isolates confirmed as *E. parasitica* are stored at the Institute for Plant Protection in Zagreb.

RESULTS AND DISCUSSION

Declining maple trees were noted on all locations surveyed, but trees with cankers on the main trunk were recorded only in the City of Zagreb, Osijek, Desinec, Beli Manastir, Novska, Čakovec and Varaždin. Typical symptoms of Eutypella canker were observed on two field maple trees and on two boxelder maple trees in Bundek Park in Zagreb. On other locations, cankers were different from those described to be caused by *E. parasitica*, although bark cracking and callus formation were visible on trees affected. However, no characteristic white mycelial mats were found beneath the bark of such trees. Fungi belonging to Botryosphaeriaceae family were isolated from such samples.

In Bundek Park, "cobra neck" symptom with large swollen old canker 45 cm wide and 120 cm long was visible on the trunk of one field maple tree (Figure 1), while distorted trunk growth around the canker (25×58 cm) was evident on the other symptomatic field maple. Similar cankers were noted on two boxelder maples, typically sunken, swollen and also evident on the main trunk (Figure 2), but notably smaller (30×38 cm and 26×25 cm). Mats of white mycelium were visible after removing bark layers at the edge of the cankers (Figure 3). The fungus was readily isolated from both mycelial mats placed directly on PDA, or from the wood tissue chips cut from the edge of the advancing mycelial mats. Twelve isolates were collected from the trees with typical Eutypella canker symptoms. Their colonies on PDA were white and sterile, and all 12 cultures were morphologically similar. Among 12 isolates, 11 yielded 341-bp fragments reported to be specific for *E. parasitica* [10]. Nine isolates originated from field maples, while the remaining two were isolated from boxelder maples.

E. parasitica was isolated from and confirmed in four trees with typical symptoms, but the number of infected maple trees in Bundek Park may be higher. Bark cracking and possible initial phases of canker development were observed

FIGURE 1. Large canker on a field maple tree

FIGURE 2. *Eutypella canker* on a boxelder maple tree

FIGURE 3. White mycelial fans beneath the bark of field maple

on other field maples, sycamores and Tatarian maples within the park. Such trees were not sampled.

Introduction pathway of *E. parasitica* in Zagreb is unknown, but it may be independent of its introduction to the forests around Hum na Sutli. Considering the slow development of Eutypella canker symptoms [7] and the appearance of very large canker on one infected field maple in Bundek Park, the disease has probably been present in the park for decades, as speculated by Cech *et al.* [5], who described the situation with Eutypella canker of maples in Germany. From the initial focus, after *E. parasitica* perithecia develop on an infected tree, the disease may continue to spread to nearby susceptible hosts.

Finding of *E. parasitica* in urban area reflects the risk of introduction of alien, new forest pests and pathogens into urban areas, from where these harmful organisms could spread to forests causing long-term losses. Cases of Asian longhorn beetle (*Anoplophora chinensis*), redneck longhorn beetle (*Aromia bungii*) or thousand cankers disease (*Geosmithia morbida*) are clearly showing such risks [11-13]. In different European countries, all these quarantine and non-quarantine alien harmful organisms were found in gardens in urban areas [11-13] where they can establish their initial populations if efficient phytosanitary measures are not taken. Alien forest pests and pathogens can be introduced from plants imported from all over the world and distributed as "ornamental" or "horticultural" woody plants. The analysis of 123 invasive forest pathogens in Europe has shown that 38% of these organisms have been found on ornamental trees in parks and gardens, while 36% have been found in forests [14]. Trade was indicated to be among the most common pathways of the introduction and diffusion of invasive forest pathogens [14]. Early detection of an invasive forest pathogen and the investigation of pathways for its introduction and spread seem to be the only measures for finding a strategy to prevent this kind of biological invasions [14].

CONCLUSIONS

Finding of *E. parasitica* in Zagreb is the first record of this fungus in an urban area in Croatia. Boxelder maple is a new host species recorded for *E. parasitica* in Croatia, beside previously reported field maple and sycamore [6].

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Dynamics, Hydrological Relations and Pollution of Precipitation and Flood Waters in a Forest Ecosystem

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ABSTRACT

Background and Purpose: Water in forest ecosystems can be present in various forms. The hydrological water cycle unfolds via fundamental hydrological processes such as evapotranspiration, precipitation, infiltration and outflow. Certain infrastructure works and recent climate changes within lowland forest areas have resulted in changes in flood water and ground water trends, and in quantities of precipitation and evapotranspiration. One of the chemical water quality indicators is the presence of metals in water. Higher metal concentrations in natural waters are undesirable since they are polluters of aquatic systems and detrimental to living organisms. Particularly dangerous are cadmium and lead. The objective of this paper was to analyse watercourse levels, ground water depths, and relations between precipitation waters, flood waters, ground waters, relative air humidity and evapotranspiration. An additional objective was to analyse the pollution of precipitation and flood waters in lowland forest ecosystems.

Materials and Methods: The study was conducted in the Posavina region in Croatia. Precipitation data from Nova Gradiška meteorological station, watercourse levels of the Sava River and ground water depth data from piezometer stations were used in the analysis of the hydrological relations. For water quality analysis, precipitation was collected at six sample sites during the spring of 2015 and 2016. Flood water and precipitation were collected in three repetitions during the spring of 2015 and 2016.

Results: Trends of the Sava River water levels and ground water levels dropped significantly. The precipitation volume trend in the study area was positive, but not statistically significant, while evapotranspiration amounts increased significantly.

Conclusions: A significant correlation has been found between particular water forms in the hydrological cycle, i.e. between precipitation waters, flood waters and ground waters, and between relative air humidity and evapotranspiration. No pollution of precipitation waters and flood waters with metals was found.

Keywords: hydrological cycle, forest ecosystem, water pollution

INTRODUCTION

As an ecological factor in an ecosystem, water can be present in the form of precipitation, flood water, ground water or air moisture. Precipitation water usually comes in the form of rain or snow, and is a result of water vapour condensation in the atmosphere. Other forms of precipitations, such as fog, dew and frost, can also be conditionally added to the total sum of precipitation. Precipitations are an important part of the water cycle and a primary source for ground water charging [1]. Flood water is necessary for normal functioning of lowland forest ecosystems. Floods of the Sava River and its tributaries have a specific rhythm. Maximal water levels of the Sava are achieved in March, April, October, November and December, when floods can be expected in lowland forests [2]. Ground water depth directly depends on the water level in rivers [3], while it indirectly depends on precipitation and flood waters. Part of precipitation that seeps into soil is used to moisten it, while the remainder runs off to parent soil, moistens it and on impermeable layers forms the aquifer

[4]. Air humidity as a factor has less of an effect on forest ecosystems and their formation, but is very important for cells, tissues and other plant organs that are saturated with water vapour. Temperature affects the capacity of air to hold water vapour. The higher the temperature, the greater the capacity for water vapour and air humidity, and the lesser the transpiration. Many studies have reported changes in hydrological relations, particularly changes in the dynamics of ground water [5-7]. Flood intensities also change and vary from year to year, in the range from minimum to maximum water, and as such are an important ecological factor.

