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Dear readers,

With great pleasure we would like to inform you and introduce you to some changes that have been done both in the printed and the online version of the journal all in order to improve and enhance the journal's quality.

First, you will notice that the layout of the papers in the printed version has undergone some minor changes. We have tried to improve the visual appearance as well as provide more information on the main page of each paper. Nevertheless, the biggest change is the new journal's website (www.seefor.eu) where you can find much more information on the journal, its publication policy, the publishing procedure, etc.

The novelty is the online submission of the manuscript which substantially reduces the editorial processing and reviewing time and shortens the overall publication time. It also allows authors to follow the whole editorial process and check the status of their manuscript.

We have also sought to expedite the publishing time by introducing Next Issue - Early View section. As soon as they are accepted and prepared in the final format, the papers are published online and can be accessed within the Next Issue - Early View section. Every six months, the online published papers will be page-numbered and published in the new, upcoming SEEFOR issue.

We will continue with the Open Access policy of the journal which provides free access to full-text papers in pdf or html format. The full-text papers in html have been available since 2013, from Volume 4 Number 1. For earlier issues abstracts of the papers in html will be available soon.

Please visit our new website and register as a reader, author and/or potential reviewer. You are also invited to contribute to the journal with your valuable research. We have issued a call for papers for the next issue (Vol 5 No 1) which is scheduled to be published on 31*st* June 2014. However, as soon as they are accepted, the papers will be published online in the Next Issue – Early View section. Submission deadline is 31*st* March 2014.

We hope you will like the new 'refreshed' look of the journal and stay or become our faithful reader.

Editor-in-Chief
Dijana Vuletić

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Review paper

Airborne Laser Scanning - the Status and Perspectives for the Application in the South-East European Forestry

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Abstract

Background and Purpose: Over the last twenty years airborne laser scanning (ALS) technology, also referred to as LiDAR, has been established in a many disciplines as a fully automated and highly efficient method of collecting spatial data. In Croatia, as well as in most countries of the South-East Europe (SEE) with the exception of Slovenia, the research on the application of ALS in forestry has not yet been conducted. Also, regional scientific and professional literature dealing with ALS application is scarce. Therefore, the main goal of this review paper is to present the ALS technology to the forestry community of SEE and to provide an overview of its potential application in forest inventory. The primary focus is given to discrete return ALS systems.

Conclusions and Future Research Streams: Results presented in this paper show that the ALS technology has a significant potential for application in forest inventory. Moreover, the two-phase forest inventory based on the combination of ALS and field measurements has become a quite common operational method. Due to the expected advancement of the ALS technology, it may be presumed that ALS will have an even more important role in forestry in the future. Therefore, researches on application of ALS technology in SEE forestry are needed, primarily focusing to question of "if" and "to what extent" the ALS technology can improve the existing terrestrial method of forest inventory. Besides the application in the classical forest inventory, the option to apply it for estimation of the biomass, carbon stock, combustible matter, etc, should also be further investigated.

Keywords: LiDAR, airborne laser scanning, discrete return system, forest inventory

INTRODUCTION

Remote sensing is nowadays commonly used within many environmental disciplines, such as geography, geology, botany, zoology, civil engineering, forestry, meteorology, agriculture, oceanography, etc. [1]. Besides the commonly used remote sensing techniques (e.g. satellite and aerial digital images), laser scanning technology has been established over the last twenty years as a fully automated and highly efficient method of collecting spatial data [2]. Laser scanning technology is also referred to as LiDAR (the acronym for *Light Detection and Ranging*) which means detection and distance determination using a pulse of light [3, 4].

The main characteristic of LiDAR systems is the ability to collect large quantities of highly accurate three-dimensional spatial data over large areas in a relatively short time [5]. The collected data, whether from airborne LiDAR systems mounted on aircrafts or spacecrafts, or from terrestrial LiDAR systems, have a high vertical and horizontal resolution. Airborne systems usually have decimetre and sometimes even a centimetre resolution, while terrestrial systems can have up to a millimetre resolution [6].

Although the invention of the laser and laser scanning goes back to the early 1960s, only with the development of the Geographic Positioning System (GPS) in the 1980s and the Inertial Measurement Unit (IMU) in the 1990s, as well as the rapid development of computer technology, a faster and significant progress in LiDAR technology was enabled [7]. This happened when a wider practical application of LiDAR systems, primarily for topographic mapping, began [8]. In the meantime, many geodetic companies have recognized the advantages of the LiDAR technology, so its application is expanding rapidly and in some cases replaces traditional geodetic methods [5].

The first studies of LiDAR systems in forestry started at the end of the 1990s, with the determination of terrain elevations, the estimation of stand height and volume, and the location and segmentation of individual trees [9, 10]. Since then, the LiDAR technology has been continuously and rapidly developing and therewith the possibilities of its application in forestry. In the last 15 years, this technology has encountered great interest among the scientist and researchers worldwide [3, 11].

In Croatia, as well as in most countries of the South-East Europe (SEE) (e.g. Bosnia and Herzegovina, Serbia, Montenegro, Macedonia, Albania, etc.) with the exception of Slovenia [12-14], research on the application of LiDAR in forestry have not yet been conducted. Also, regional scientific and professional literature dealing with the topics on LiDAR is poor [15]. Therefore, the main goal of this paper is to introduce the LiDAR (airborne laser scanning) technology to the forestry community of SEE providing an overview of its potential application through a critical review. Essentials of the LiDAR technological characteristics, with the focus on the possibilities of LIDAR application in forestry, primarily in forest inventories, are discussed. The primary focus is given to discrete return systems, the most often used type of airborne laser scanners both in research and practice.