Water constantly cycles in nature and this circulation is called the hydrological cycle [8]. The hydrological cycle unfolds in the atmosphere, hydrosphere (surface) and in the lithosphere. All plants, along with the rest of the living world, are part of the water cycle, thus changing form, but never disappearing. This cycle is controlled by the Sun's energy and by gravity. The hydrological cycle has five processes: condensation, precipitation, infiltration, runoff and evapotranspiration [9]. In the hydrological cycle, water changes are the fastest in the atmosphere and biosphere [10]. Few studies have examined the relationship between specific water forms and climate indices in the hydrological cycle of lowland forests. Direct relationship between the Drava River water level and ground water depths in the Repeš forest was reported by [3]. The present study examines a range of different water forms and climate indices, in order to obtain data on interrelationships in the hydrological cycle of lowland forests. It can be expected that changes in global climate will have effect on the hydrological cycle, and that they will change the level of surface water and ground water charging, together with other accompanying factors on natural ecosystems [11].

Water quality for specific use is determined using a series of indicators according to its composition, properties and concentration of matter in water. Quality is determined using a range of indicators than can be categorised as physical, chemical or biological indicators. Chemical indicators represent particularly harmful additives to water, that due to their composition, characteristics and concentration are detrimental not only for the life and health of humans, plants and animals, but also have a negative impact on the aquatic system as a whole. Chemical indicators can be categorised as inorganic and organic. Ecologically important compounds are heavy metals, which can be present in trace amounts (cadmium and lead) in natural waters, and are potentially harmful for plants, animals, and humans [8]. Significant side effect of climate changes can be the changes in the level and quality of surface waters [12], as well as changes in quality and quantity of ground water [13].

The objective of this study was to analyse the trends of specific water forms and certain climate elements and their relationships in the hydrological cycle, as well as the pollution of precipitation and ground water.

MATERIAL AND METHODS

The study was conducted in the Međustrugovi forest unit, Stara Gradiška forestry district (Figure 1). This is a lowland area with a moderately warm climate. The mean annual air temperature for this area is 10.9°C, and the average annual precipitation is 782 mm (Nova Gradiška weather station, period of 1981–2012). The geological substrate of this forestry unit is redeposited marsh loess, covered by a mineral marsh soil with poor to neutral acidity. For the analysis of hydrological relationships in a lowland forest habitat, data on climatic elements and indices from Nova Gradiška weather station, water levels (cm) of the Sava River, and data on depths of ground water (cm) from the Međustrugovi piezometer station were used. The analysed climatic elements were mean annual precipitation (mm) and relative air moisture (%). The climate indices used were the climate moisture deficit index (CMD; mm) and the potential evapotranspiration values (mm). The moisture deficit index represents the sum of the monthly differences between referential evaporation and precipitation [14]. Direct determination of evapotranspiration is demanding since it is difficult to achieve the natural condition, and therefore indirect methods are used, including data on a greater or lesser number of measured climate element values [8]. Potential evapotranspiration was calculated indirectly according to [15]. Data on climate elements and indices were collected for the period of 1901–2012.

For the analysis of water levels in the Sava River, data on the maximum, mean and minimum water levels from Stara Gradiška measuring station in the period 1970–2012 were used. Ground water was measured in the Međustrugovi forest unit at four depths (PJ10.5 m; PJ2-1.5 m; PJ3-2.5 m and PJ4-7 m) in the period 2001–2012. A decrease or increase of climate and hydrological elements and indices was analysed using linear trend regression analysis. Precipitation was collected at a total of six sampling stations, and ground water was collected in three repetitions during March in 2015 and 2016. Water samples were collected in plastic (polypropylene) bottles (100 mL). The bottles had been previously submerged in diluted nitric acid (HNO_3, *p.a.*, *v/v* 10%), thoroughly rinsed with ultrapure water, and dried at room temperature in a pure air atmosphere. Determination of metal contents in the prepared samples was performed using inductively coupled plasma atomic emission spectroscopy (ICP-AES). Measurement quality was determined by measurements against the certified reference material for water SLRS-5 (National Research Council of Canada). The limit value of water contamination was taken from the Regulation of hazardous compounds in water [16], Ordinance on natural minerals, natural spring and table waters [17], Ordinance on health safety of drinking water [18], and Regulation of standard water quality [19].

Statistical data analysis (descriptive statistics, linear regression analysis, Spearman rank R correlation, ANOVA) were performed using the statistical program Statistica 7.1 [20].

RESULTS

The mean annual precipitation in the study area was 772.44 mm. The total potential evapotranspiration was 836.77 mm, and was higher than the total annual amount of precipitation (Table 1).

According to the results shown in Table 2, only the trend of potential evapotranspiration was positive and statistically

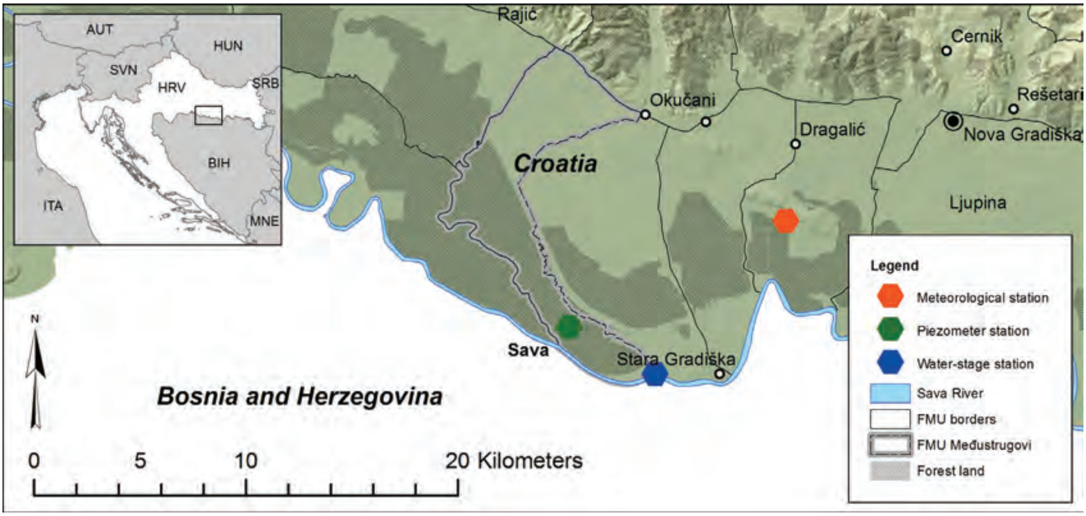

FIGURE 1. The study area

significant. The trends of annual and summer amounts of precipitation were not statistically significant.

The highest maximum water level of the Sava River was 906.00 cm, and the minimum 106.00 cm. The mean water level was 249.15 cm (Table 3).

Linear trends of maximum, mean and minimum water levels of the Sava River in the study area were negatively and statistically significant (Table 4).

The minimum ground water depth in the piezometer was 56.87 cm, and the maximum depth was 235.73 cm. The mean ground water depths in the piezometer ranged from 78.15 cm to 169.16 cm (Table 5).

Linear trends and the significance of trends of mean ground water depth for each piezometer were positive, though only column no. 4 showed a statistically positive trend (Table 6).

Table 7 shows the correlation of various forms of water in a lowland forest ecosystem. The strongest statistically significant correlation coefficient was found between ground water depths in piezometers no. 3 and 4 (0.98*) and the lowest statistically significant correlation coefficient was found between precipitation and ground water depth in piezometer no. 4 (0.66*).

TABLE 1. Descriptive statistics of climate elements and indices from Nova Gradiška weather station.

Climate element / index	Average	Minimum	Maximum	Std. Dev.
Precipitation (mm)	772.44	571.00	1105.00	108.81
PET (mm)	836.77	749.00	906.00	29.22
CMD (mm)	290.45	115.00	566.00	92.01

PET – Potential evapotranspiration; CMD – climate moisture deficit index

TABLE 2. Linear trends and the significance of trends for precipitation, air humidity, evaporation (PET) and moisture deficit (CMD).

Climate element / index	Linear trend	Beta	B	t	p-level
Annual precipitation (mm)	Y=0.121x+765.7	0.0352	0.1213	0.3649	0.7159
Relative air humidity (%)	Y=-0.166x+74.72	-0.1971	-0.1667	-0.5319	0.6111
PET (mm)	Y=0.294x+820.5	0.3184	0.2943	3.4739	0.0007*
CMD (mm)	Y=0.124x+283.6	0.0427	0.1243	0.4420	0.6594

* significant at p<0.05

TABLE 3. Descriptive statistics of the Sava River water levels.

Variable	Average	Minimum	Maximum	Std. Dev.
Maximum (cm)	698.27	517.00	906.00	87.24
Average (cm)	249.15	58.00	384.00	82.03
Minimum (cm)	-22.21	-106.00	58.00	48.84

TABLE 4. Linear trends and significant trends of maximum, mean and minimum water levels of the Sava River.

Water level	Linear trend	Beta	B	t	p-level
Maximum	Y=-6.270x+756.2	-0.4262	-2.655	-2.6235	0.0134*
Average	Y=-5.014x+274.8	-0.5951	-3.486	-4.1226	0.0003*
Minimum	Y=-4.341x+2.883	-0.8374	-2.921	-8.5292	0.0000*

* significant at p<0.05

TABLE 5. Descriptive statistics of ground water depths, measured by piezometer.

Piezometer	Average	Minimum	Maximum	Std. Dev.
PJ 1 (cm)	78.15	56.87	91.95	11.53
PJ 2 (cm)	145.53	127.03	169.88	14.52
PJ 3 (cm)	169.16	126.60	212.32	30.53
PJ 4 (cm)	168.65	125.35	235.73	36.95

TABLE 6. Linear trends and significance of trends of mean ground water depth for piezometer at the Međustrugovi forest unit.

Piezometer	Linear trend	Beta	B	t	p-level
PJ 1	Y=1.048x+71.88	0.3395	1.05	1.1972	0.2564
PJ 2	Y=1.609x+136.8	0.2964	1.61	1.0291	0.3255
PJ 3	Y=4.951x+144.6	0.5001	4.95	1.9154	0.0818
PJ 4	Y=7.577x+131.3	0.5880	7.60	2.4109	0.0346*

* significant at p<0.05

The strongest statistically significant negative correlation was between the climate moisture deficit index and minimum ground water levels (-0.96*), while the lowest negative correlation was between precipitation and climate moisture deficit index (-0.68*) (Table 7).

The metal concentrations in precipitation and flood waters during 2015 and 2016 were lower than the limit values. There was a significantly higher content of aluminium, cadmium, copper and zinc in precipitation than in flood waters. The content of iron was significantly higher in flood waters than in precipitation (Figure 2).

DISCUSSION

In the study area, of all the analysed climatic elements and indices, only the potential evapotranspiration trend showed a statistically significant increase. Global trends of warming can have effect on evapotranspiration which has direct effect on the sustainability of surface and ground water [21]. Annual quantities of precipitation showed a positive trend, though this was not statistically significant. Atmosphere capacity for taking and holding water exponentially increases with temperature, and due to that the increase of precipitation in forecasted.

TABLE 7. Spearman's R correlation of hydrological factors

Variable	P	RH	PET	CMD	Max. V	Ave. V	Min. V	PJ 1	PJ 2	PJ 3	PJ 4
P	1.00	-	-	-	-	-	-	-	-	-	-
RH	0.53	1.00	-	-	-	-	-	-	-	-	-
PET	-0.41	-0.88*	1.00	-	-	-	-	-	-	-	-
CMD	-0.68*	-0.79*	0.63	1.00	-	-	-	-	-	-	-
Max. V	0.66*	0.62	-0.65	-0.85*	1.00	-	-	-	-	-	-
Sred. V	0.71*	0.85*	-0.78*	-0.90*	0.83*	1.00	-	-	-	-	-
Min. V	0.63	0.72*	0.61	-0.96*	0.88*	0.88*	1.00	-	-	-	-
PJ 1	0.56	-0.15	0.08	0.11	-0.25	-0.13	-0.31	1.00	-	-	-
PJ 2	0.60	0.40	-0.65*	-0.40	0.50	0.58	0.40	0.68*	1.00	-	-
PJ 3	0.68*	0.80	-0.81*	-0.48	0.33	0.60	0.46	0.40	0.83*	1.00	-
PJ 4	0.66*	-0.73	-0.40	-0.80	-0.48	0.71*	0.76*	0.35	0.78*	0.98*	1.00

* significant at $p < 0.05$
P – precipitation, RH - relative air humidity, PET - potential evapotranspiration, CMD - climate moisture deficit, Max. V - maximum water level, Ave. V - average water level, Min. V - minimum water level, PJ - piezometer

However, changes in spatial and seasonal amount of precipitation will occur [22]. This increase in the quantity of precipitation in the study area does not necessary mean greater quantities of available water for vegetation. According to Ondrašek *et al.* [10], the water balance in an ecosystem can be described by the equation: water balance = input (precipitation, surface and ground flow) – output (evaporation, transpiration, runoff, infiltration).

Changes in trends of any of the components of this equation will certain impact the water balance in the ecosystem. Significant increases in evapotranspiration as an output variable will negatively impact the water balance in the ecosystem. A significant increase in the amount of evapotranspiration is primarily due to strong increases in air temperature [23].

The increase of precipitation, temperature and evapotranspiration could have different effect on different water-holding layers, i.e. aquifers [11].

In lowland forests, a particular problem is the disturbance of the regime of surface and ground waters caused by agricultural amelioration and other water regulation works for the purpose of flood control. Water regulation works in lowland forest areas have changed the dynamics of the flood and ground waters, and recent climate changes have altered river water levels. Ground water is not a static category and instead shows a seasonal tendency associated with the regime of the catchment area. In the winter/spring period, the ground water levels reach the soil surface in most of the lowland forests, connecting with flood waters in certain areas [24]. A higher number of dry days were recorded in the Međustrugovi forest unit in the period from 2001 to 2012, resulting in a drop in ground water levels in certain piezometer columns [25]. In this area, the water levels in the Sava River also affect ground water levels, which also decreased during the study.

In the hydrological cycle, water is found in various forms, from liquid to gaseous. Water also passes through various spheres, from the atmosphere through the ground surface to the underground. This study established significant correlations between atmospheric, surface and ground waters in the lowland forest ecosystem. A significant and negative correlation was found between potential evapotranspiration and the level of ground water at depths of 1.5 m and 2.5 m. An increase in the amount of potential evapotranspiration increases water consumption and reduces soil moisture, thus reducing ground water stocks in lowland forests. These results confirm the results of comparative water balance study in Hungary [26]. They stated that during periods of drought, the share of water consumption from ground waters in English oak forests was up to 90% of the amount of transpiration, while during wet weather, water consumption from ground water was significantly lower.