AIRBORNE LASER SCANNING BACKGROUND

LiDAR is an active remote sensing system that uses laser light (pulses) for scanning and collecting highly accurate three-dimensional (*x, y, z*) spatial data of targets [16, 17]. LiDAR systems are based on laser ranging, which measures the range (distance) between the sensor (scanner) and the target by calculating the product of the speed of light and the time required for an emitted laser pulse to travel to the target object [16].

Since LiDAR is an 'active' system, it is independent of natural sunlight, and therefore operates in all 'clear' conditions - day or night (i.e. obstacle free, including dense fog or smog, which can intercept or scatter too much the infra-red light pulse emitted from the system) [18, 19] which results in the extended time for data collection [20]. Moreover, LiDAR cannot operate during rainy days, because the most commonly used infrared light does not penetrate water vapour [5].

Depending on the platform on which the LiDAR system is mounted, the laser scanning technology may be divided into: (a) *Terrestrial Laser Scanning*, (b) *Airborne Laser Scanning*, and (c) *Spaceborne Laser Scanning* [7, 21]. Airborne laser scanning (ALS) systems are the most common type of LiDAR sensors [22] and, compared to terrestrial and spaceborne laser scanning systems, they are the most suitable for application in forestry [23].

Generally, most ALS systems have four major hardware components: (a) a laser scanner, (b) a GPS, (c) an IMU, and (d) a computer for system management and storage of the collected data [9, 24]. ALS can be performed from an aircraft or a helicopter. Flying heights may vary from 20 to 6000 m, while they usually are in the range of 200-1000 m (200-300 m for helicopters, 500-1000 m for airplanes) [18, 24]. The ALS systems for terrestrial application (including forestry) generally operate in the near-infrared wavelength range of 900-1064 nm where the vegetation reflectance is high. Namely, due to the fact that in the visible wavelengths the absorption by vegetation is very high, thus relatively small share of incoming energy would be reflected back to the sensor [25].

Based on the ranging principle applied in the range (distance) measurements between the scanner and the target object, ALS systems may be categorized as *discrete return* (DR) or *full-waveform* (FW) systems [8, 16]. A FW system emits a continual pulse of laser radiation and records the entire reflected energy (waveform) for analysis. The range value is obtained by measuring the phase difference between the transmitted and the received signal (radiation) backscattered from the object's surface [8, 9]. In contrast, a DR system records single or multiple returns from an emitted laser pulse [22]. The distance from the scanner to the reflecting objects is calculated as $R = c \times \frac{t}{2}$, where *c* is the laser pulse speed (assumed to be equal to the speed of light in the air) and *t* is the travelling time of the laser pulse from the scanner to the object and back [16].

During the last twenty years, the DR return system has been used more frequently in forest research and commercial purposes [26, 27]. Therefore, the primary focus in this paper is on the discrete return ALS.

The laser scanner is the core of any ALS system, and thus the DR system as well. According to Gajski [2], the main components of a discrete return laser scanner are: (a) a transmitter of laser pulses, (b) the scanning mechanism (e.g. rotating prism, oscillating mirror), and (c) a receiver with the component for measuring the travelled time of laser pulses.

During the ALS, laser pulses are emitted toward the terrain in the direction given by the scanning mechanism, usually side-to-side, perpendicular to the flight direction [2, 16]. Due to the aircraft (or helicopter) flight pattern, the scanning lines on the ground usually form Z-shaped (seesaw) *scanning patterns* (Figure 1). Depending on the type of the scanning mechanism, scanning patterns may also be of parallel, elliptical, sinusoidal or other forms [28, 29]. *The scanning swath* (or the *swath width*), i.e. the width of the area that may be 'covered' during the flight in one direction, is determined by the selected *scanning angle* (or the *field of view*) and the flying height [2, 30]. In order to provide a more complete representation of any given object within the scanning area, as well as to provide more rigorous and efficient swath-to-swath adjustments to remove swath biases, large areas are usually scanned with a series of swaths that often overlap by 50% or more [3, 29].

Therefore, along with the scanning lines, usually perpendicular to the flight line, the DR laser scanner emits near-infrared pulses of laser energy with a typical duration of a few

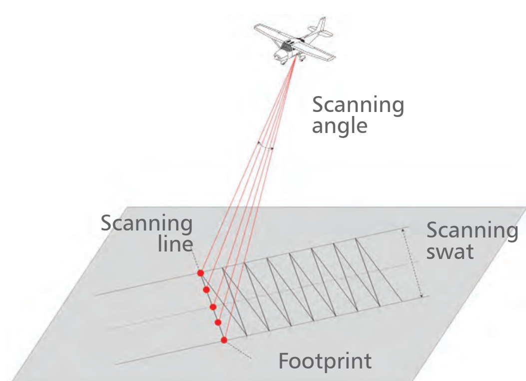

FIGURE 1. An illustration of the basic scanning attributes of the ALS data acquisition [28]

nanoseconds (10^{-9} s) and with a high rate of the scanning frequency (up to 300 kHz) [5, 30]. This means that DR laser scanners are capable to emit up to 300,000 laser pulses per second. A diameter of the reflecting surface illuminated by a laser pulse is called the *footprint diameter* and depends on the pulse (beam) divergence and the flying height [28, 30]. For example, for the pulse divergences of 0.3 mrad, at a typical flying height of 1000 m, the laser footprint diameter is about 0.3 m [7]. Since the footprint diameter of DR systems usually ranges between 0.2-1.0 m, they are considered '*small-footprint*' systems [3, 29]. On the other hand, ALS systems with a footprint diameter greater than 1.0 are called '*large-footprint*'.

The earliest DR systems were able to record only one 'return' (echo, reflection) or two (first and last) returns from a single laser pulse. Their primary use was for mapping applications, e.g. to create Digital Surface Models (DSMs) and Digital Terrain Models (DTMs) from the first and last returns, respectively [8, 31]. The most modern, so-called '*multiple-return*' systems may record up to five returns from a single laser pulse [25, 28]. In multiple-return systems, when the laser pulse is intercepted by an object, a part of the energy is reflected toward the receiver and recorded as the first return. When the object is not solid or too dense (e.g. tree branches) and does not completely block the pulse, the remaining part of the pulse continues its path and may be reflected by lower objects as e.g. the second, third, or fourth return, or eventually reflected from the ground surface as the fifth (the last) return (Figure 2) [3, 15]. This case often occurs in forests where crowns have small gaps between the branches and foliage [3]. In theory, the last return should be reflected from the ground surface, but in practice, especially in environments such as a forest, the situation could be different. According to the study conducted by Chasmer et al. [32], only 50% of last returns in forests are usually reflected from the ground surface. Therefore, it is necessary to determine which of those last returns are reflected from the ground surface and which from some understory layer using different filtering and segmentation techniques. When the primary objective of ALS is to produce a DTM of a forested area, most of the scanning missions are taken during the leaf-off conditions, to maximize the percentage of pulses reflected from the ground surface. In contrast, when the primary objective is the determination of forest structure, ALS is usually done in leaf-on conditions to maximize the number of returns from tree crowns and other sub-canopy (understory) layers [3]. The major strength of multiple return systems is their ability to 'see' through the canopy and to record and measure the vertical forest structure [9, 33]. Therefore they could be useful in forest research or forest inventory measurements.

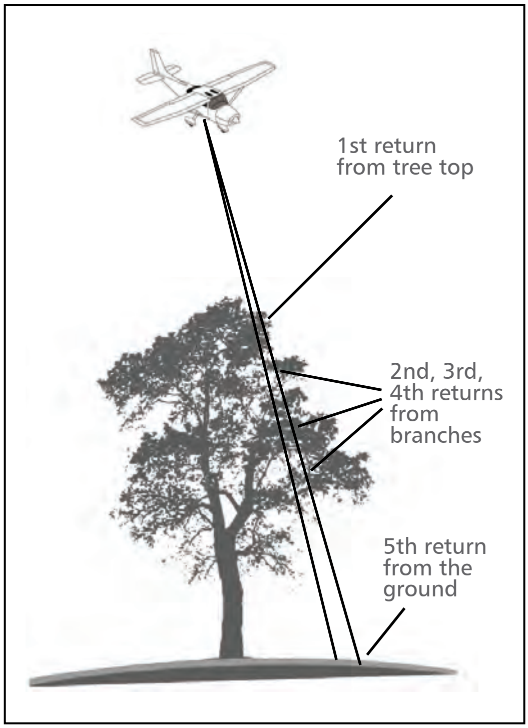

FIGURE 2. Multiple returns from a single laser pulse [26]

Pulse density, point density or scanning density is the most consistent measure of the spatial resolution of an ALS data set [28] and is commonly expressed as the number of pulses per m^2. It is often confused with the *return density* (the mean number of returns per m^2) even though the two densities are different, especially in cases of multiple return systems. Pulse density is an important parameter in the planning process of ALS, and is defined by horizontal footprint spacing. It may range from 0.3 to 20 pulses/m^2 (or even more) and the optimal density is indicated by the application and a desired results [29]. It is important to recognize that the pulse density is positively correlated with the quality and precision of the resulting products, and consequently, with the acquisition costs. According to Evans et al. [29], pulse densities of 4-6 pulses/m^2 are a good compromise between the cost and accuracy of the obtained data in vegetation applications, while some ALS providers recommend a minimum of 8 or even 15 pulses/m^2 for forestry applications [34].

In order to geo-reference all the obtained returns the ALS systems are combined with a *Position and Orientation System* consisting of the GPS and IMU components. Three-dimensional *(x, y, z)* coordinates of the reflected points (returns) are then calculated based on the accurate position of the scanner determined from the GPS and the orientation of the scanner measured by the IMU [8, 16].

Each return of the laser pulse, besides the 3D coordinates, contains a record of the signal's *return intensity* [16, 18]. The return intensity is usually recorded in 8 bits (values 0 to 255) or 12 bits (0 to 4095), and therefore may be presented as a grey-scale raster that looks like a black-white aerial photograph [28]. Because of the several factors influencing the recorded intensity, such image may not be used for classification purposes in the same way as aerial photograph. According to Baltsavias [16, 18], the recorded intensity depends on the flying height, atmospheric conditions, directional reflectance properties, the reflectivity of the target, and the laser settings. To overcome such an issue, ALS data may be combined with some other remote sensing data (i.e. multispectral, hyperspectral, etc.). For example, digital aerial cameras may be integrated with ALS system to simultaneously provide data of the surveyed area [35, 36].

The initial resulting product of any ALS system is a dense dataset of recorded returns with range measurements and additional positional information (GSP and IMU measurements), known as the *point cloud*. In order to obtain georeferenced data of high vertical and horizontal accuracy and other products (e.g. DTM, DSM), the processing of such raw data is necessary. According to Gajski [2], five major steps of the ALS data processing can be identified: (I) *direct georeferencing* based on the GPS and IMU measurements; (II) swath-to-swath (strip) *adjustments* for system *calibration* and detection of erroneous points; (III) the point cloud *segmentation* based on geometric characteristics of objects to which they refer; (IV) *filtering* by which useful information (points) are separated from the useless, and *classification* by which useful information is divided into classes (e.g. vegetation, objects, bare ground, *etc*.); and finally (V) *data reducing* to the minimum amount sufficient for a 'description' of the object with satisfactory quality.