According to Ondrašek *et al.* [10], in the moderate climate belt, where the average annual precipitation ranges from 500 to 1500 mm, the output variables of the hydrological cycle (evapotranspiration, infiltration and runoff) are equally represented, each accounting for approximately 33% of the quantity of precipitation. It can be assumed that with significant increases in the amounts of potential evapotranspiration, this percentage ratio will change. According to the results in Table 7, the quantity of precipitation significantly affects water levels in the Sava River. Also, precipitation significantly increases ground water levels. The results of this study in the Posavina region (Međustrugovi forest unit) confirmed an earlier study in the

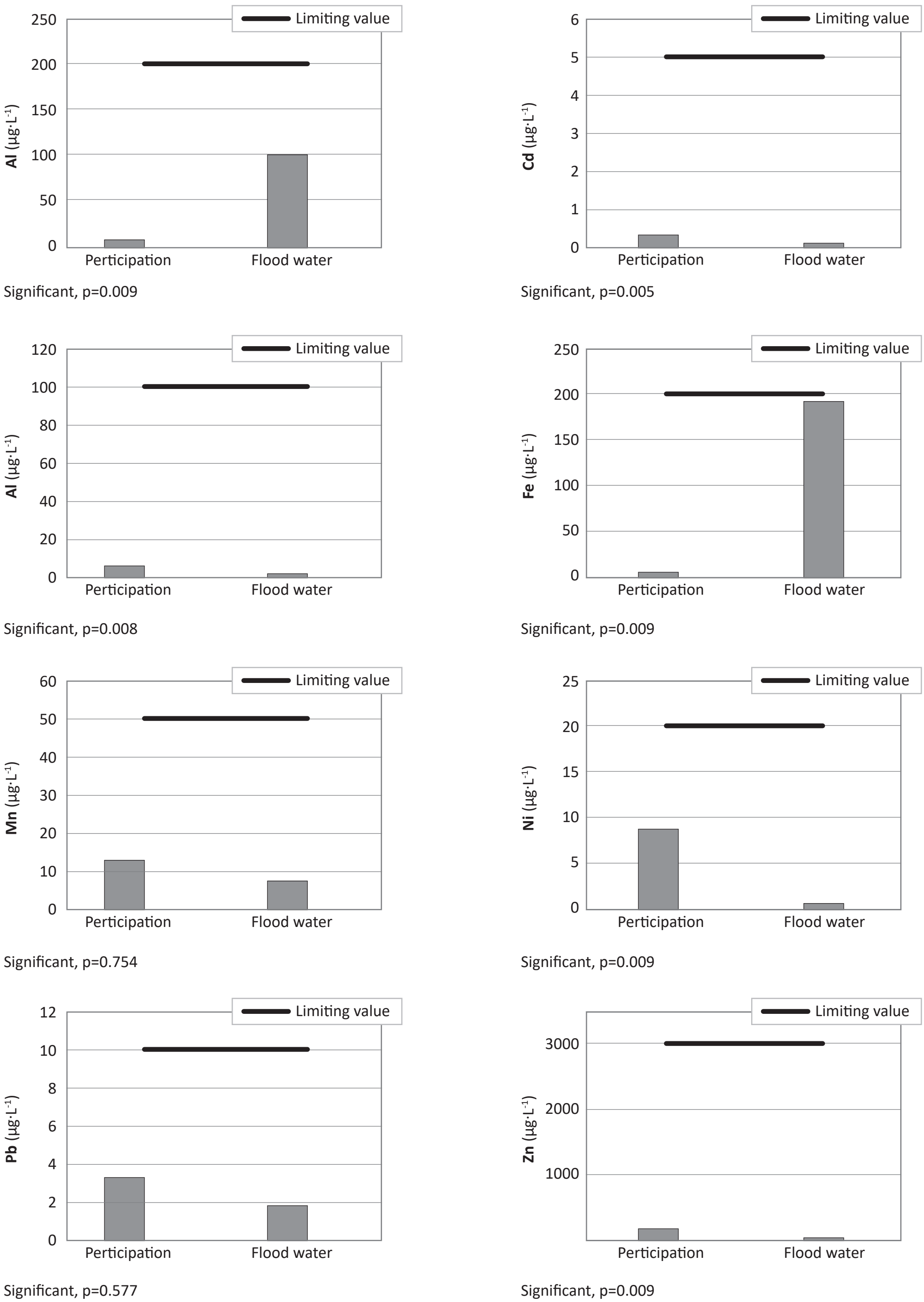

FIGURE 2. Metal content in precipitation and floods

Podravina region in the Repaš forest unit on the connection of surface water courses with ground water levels [3].

However, the trends of maximum, mean and minimum water levels of the Sava River were significantly reduced in the study area, meaning that the ground levels will also be reduced, while with increased amounts of potential evapotranspiration, the amount of water in the lowland forest ecosystem will decline. According to Ceglar and Rakovec [27], in the catchment basin of the Sava River, forecasts for the 21st century include an increase in air temperatures in all seasons of the year, and significantly decreased quantities of precipitation in the summer period, while there will be less reductions of precipitation in spring and autumn. The decrease of precipitations in summer months will result also in the decrease of Sava river water level, and the decrease of ground water level, since they are correlated. Surely, forecasted decrease of precipitations in summer months will cause changes in the precipitation regime in lowland forest areas.

Knowing water quality enables an understanding of its origin, the possibilities for use of such water, the presence of pollutants, and the possibility of removing those pollutants [28]. From the chemical indicators monitored in precipitation and ground water, all analysed metals had concentrations under the limit values (Figure 2). This supports a previous studies [29, 30] that reported that water pollution of the Sava River with elements such as Cu, Ni, Zn and Pb was low. Iron (Fe) is present in nature as a result of pipe corrosion, the rinsing of acidic ores, and industrial waste waters containing iron. It is found completely dissolved in water, or in colloid form. Iron concentrations in this study approached the limit values of 200 $\mu g \cdot L^{-1}$ [18]. Higher concentrations of aluminium and iron can be explained by the stagnation of flood water. The atmosphere also influences the pollution of precipitation and ground water, and is an important medium for pollution transport. Pollutants are deposited from the air onto soil as parts of aerosols. Some metals settle due to the activity of gravity, and are then rinsed from vegetation into the soil and further into the ground waters, lakes, rivers and seas [24]. Furthermore, the activity of microorganisms in water and the anthropogenic effects in the environment post a significant threat for watercourse pollution [8]. The established differences in the concentrations of heavy metals in precipitation and flood waters are certain due to the composition of water, determined by a series of processes that unfold in the environment, primarily physical, chemical and biological processes.

CONCLUSIONS

The trends of the potential levels of evapotranspiration were positive and statistically significant. The precipitation trends and moisture deficit index were also positive, but not statistically significant. The maximum, mean and minimum water levels of the Sava River showed a statistically significant reduction in the study area. Ground water depths increased in all piezometer columns. This trend, however, was statistically significant only for column no. 4. This study found statistically significant correlations between atmospheric, surface waters and ground waters in lowland forest ecosystems. Increased precipitation significantly increased the maximum and mean water levels of the Sava River. Additionally, an increase in precipitation levels significantly decreased the depths of ground water, especially in columns at greater depths. An increase in relative air moisture reduced the moisture deficit and the amount of potential evapotranspiration. With increasing amounts of potential evapotranspiration, forest trees increase their use of water from the ground water. At higher water levels of the Sava River, the moisture deficit index in the ecosystem was significantly reduced. With an increase in the mean and minimum water levels of the Sava River, the level of ground waters increased at greater depths. Increased concentrations of Cd, Cu, Mn, Ni, Pb, Zn were measured in precipitation. Flood water contained increased concentrations of Al and Fe. The pollution of precipitation and flood water was beneath the limit values.