As already mentioned, ALS data and products have a high vertical and horizontal accuracy which however primarily depends on the pulse (scanning) density. Accuracy is usually expressed as the root mean square error (RMSE): most ALS system vendors place the RMSE in the range of 5-15 cm for vertical and 25-100 cm for horizontal direction [3, 5].

APPLICATION IN FORESTRY

During the last 15 years, the ALS technology has encountered great interest within the forestry scientific and research community. Considerable research has been made on the possibilities of ALS application in forestry, in particular in forest inventories and in estimation of stand structure elements [27, 37]. However, the earliest research in forestry primarily focused on the creation of two main cartographic ALS products: DTMs and DSMs, used to describe forest terrain surfaces and tops of forest surfaces, respectively. These products were used for deriving the Canopy Height Model (CHM) which is the difference between canopy altitudes (DSM) and bare ground altitudes (DTM). From CHMs it is possible to estimate the stand structure elements, such as canopy (stand) heights, gain an insight into the vertical structure of stands [38] and derive other stand attributes such as stand volume or, stand biomass.

Generally, there are two main approaches to derive forest information from ALS data: the *area-based* (or *distribution-based*) approach (AB) and the *individual tree-based approach* (ITB) [3, 17, 26, 39]. The choice of the approach mostly depends on the desired accuracy of the final result and the available pulse density [17, 26].

Area-based approach

In the AB approach, the mean forest stand characteristics for a certain area (e.g. plot, stand) are estimated using statistical analyses and established empirical relationships (models) between ALS data (processed point clouds, DSMs or CHMs) and terrestrial measured variables [3, 37]. This approach was originally devised by Næsset [40, 41] and is also known as the *two-stage procedure for stand inventory* or the *double-sampling forest inventory* [42]. In the first phase, empirical relationships of ALS data (e.g. all returns aggregated at the plot level, percentiles of the relative height above ground, etc.) and the terrestrially measured data (e.g. height, density, basal area, volume, aboveground biomass) for particular sample plots are obtained.

These relationships, in the second phase, are used to estimate forest characteristics (variables) on other plots in a particular area [38, 42].The results of past researches showed the potentials of AB methods in estimating stand structure elements, such as tree density [42, 43], mean stand height [17, 40, 42, 44-48], mean stem diameter [16, 42, 46, 49], mean basal area [42-46, 49], volume [41-43, 45-47, 49, 52, 53], aboveground biomass [45, 53-55] and carbon stocks [50, 56, 57] (Table 1). In addition, AB methods could be used for assessing leaf area index [58-60] and fuel parameters [61, 62].

The advantage of the AB methods lays in the fact that they are applicable even with a lower pulse density. However, they require more ground measurements in the forest [17, 39], which are usually time consuming. The disadvantage is that the derived models are locally applicable, that is, specific for certain localities, types of forest stands and applied scanning methodology (flying height, pulse density, scanning angle, etc) [37, 38].

Individual tree-based approach

The main goal of the ITB methods is to identify individual trees from ALS data (the processed point cloud, DSM or CHM) visually or by various segmenting processes and to extract individual tree attributes, such as total height and crown dimensions (diameter, area, height). Based on such directly estimated variables and by using existing models, other variables could be derived (i.e. diameter at breast height, the basal area, volume, biomass, carbon stock, combustible matter for fuel, etc). Similarly to AB methods, ITB methods also require a set of ground measurements. Reference data are usually obtained from direct measurement of trees on sample plots within the surveyed area. However, ITB methods require a significantly smaller reference data set [26], but they needs for a higher pulse densities than AB methods [17, 39].

According to Andersen et al. [63], LiDAR data (processed point cloud) enables the visual identification of individual trees, determining the tops and delineating the crowns, if the pulse density is at least 4-5 points /m^2. Moreover, the previous research determined that in the forest stands of homogeneous structure the application of computer algorithms and segmentation may automatically detect individual trees and measure its parameters, such as the total tree height, crown height and crown diameter [63-67].

Tree detection

The research results indicated that the application of the ALS technology may detect the majority of the trees, that is, their crowns from the canopy layer (dominant and co-dominant layer), especially in the older coniferous stands

[65, 67-72]. However, problems arise for detecting trees of the understory layer, trees in young stands and/or with high stem densities, as well as deciduous stands. In such cases, the number of trees per ha is usually significantly underestimated [67-71] (Table 2).

Tree height estimation

Previous studies mostly focused on both tree and mean stand height estimation using AB and ITB methods, mostly because height is a variable which can be directly determined from ALS data [27]. Moreover, height can be correlated with other stand variables (diameter at breast height, volume, biomass) which are difficult to measure directly (or even impossible) with current ALS technology [3, 33]. In many research papers [63-65, 67, 70, 73-78] it was concluded that, especially for trees in dominant and co-dominant layers, precise estimation of tree heights from ALS data is possible, although the height is underestimated in most cases (Table 3). According to Nelson et al. [79], the principal cause of such an underestimation lies in the small probability that the laser pulse hits the real top of the tree, especially in the case of low pulse density. As said before, the requirement to "hit" the top of tree crowns with a laser pulse, as well as to go all the way through the crown to the understory vegetation and to the ground, requires that the ALS is made with appropriate pulse density. This issue was underlined by Lefsky et al. [25] who emphasizes that the proper pulse density remains an important research question.

Based on the research results in spruce and Scots pine forests, Næsset and Økland [64] concluded that a pulse density lower than 2.3 points/m^2 is insufficient to measure the size of individual trees (the total tree height and crown diameter). Takahashi et al. [80] conducted a study in *Cryptomeria japonica* (D. Don) plantations and concluded that the height estimations with deviations less than 1 m relative to the terrestrially measured heights require a pulse density higher than 8.8 points/m^2. Hyyppä and Inken [81] stated that for a successful estimation of individual trees parameters the pulse density should be higher than 10 points/m^2. Hyyppä et al. [10] emphasized that the accuracy of tree height estimation is influenced not only by the pulse density, but also by other variables such as: ALS system characteristics (footprint diameter, laser pulse divergence, scanning angle); the algorithms used for data processing; and the structural characteristics of the scanned vegetation (i.e. tree species, stand density, percentage and height of understory and ground vegetation, etc). Generally, the underestimation of tree height is less prominent for coniferous trees as they form conical, more compact and denser crowns, so that the penetration of the sent laser pulses through crowns is lower. On the other hand, the underestimation is higher with round crowns, as with most of deciduous trees, but also Scots pine [38].

Although underestimation of tree height from ALS data is common, overestimation of tree height with ALS is common in hilly and mountainous areas, that is, terrains with slopes greater than 20° [70, 80, 82, 83]. Véga and Durrieu [83] estimated tree heights on the sample of 245 Black pine (*Pinus nigra* ssp. *nigra*) trees located in the southern French Alps with the mean terrain slope of about 53%. Tree heights obtained from ALS were overestimated on average 0.84 m (± 1.63 m SD) in comparison to terrestrially measured heights. Moreover, Véga and Durrieu [83] found that overestimation of tree height from ALS increases with the increase of the terrain slope (Table 4). They suggest that there are two main reasons that cause overestimation of ALS tree heights: (i), DTM errors, and (ii) difference in the calculations of tree height between terrestrial and ALS measurements. The difference arises from the fact that ALS tree height is calculated as difference between z-coordinate of the tree top and the z-coordinate of the corresponding tree top projection on the terrain. But, the projection of the tree's top for the tree that grows on slope is, on average, positioned slightly downhill with respect to centre of the tree's stump, resulting with the overestimation of tree height. In addition, in terrestrial measurements, tree height is usually measured as the distance between up-hill side of the base of the stump and tree top,

TABLE 1. Overview of the results of ALS estimated forest stand variables using various area-based methods relative to terrestrially measured forest stand variables

Reference	Research area	Tree species	Pulse density (points/m²)	Footprint diameter (cm)	Results: RMSE	Results: R^2
Number of trees						
Næsset, 2002 [42]	Norway	*Picea abies, Pinus sylvestris*	n/a	21	28 - 35 %	0.50-0.68
Lindberg and Hollaus, 2012 [43]	Sweden	Mixed forests (deciduous and coniferous)	7	n/a	387.4 - 410.8 ha^{-1} (52.7 - 55.8 %)	n/a
Mean stand (plot) height						
Næsset, 2002 [42]	Norway	*Picea abies, Pinus sylvestris*		21	5 - 7 %	0.82-0.95
Coops et al., 2007 [44]	Canada	*Pseudotsuga menziesii, Tsuga heterophylla*	0.7	19	n/a	0.85
Yu et al., 2010 [17]	Finland	*Picea abies, Pinus sylvestris*	2.6	70	6.42 %	0.88
Gonzalez-Ferreiro et al., 2012 [45]	Spain	*Pinus radiata*	0.5 8	n/a	1.8 m (10.7 %) 1.9 m (11.3 %)	0.79 0.76
Järnstedt et al., 2012 [46]		*Pinus sylvestris, Picea abies*	10.43	10	18.6 %	n/a
Alberti et al., 2013 [47]	Italy (Alps)	Mixed forests	2.8	20	n/a	0.64
Mean diameter at breast height						
Næsset, 2002 [42]	Norway	*Picea abies, Pinus sylvestris*		21	12 %	0.39-0.78
Holmgren and Jonsson, 2004 [49]	Sweden	*Picea abies, Pinus sylvestris*	1.2	n/a	1.9 cm (8.9 %)	n/a
Yu et al., 2010 [17]	Finland	*Picea abies, Pinus sylvestris*	2.6	70	10.32 %	0.71
Järnstedt et al., 2012 [46]		*Pinus sylvestris, Picea abies*	10.43	10	25.3 %	n/a
Basal area						
Næsset, 2002 [42]	Norway	*Picea abies, Pinus sylvestris*	n/a	21	14 - 21 %	0.69-0.89
Holmgren and Jonsson, 2004 [49]	Sweden	*Picea abies, Pinus sylvestris*	1.2	n/a	3.0 $m^2 \cdot ha^{-1}$ (12.5 %)	n/a
Coops et al., 2007 [44]	Canada	*Pseudotsuga menziesii, Tsuga heterophylla*	0.7	19	n/a	0.65