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Structural Elements and Morphological Characteristics of Pedunculate Oak (*Quercus robur* L.) in Young Even-Aged Stands of Spačva Forest

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ABSTRACT

Background and Purpose: Croatian Forest Research Institute and Croatian Forests Ltd., Zagreb, have in 2010 jointly proposed a scientific experiment on permanent experimental plots called “The Impact of the Intensity of Silvicultural Tending on Pedunculate Oak Dieback”. The basis for setting up experimental plots were the results of the analysis of surface structure of pedunculate oak (*Quercus robur* L.) stands of Spačva Forest and its projection area for the next 140 years, and the related issues of regeneration of old and tending of young stands in conditions of increasing climate change. In the future this will present a major problem for forestry practice in silvicultural operations, both in terms of workers and materials.

Materials and Methods: The experiment was conducted in the area of Forest Administration Vinkovci, Forest Office Vinkovci, Management Unit Kunjevci, in three subcompartments of different age (10, 15 and 20 years) where different intensities tending operations of cleaning were conducted. A total of 20 plots were established by using the already established network of silvicultural lines and paths, while the position was recorded by a GPS device. On each plot 30 pedunculate oak trees were permanently marked (600 trees in total). Tree selection was based on spatial and phenotypic criteria.

Results: The initial measurement on permanent experimental plots shows unsatisfactory number of pedunculate oak trees along with the high number of common hornbeam trees. The overall basal area has a tendency of continuous growth in relation to the age of experimental plots. The value of crown length in relation to the total height of pedunculate oak trees is 74.3% in subcompartment 32A, 53.5% in subcompartment 34 A, and 54.3% in subcompartment 38A. Trunk length, i.e. trunk purity also increases with age; in subcompartment 32A on average it amounts to 1.35 m, in subcompartment 34A to 3.28 m and in subcompartment 38A to 4.85 m.

Conclusion: After conducting periodic surveys of the established plots by the year 2020 enough data should be collected whose processing, analysis and interpretation would provide guidelines for improving the future management of young pedunculate oak stands.

Keywords: silvicultural tending intensities, crown characteristics, young stands, future management

INTRODUCTION

Morphological characteristics of trees play an important role in trees’ defence and adaptation to changing habitat conditions in the context of global climate change. Developed crown indicates a more developed root system [1, 2] and therefore a greater degree of adaptation to habitat and climate changes [3]. Vajda [4] determined that in the same habitat conditions the proportion of dead pedunculate oak (*Quercus robur* L.) trees is smaller in the group with large diameter at breast height and well-developed crowns, while Shifley *et al.* [5] identified the social position of trees as one of the significant factors that increase the likelihood of the decline of North American oaks from the red oak group. Dekanić [6] considered the morphological features of pedunculate oak trees to be an extremely important preparatory factor in the complexity of individual tree dieback, while size, diameter increment and basal area increment are a good indicator of its vitality [7-9] and an indicator of habitat change [10].

Previous research shows that in the process of dieback of penduculate oak, trees with larger crowns, i.e. greater assimilation surface, are more resistant, while their crowns become more vital as their increment increases. It is known that in general pedunculate oak trees with underdeveloped crowns are more likely of dieback. One of the main causes of such crown development and intensive dieback is, among other things, the insufficiently intensive thinning which failed to be conducted in young stands. Thinning is known to be a necessary and essential silvicultural operation, while absence of tending in young stands causes a high degree of tree legginess and small reduced broom-like crowns which are not resistant to biotic and abiotic factors. Such crowns indicate small root systems that have difficulties to adapt even to smaller (ten year) oscillations in water-air regime in the soil.

Spačva Forest (Figure 1) comprises of diverse lowland habitats in which forests of pedunculate oak management class occupy 96% of the total area which amounts to almost 40,000 hectares. This makes it one of the largest coherent complexes of lowland pedunculate oak forests in Europe whose value cannot be measured monetarily because its environmental effect, primarily the anti-erosion and hydrological effect, is much more important than the economic one [11]. Today's oak groves of Spačva are remnants of old-growth forest structures which were mostly clear-cut between 1880 and 1914, reducing the forest cover of Slavonija from 60% to 35% [12]. Almost 75% of Spačva Forest consists of stands older than 80 years [13], while analysis of surface structure of pedunculate oak stands in Spačva Forest and its projection area shows that in the next thirty years regeneration will be very intense and consequently lead to a significant increase of areas with the stands of age-classes I and II.

Bearing in mind these facts and previous research on the structure and dynamics of the harvest of dead and declining pedunculate oak trees in Spačva Forest [14], as well as the dynamics of the decline of pedunculate oak trees depending on phytosociology and age [15], a real problem has appeared in that same areas in terms of financial and

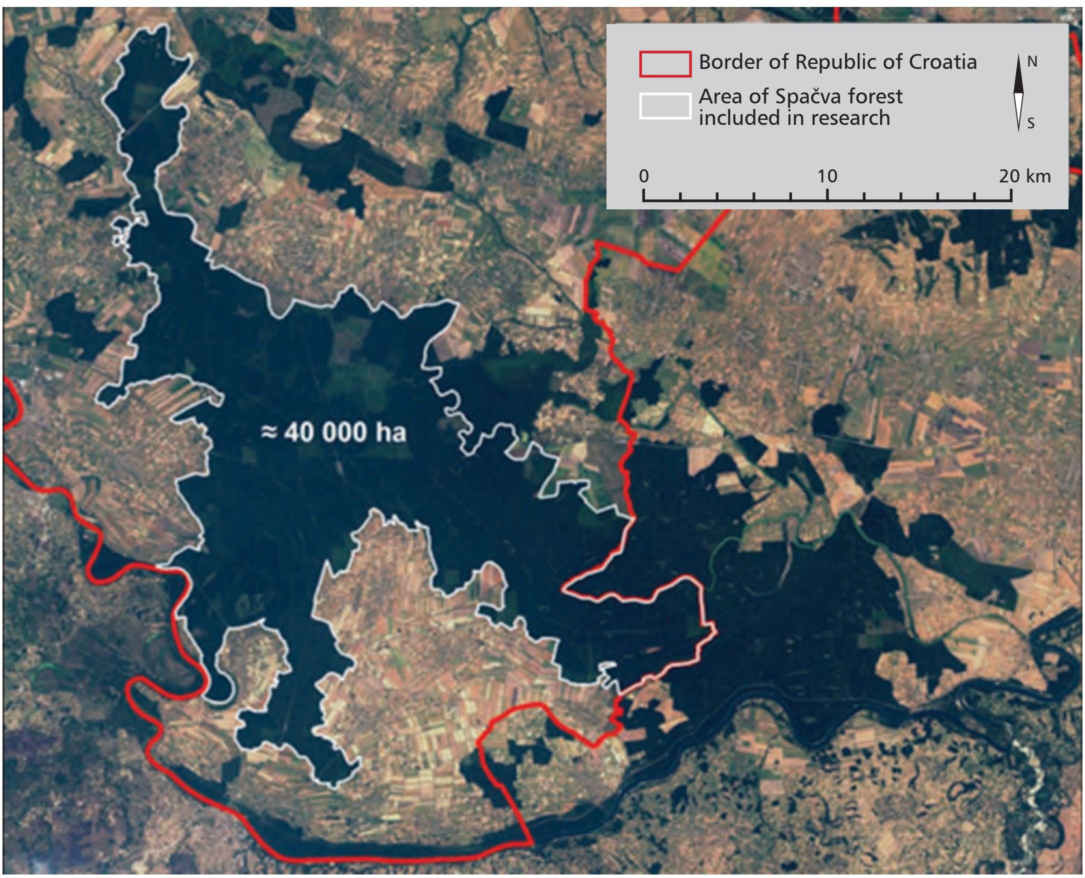

FIGURE 1. "Spačva" forest and investigated area on the LANDSAT satellite image from August 20, 2000.

human resources and how to carry out all necessary work during both the regeneration phase and tending phase of the stand. Tending operations conducted in young stands are essential to their structure, quality and productivity; the intensity and methods of tending have to be harmonized with natural processes prevalent in the stand and with biological characteristics, environmental requirements and silvicultural traits of the tended species [16].