Järnstedt et al., 2012 [46]		*Pinus sylvestris, Picea abies*	10.43	10	27.9 %	n/a
Gonzalez-Ferreiro et al., 2012 [45]	Spain	*Pinus radiata*	0.5 8	n/a	8.1 $m^2 \cdot ha^{-1}$ (19.8 %) 7.9 $m^2 \cdot ha^{-1}$ (14.3 %)	0.68 0.69
Lindberg and Hollaus, 2012 [43]	Sweden	Mixed forests	7	n/a	6.2 - 6.7 $m^2 \cdot ha^{-1}$ (21.5 - 23.2 %)	n/a
Volume						
Næsset, 2002 [42]	Norway	*Picea abies, Pinus sylvestris*	n/a	21	16 - 22 %	0.80-0.93
Holmgren and Jonsson, 2004 [49]	Sweden	*Picea abies, Pinus sylvestris*	1.2	n/a	28.0 $m^3 \cdot ha^{-1}$ (14.1 %)	n/a
Yu et al., 2010 [17]	Finland	*Picea abies, Pinus sylvestris*	2.6	70	20.9 %	0.62
Packalén et al., 2011 [52]	Brazil	*Eucalyptus* sp. plantation	1.5	35	- (4.90 - 11.82 %)	n/a
Estornell et al., 2012 [53]	Spain	*Quercus coccifera*	4	n/a	16 $m^3 \cdot ha^{-1}$	0.55
Järnstedt et al., 2012 [46]		*Pinus sylvestris, Picea abies*	10.43	10	31.3 %	n/a
Gonzalez-Ferreiro et al., 2012 [45]	Spain	*Pinus radiata*	0.5 8	n/a	92.53 $m^3 \cdot ha^{-1}$ 76.93 $m^3 \cdot ha^{-1}$	0.69 0.79
Lindberg and Hollaus, 2012 [43]	Sweden	Mixed forests	≈ 7	n/a	66.9 - 75.1 $m^3 \cdot ha^{-1}$ (37.3 - 41.9 %)	n/a
Alberti et al., 2013 [47]	Italy (Alps)	Mixed forests	2.8	20	n/a	0.58
Aboveground biomass						
Næsset, 2004 [54]	Norway	*Picea abies, Pinus sylvestris*	n/a	21	14 %	0.92
Estornell et al., 2012 [53]	Spain	*Quercus coccifera*	4	n/a	18.6 $t \cdot ha^{-1}$	0.64
Gonzalez-Ferreiro et al., 2012 [45]	Spain	*Pinus radiata*	0.5 8	n/a	40.5 $t \cdot ha^{-1}$ 35.9 $t \cdot ha^{-1}$	0.75 0.80
Kankare et al., 2013 [55]	Finland	*Picea abies, Pinus sylvestris*	10	n/a	23.0 $t \cdot ha^{-1}$ (24.9 %)	0.73
Aboveground carbon stock						
Patenaude et al., 2004 [56]	UK	Mixed forests Plot level Stand level	n/a	25	n/a	0.55 0.72
Stephens et al., 2012 [57]	New Zeland	Mixed forests	3	n/a	n/a	0.74
Alberti et al., 2013 [50]	Italy (Alps)	Mixed forests	2.8	20	n/a	0.58

n/a - not available, i.e. not reported in the paper.

TABLE 2. Overview of the results for detection of trees with ALS

Reference	Research area	Forest type/Tree speces	Flying height (m)	Pulse density (points/m^2)	Footprint diameter (cm)	Tree/stand class	Portion of trees detected (%)
Persson et al., 2002 [65]	Sweden	Middle and old aged forest dominated by *Picea abies* and *Pinus sylvestris*	130	n/a	26	DBH > 20 cm DBH > 15 cm DBH > 10 cm DBH ≥ 5 cm	90 86 79 71
Maltamo et al., 2004 [67]	Finland	Semi-natural, multi-layered forest consisted of *Picea abies* (50%), *Pinus sylvestris* (35%) and *Betula* sp. (15%)	400	10	20	Dominant layer All trees	83 39.5
Koch et al., 2006 [68]	Germany	1. Mixed, uneven-aged, multi-layered forest of (*Quercus robur*), and one 30-years old stand of *Pseudotsuga menziessi* 2. Mixed, mountain forest of *Fagus sylvatica*	400 800	20	40 85	*P. menziessi* Decidious	87.3 50
Solberg et al., 2006 [69]	Norway	Primeval multi-layered forest dominated by *Picea abies* of different social status	600	5	18	Dominant layer Co-dominant Sub-dominant Supressed	93 63 38 19
Heurich, 2008 [70]	Germany	Mixed, multi-layered forest stands dominated by *Picea abies* and *Fagus sylvatica*	800	5-10	80	Decidious Coniferous All Upper layer Decidious Coniferous Intermediate Lower Mature conifer stands Dense mixed stands	40.3 51.1 45.4 76.8 67.7 86.2 20.6 2.3 >90 60-70
Hirata et al., 2009 [71]	Japan	Mature (53-year old) stand (plantation) of *Chamaecyparis obtusa* with different level of thinning	600	40.5	n/a	Heavy thinning Moderate thinning No thinning Total	95.3 89.2 60.0 81.1
Li et al., 2012 [72]	Sierra Nevada, USA	Mixed conifer forest dominated by *Abies, Concolor*, *Pinus ponderosa*, *Calocedrus decurrens*, *Pinus lambertiana*, etc.	700	>6	n/a	n/a	86

n/a - not available, i.e. not reported in the paper.

TABLE 3. Overview of the differences in tree height obtained with ALS and terrestrial measurements. Note that, when D is negative, ALS underestimates tree height.

Reference	Research area	Tree species	Pulse density (points/m²)	Footprint Diameter (m)	Sample size (No of trees)	Results: Δ ± SD (m)	Results: RMSE (m)	Results: R^2
Næsset and Økland, 2002 [64]	Norway	*Picea abies, Pinus sylvestris*	0.6-2.3	0.18	51	-0.18 ± 3.15	n/a	0.75
Persson et al., 2002 [65]	Sweden	*Picea abies, Pinus sylvestris*	4.7	0.26 0.52 1.04 2.03 3.68	135	n/a	0.65 0.72 0.64 0.64 0.76	n/a
Gaveau and Hill, 2003 [73]	UK	Deciduous	5	0.25	70	-1.27	n/a	n/a
Leckie et al., 2003 [74]	Canada	*Pseudotsuga menziesii*	2	0.93	61	-1.32 ± 0.81	n/a	0.84
Yu et al., 2004 [75]	Finland	*Picea abies* *Pinus sylvestris* *Betula sp.*	5	0.2	1416	-0.20 ± 0.74 -0.09 ± 0.81 -0.09 ± 0.94	n/a	n/a
Maltamo et al., 2004 [67]	Finland	*Pinus sylvestris*	10	0.2	29	-0.65 ± 0.49*	n/a	0.99
Morsdorf et al., 2004 [76]	Switzerland	*Pinus montana, P.cembra*	> 30	0.2-0.3	918	n/a	0.6	0.92
Andersen et al., 2006 [63]	Washington State, USA	*Pseudotsuga menziesii,* *Pinus ponderosa*	6	0.33	29 30	-1.05 ± 0.41 -0.43 ± 0.13	n/a	n/a
Falkowski et al., 2006 [77]	Idaho, USA	Coniferous	≈ 2	n/a	30	- 1.07	2.64	0.94
Heurich et al., 2008 [70]	Germany	Deciduous Coniferous (high altitude) Coniferous (valley bottoms and slopes)	5-10	0.8	431 160 343	-0.43 ± 1.42 -0.85 ± 1.61 0.17 ± 0.93	1.26 (4.3%) 0.69 (3.3%) 1.17 (3.4%)	0.97 0.98 0.98
Hunter et al., 2012 [78]	Brazilian Amazon	Deciduous	10	n/a	n/a	-1.20 ± 6.40	n/a	n/a

n/a - not available, i.e. not reported in the paper.
Δ - mean difference between tree heights derived from ALS and by terrestrial measurement; SD - standard deviation
*** only Maltamo et al. 2004 reported values of standard error instead of SD**

which could also result with lower values for tree heights in comparison with those measured with ALS (Figure 3).

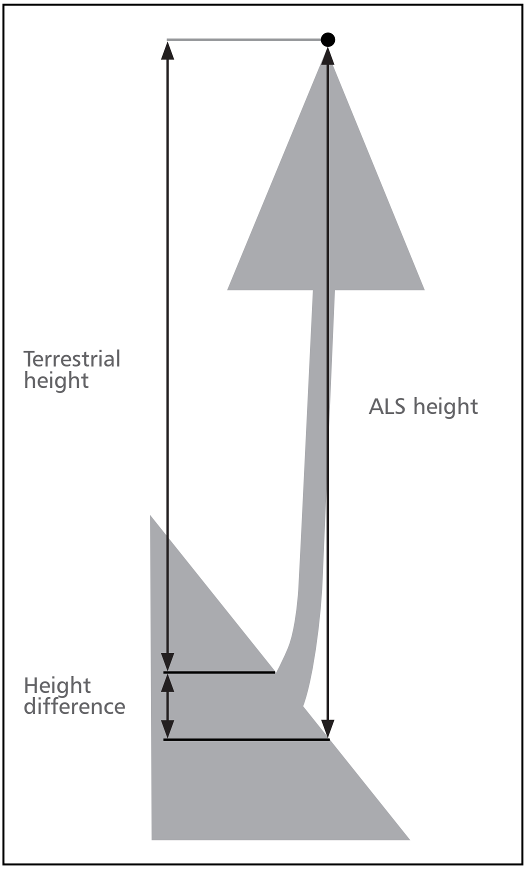

FIGURE 3. Difference between terrestrial derived and ALS derived tree height on steep slope. Terrestrial tree height is defined as the vertical distance from the tree apex to the up-slope base of the tree. The ALS tree height is usually calculated as the maximum value of the Canopy Height Model within the crown area [83].

Crown area and crown diameter estimation

Unlike tree height, it is harder to measure crown size (area, diameter) of individual trees from ALS data, since the results are more influenced by the pulse density, stand structure, but also the computer algorithm used for crown delineation [84]. Under the influence of these factors, ALS measurement can result with both an underestimation of crown size in some cases [65, 66, 70, 83], and an overestimation of crown size in other [68-70]. For example, based on their research Koch et al. [68] concluded that the applied automatic segmentation of crowns produces encouraging results in coniferous stands, as well as deciduous stands of lower density, where the 87.3% of trees and their location were correctly determined. However, crown areas were overestimated: the mean crown area of the segmented trees was 11 m^2, compared to 8.2 m^2 obtained from the terrestrial or photogrammetric measurement of the reference tree. Furthermore, in their research Solberg et al. [69] presented a new method for single tree segmentation and characterization from CHM and its corresponding point cloud. Using segmentation method, crown diameters in multi-layered forest dominated by Norway spruce trees were overestimated by 0.8 m. Mean terrestrially measured crown diameter was 3.9 m, while the mean of the ALS derived estimates was 4.7 m. The Pearson correlation between the measured and estimated diameters was r=0.52, while the RMSE was 1.1 m. Among number of variables, Heurich [70] compared crown radii obtained by terrestrial measurement and by ALS. The research was conducted in the Bavarian Forest National Park in the mixed, multi-layered stands dominated by Norway spruce and Common beech. While the crown radii of the deciduous trees derived by the ALS

TABLE 4. Differences in tree height obtained with ALS and from terrestrial measurements for forest stands on slopes (according to research of Véga and Durrieu [83]). Note how overestimation of tree height from ALS (positive Δ) increases with slope.