In light of these findings Croatian Forest Research Institute and Croatian Forests Ltd. Zagreb, in 2010 jointly proposed a scientific experiment on permanent experimental plots called “The Impact of the Intensity of Silvicultural Tending on Pedunculate Oak Dieback”. The experiment was conducted in the area of Forest Administration Vinkovci, Forest Office Vinkovci, Management Unit Kunjevci.

Since very little research has been done on the morphology of young even-aged stands of pedunculate oak both in Croatia and globally, and since there is little data available in the literature, except on the features of growth and the development of crowns in the youngest stands of age-classes I, II and III [17-20], the purpose of this article is to contribute to the knowledge about those values. Therefore, along with other data on this study, the article includes rarely measured and published data on tree crown radius, first branch height and other features, all with the aim of better knowledge and understanding of relations within young pedunculate oak stands.

MATERIALS AND METHODS

The process of creating surface structure projection area started with the analysis of data from the management plan. Based on the management plan data 13 management units with predominant pedunculate oak management class were selected, covering the area of Spačva Forest managed by Forest Administration Vinkovci (Table 1), and were then used for further analyses.

The results from the data analysis were used for creating surface structure projection area for the studied management units for the period of the next 140 years (2011–2150) (Figure 2).

This projection has shown that with current methods of natural regeneration of pedunculate oak stands under the crown canopy of old trees already by the year 2020 the surface area of young stands is expected to increase; the area of the age-class I will reach maximum value in 2044 on a total of 18,000 ha or 43% of the studied area, while the surface of age-classes I + II will reach maximum value in 2050 on a total of 27,000 ha or 64% of the studied area.

As part of the project “The Impact of the Intensity of Silvicultural Tending on Pedunculate Oak Dieback” 20 permanent experimental plots were established in the area of Forest Administration Vinkovci, Forest Office Vinkovci,

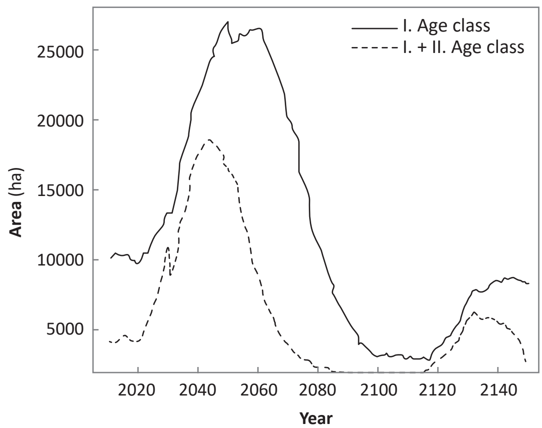

FIGURE 2. Graphical overview of trending projection of I. and II. age class for the next 140 years

TABLE 1. List of managment units and number of subcompartments for pedunculate oak managment class used for analysis

No	Managment unit	Managment plan (starting year)	Number of subcompartments	Area (ha)
1	Ceranski lugovi	2001	113	2064.92
2	Debrinja	2007	234	4551.87
3	Desićevo	2007	160	2082.85
4	Dubovica	2002	43	809.46
5	Kragujna	2003	256	3310.11
6	Kunjevci	2002	169	2731.44
7	Kusare	2003	120	2707.73
8	Naračke	2003	82	1577.88
9	Otočke šume	2001	110	2413.36
10	Slavir	2004	434	7858.32
11	Topolovac	2002	121	3208.66
12	Trizlovi-Rastovo	2007	133	1809.72
13	Vrbanjske šume	2005	600	7569.98
	Total		2575	42696.30

Management Unit Kunjevci, in subcompartments 32A, 34A and 38A (Figure 3). All the plots were established in a typical pedunculate oak-hornbeam forest (*Carpino betuli-Quercetum roboris typicum* Rauš 1971).

Preliminary selection of experimental plot locations in each subcompartment was made by terrain reconnaissance along with the digital terrain model created for the purpose of removing the effect of the microrelief. First the plots were temporarily staked out by using the already established network of silvicultural lines and paths and their position was recorded with a GPS device. After importing the preliminary locations of plots into the ArcMap program, the plots were arranged so that all plots are within 50 cm of the altitude range of the terrain. The final locations of plots were permanently marked by wooden stakes containing repetition marks and the number of the plot (Figure 4). The size of each of the 20 staked out plots is 33 x 35 m (Figure 5). The area of each plot is 0.12 ha (Table 2).

On each plot, 30 pedunculate oak trees were permanently marked with orange plastic tags for log classification (Figure 6). In total 600 trees were marked. The selection of trees was done according to the phenotypic and spatial criteria. Phenotypically best trees were chosen which are completely healthy and without noticeable damage (mechanical, game damage, barkpeeling damage, bitten off shoots). The trunks of those trees had to be of good quality (straight, without rowlocks or thick branches), while the trees had to be the highest in the vertical structure. They also had to be grown from seeds and had to have well-developed crowns (crown tops in the upper third of the crowns). The older trees that represented pre-growth were not selected. By using the spatial criterion 10 pedunculate oak trees, evenly distributed on the surface with triangular spacing between the selected trees, were chosen on each line. Depending on the field conditions the distance was 2-3 meters.

In each subcompartment two repetitions composed of three experimental plots called "Standard practice", "Treatment" and "Control" were set up, with the exception of subcompartment 32A in which an additional plot called "Reduction" was set up as well.

On "Standard practice" plots, procedures in accordance with current standards in practice were carried out. In this process it is assumed that the number of oak tree trees was not reduced or that it was reduced only minimally.

On "Treatment" plots the number of oak tree trees was reduced to about 1000 future trees per ha with spacing

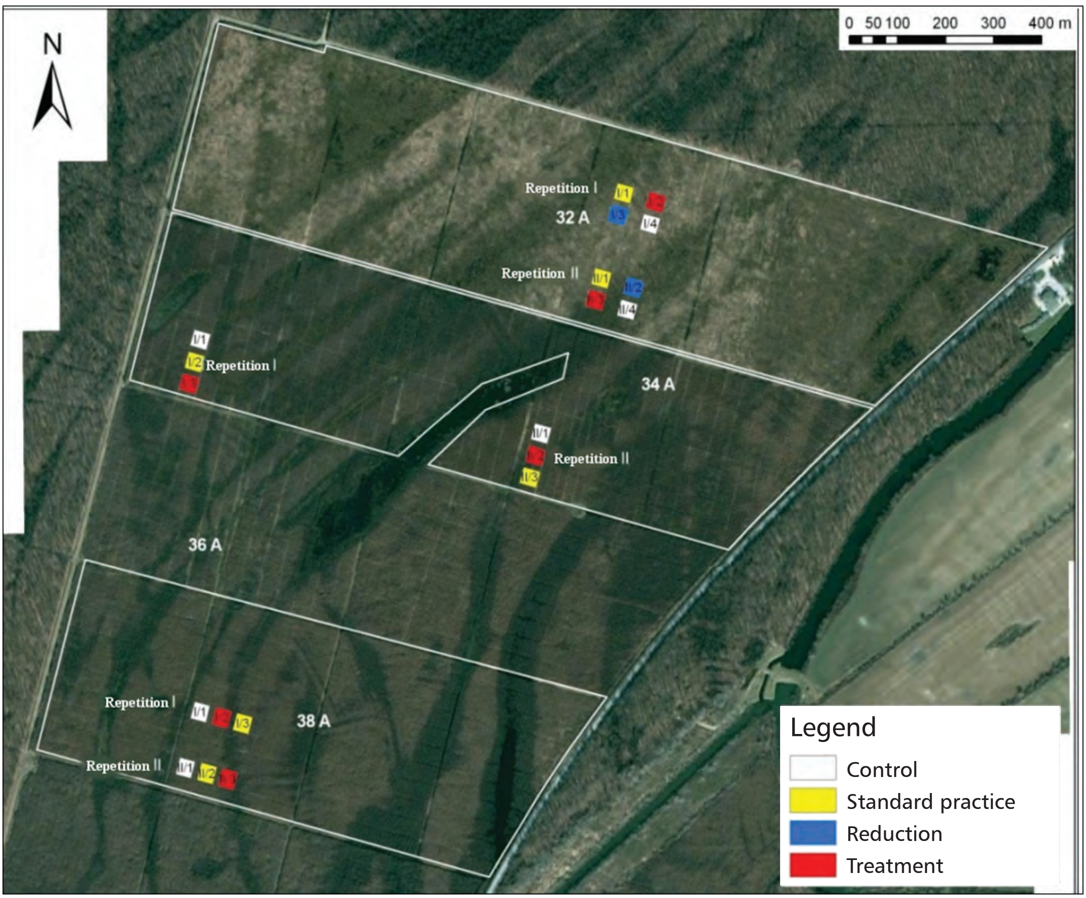

FIGURE 3. Location of permanent experimental plots

TABLE 2. Basic information about subcompartments in which experimental plots are established.

Subcompartment	Stand age* (year)	Area (ha)	Number of experimental plots			Area of experimental plots (ha)		
			Control	Treatment	Total	Control	Treatment	Total
32A	10	65.11	2	6	8	0.24	0.72	0.96
34A	16	46.13	2	4	6	0.24	0.48	0.72
38A	21	41.14	2	4	6	0.24	0.48	0.72
Total			6	14	20	0.72	1.68	2.4

*Stand age during initial measurement in 2011

FIGURE 4. Marking of the location of permanent plots

between the selected trees of 2.5 to 3 m. Cleaning was conducted only around marked trees, thus removing all the trees that impeded their growth, including pedunculate oak trees.

On "Control" plots no treatment was conducted and the plots were left to develop naturally. The measured values will be used for comparison with other plots.

In subcompartment 32A the "Reduction" plot was established on which high quality pedunculate oak trees were left with spacing of about 1.5 m, while all competitors were removed by cleaning, carried out on the entire surface of the line. All other pedunculate oak trees were removed, regardless of whether or not they obstructed the selected trees.

After the establishment and marking of permanent experimental plots, the selection of future trees and the conducted cleaning, measurements were carried out. The measurements were carried out in the spring of 2011. On each of the three inner lines two cross-sectional diameters at breast height, trunk length (height of the beginning of the crown), the height of the widest part of the crown, two crown radius and the total height of the tree were measured on marked pedunculate oak trees.

On two subplots of 5x5 m in size, the total measurement of trees was conducted by tree calliper gauge millimetre. Heights (with a bar for measuring height in cm) and diameters at breast height were also measured on the subsample of pedunculate oak and common hornbeam trees for the purpose of creating height curves. The diameter of trees which did not outgrow their breast height was measured at the half of tree height (0.5 H).

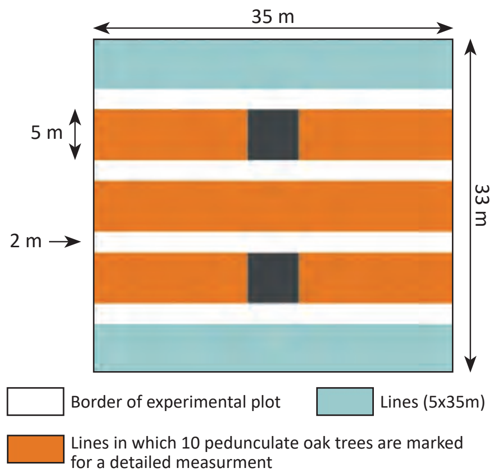

FIGURE 5. Structure of permanent experimental plot

FIGURE 6. Marking future trees of pedunculate oak

The obtained data were analysed using Microsoft Office 2010 package and STATISTICA 7.1 [21]. In order to eliminate the impact of outliers and extreme values the median was taken as the mean value.

RESULTS WITH DISCUSSION

The analysis and processing of filed data provided basic elements of the structure which are shown in Tables 3 and 4 which offer interesting conclusions.

The number of pedunculate oak trees as compared to hornbeam (Table 3) is not optimal; in young stands of pedunculate oak and common hornbeam (3-10 years) the total number of plants ranges from 35,000 to 40,000 per ha, out of which pedunculate oak trees should amount to 24,000–32,000 trees per ha and common hornbeam to about 18,000 trees per ha, along with other accompanying plant species [22].

Novotny *et al.* [23] have found that for the middle of first age-class there are 2175 trees per ha of pedunculate oak with a basal area of 9.47 $m^2 \cdot ha^{-1}$, 2850 trees per ha of common hornbeam with a basal area of 8.23 $m^2 \cdot ha^{-1}$ (in total 5750 trees per ha and 20.34 $m^2 \cdot ha^{-1}$), while according to the guidelines for creating ecological-management types [24] in the first age-class there are 3495 trees per ha of pedunculate oak with a basal area of 9.4 $m^2 \cdot ha^{-1}$, and 2460 trees per ha of common hornbeam with a basal area of 4.9 $m^2 \cdot ha^{-1}$ (in total 5955 trees per ha and 14.3 $m^2 \cdot ha^{-1}$). If we compare this data with the results from Table 3, we can clearly see big difference which indicates a significantly disrupted natural structure according to the number of pedunculate oak trees and their basal area. The situation is in a way satisfactory in subcompartment 32A, while in subcompartments 34A and 38A the values are above the optimum. Such results show the problematic future of these stands in terms of their stability and productivity.

The value of the crown length in relation to the total height of pedunculate oak trees in subcompartment 32A is 74.3%, in 34A 53.5% and in 38A 54.3%. These values are higher than the results of previous research; Dubravac [25] and Hren and Krejči [26] determined the value of crown length to be 45% of the total tree height.

Figure 7 represents a box-and-whisker chart. Based on this figure, while taking into account the subcompartment age, it can be concluded that trunk length, i.e. trunk purity increases with age; in subcompartment 32A its average value is 1.35 m, in 34A 3.28 m and in 38A 4.85 m.

Crown length of the tree also increases with age (Figure 8). The mean values range from 2.78 m in subcompartment 32A to 5.66 m in subcompartment 38A. Dubravac [19] stated that the crown length of the age-class I amounts to 2.93 cm, but it should be emphasized that this referred a small sample (1 experimental plot, 18 trees). The same author [18], also on

TABLE 3. Number of trees and basal area in researched area

Subcompartment	Stand age* (year)	Area (ha)	Pedunculate oak		Common hornbeam		Overall	
			N (trees·ha^{-1})	G (m^2·ha^{-1})	N (trees·ha^{-1})	G (m^2·ha^{-1})	N (trees·ha^{-1})	G (m^2·ha^{-1})
32A	10	65.11	25452	6.23	21050	3.56	49875	9.79
34A	16	46.13	2733	3.79	77900	20.89	85633	24.59
38A	21	41.14	1833	10.37	23067	18.39	30667	28.76

*Stand age during initial measurement in 2011

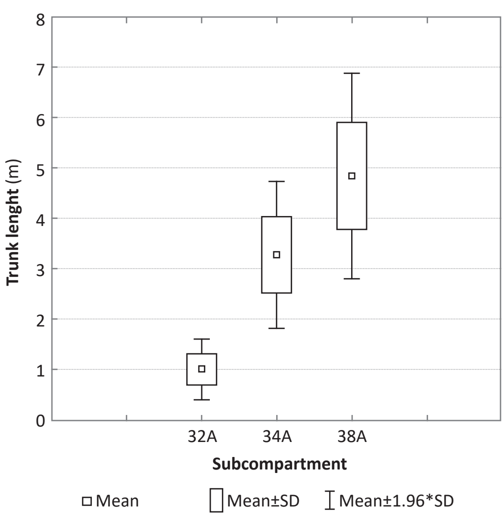

FIGURE 7. Trunk length of pedunculate oak in 3 subcompartments (n=600)

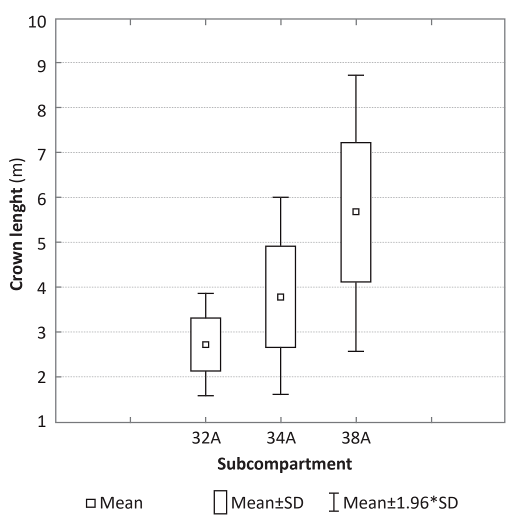

FIGURE 8. Crown length of pedunculate oak in 3 subcompartments (n=600)

TABLE 4. Morphological traits of pedunculate oak for researched area

Subcompartment	**Stand age*** (year)	**Mean diameter at breast height** (cm)	**Total height** (m)	**Trunk lenght** (m)	**Mean crown radius** (m)	**Crown lenght** (m)
32A	10	2.86	3.74	1.35	0.86	2.78
34A	16	5.73	7.08	3.28	1.07	3.79
38A	21	9.3	10.43	4.85	1.30	5.66

*Stand age during initial measurement in 2011

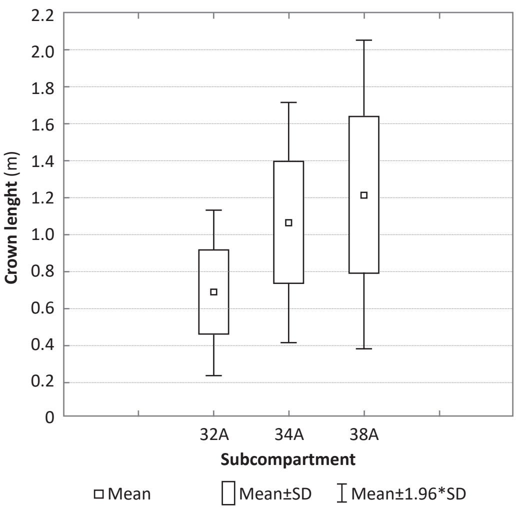

FIGURE 9. Crown radius of pedunculate oak in 3 subcompartments (n=600)

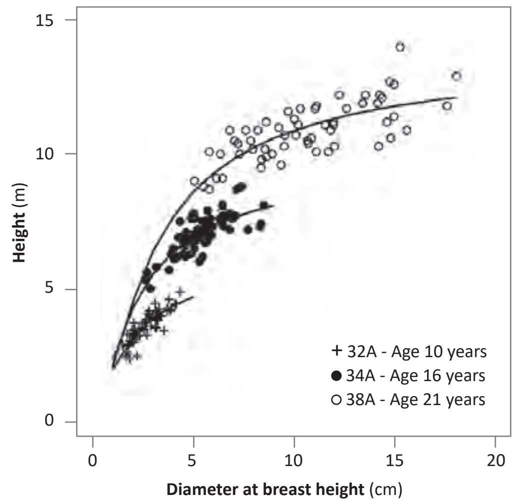

FIGURE 10. Height curve of pedunculate oak in 3 subcompartments of different age (n=180 model trees)

the sample of one experimental plot, determined the mean value of 1.39 m for crown radius in the age-class I. In our research (Figure 9) the values for crown radius are 0.73 m for subcompartment 32A, 1.07 m for 36A and 1.30 m for 38A.

From the created height curves (Figure 10) it is apparent that the height gain is intense and that the curve shifts "up and to the right". At the time of intensive height growth of the even-aged stands, a significant shift of the height curve is achieved [16], and comparison of the height curves for subcompartment 34A and 38A shows that in the older stand the trees of the same diameters have a higher height. Also, there is greater diameter dispersion with the increase of the stand's age.

CONCLUSION

The initial measurement on permanent experimental plots shows unsatisfactory number of pedunculate oak trees along with the high number of common hornbeam trees, which is in direct link with improper implementation of tending, thus endangering the future and the stability of these stands.

The overall basal area has a tendency of continuous growth in relation to the age of experimental plots. The initial increase is large, from 9.79 $m^2 \cdot ha^{-1}$ to 24.59, followed by a significant increase in the number of trees and an increase in diameter at breast height. The increase is then reduced, amounting to 28.76 $m^2 \cdot ha^{-1}$ on the oldest experimental plot with a significant reduction in the number of trees and the increase in diameter at breast height.

Trunk purity of young pedunculate oak trees was measured from the ground to the first branch height and is expressed in meters. Based on the measured data it can be concluded that with the increase in age the height at which the first branches appear also increases. In other words, trunk purity increases with age, therefore amounting to an average of 1.35 m on the youngest experimental plot, while on the oldest plot it amounts to an average of 4.85 m.

After conducting periodic surveys of the established plots by the year 2020 a sufficient amount of data should be collected whose processing, analysis and interpretation would provide guidelines for improving the future management of young pedunculate oak stands.

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CORRECTION

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