Slope (%)	Δ ± SD (m)	RMSE (m)
< 25	0.10 ± 0.65	0.65
25-50	0.18 ± 0.65	0.97
50-75	0.83 ± 1.31	1.54
> 75	1.58 ± 0.65	2.50

were underestimated (-0.25±1.09 m), those of the conifers were overestimated (0.21±0.71 m). The R^2 values of multiple regression models for estimation of crown radii from ALS data were 0.56 for deciduous and for conifers trees 0.45-0.55, respectively. At the same time, the RMSE values of the regression models for deciduous and conifers were 0.72 m (16.2%) and 0.26-0.50 m (10.3-14.5%), respectively. Véga and Durrie [83] evaluated the quality of ALS crown diameter estimation on two plots with different plot densities and concluded that measurement error, in this case underestimation, increases only slightly with the stand density. For the first plot, with density of 313 stem/ha, the mean error in crown diameter (underestimation) was -0.79 m (12.34 %), while for the second plot, with density of 746 stem/ha, it increased to -1 m (19.11 %).

Diameter at breast height, volume, biomass and carbon stock estimations

As was already mentioned, based on tree variables (height, crown diameter, crown area, etc) directly estimated from ALS data, and by using the existing empirical models, other desired variables of individual trees could be derived, such as diameter at breast height (dbh) [65, 70, 85, 86], volume [65, 66, 70], biomass [66, 85, 86], carbon stock [87, 88], etc. Some of the key findings from these studies are summarized in Table 5.

Tree species classification

The possibilities of automatic interpretations, that is, the classification of individual tree species from ALS data have been investigated in a number of studies. The automatic interpretation of tree species is largely made on the basis of the *spatial configuration* of recorded returns in the point cloud (crown structure) or on the *return intensity values* [27, 89-91]. The use of automatic interpretation based on the *return intensity values* approach presents a greater challenge for researches, mainly because there is currently no standardized ALS data calibration procedure [27, 92, 93]. For example, scanned return intensity values which are obtained for the same tree species but on different localities or in different scanning conditions usually differ. Those differences are the result of variations in a series of factors: the length and angle of the laser pulse divergences, the scanning angle, sensor characteristics, atmospheric influences on illumination reduction, the position of leaves and branches in crowns, terrain topography, etc [94]. Thus, the application of unique classification rules for the automatic interpretation of tree species in different areas and different ALS instrumental setup are hardly possible [27]. Therefore, numerous studies focus on the research of the possibilities for the improvement of tree species classification and interpretation by fusion of data from ALS and other remote sensing systems (digital airborne or spaceborne cameras, hyperspectral scanners, etc.) [74, 95-99].

CONCLUSIONS AND FUTURE RESEARCH STREAMS

In SEE countries the application of remote sensing in practical forestry usually implies only the use of orthophoto maps to assist in field orientation, although there are studies dealing with the potential use of satellite images [100], as well as digital aerial images [101-103] in forest management. But, unlike satellite and aerial images, the ALS technology has not yet been a subject of research in Croatia, as well as the entire region with the exception of Slovenia [12-14]. Therefore, we provide an overview of the state of the art of ASL technology focusing on its application in forestry.

At the beginning of applying the ALS technology, some of the main disadvantages were large and impractical records of scanning and their subsequent processing [2]. A significant progress in the latest, as well as in the technology application, occurred along with the progress of computer technology, namely with the increase in data storage capacity and development of numerous algorithms that significantly facilitated the processing and manipulation of such huge and complex records. Moreover, during the last twenty years, the ALS technology has undergone important technological improvements,

TABLE 5. Differences in values for tree dbh, volume, biomass, and carbon stock, estimated using various independent variables obtained with ALS, and values obtained from terrestrial measurements.

Reference	Research area	Tree species	Pulse density (points/m^2)	Independent variables	Results RMSE	R^2
Diameter at breast height						
Persson et al., 2002 [65]	Sweden	*Picea abies, Pinus sylvestris*	4.7	Tree height, crown diameter	3.8 cm (10%)	n/a
Heurich et al., 2008 [70]	Germany	Deciduous Coniferous (high altitude) Coniferous (valley bottoms and slopes)	5-10	Tree height, crown radius	5.7 cm (15.2%) 4.6 cm (12.5%) 5.9 cm (11.9%)	0.79 0.89 0.92
Popescu, 2007 [85]	Texas, USA	*Pinus taeda*	2.6	Tree height, crown diameter	4.9 cm (18%)	0.87
Anjin et al., 2012 [86]	South Korea	*Pinus koraiensis*	4.3	Crown diameter	n/a	0.53
Volume						
Persson et al., 2002 [65]	Sweden	*Picea abies, Pinus sylvestris*	4.7	Tree height, DBH	0.21 m^3 (22%)	0.88
Popescu et al. 2003 [66]	USA	*Pinus* sp.	1.35	Crown diameter	n/a	0.83
Heurich et al., 2008 [70]	Germany	Deciduous Coniferous (high altitude) Coniferous (valley bottoms and slopes)	5*, 10	Tree height, crown radius	0.73 m^3 (35.1%) 0.39 m^3 (28.2%) 1.02 m^3 (27.1%)	0.87 0.93 0.95
Biomass						
Popescu et al. 2003 [66]	USA	*Pinus* sp.	1.35	Crown diameter	n/a	0.78
Popescu, 2007 [85]	Texas, USA	*Pinus taeda*	2.6	DBH	169 kg (49%)	0.87
Anjin et al., 2012 [86]	South Korea	*Pinus koraiensis*	4.3	Tree height, DBH	n/a	0.66
Carbon stock						
Nakai et al., 2009 [87]	Japan	*Cryptomeria japonica* *Pinus densiflora*	n/a	Height	n/a	0.68 0.85
Hatami, 2012 [88]	French Alps	*Pinus uncinata, Pinus sylvestris*	164	Height, Crown area	22.83 kg	0.65

n/a - not available, i.e. not reported in the paper.

particularly in the sense of increasing frequencies and pulse (scanning) densities, as well as improving the accuracy of the obtained data. Consequently, this also enabled higher fly heights and increase in the scanned area per fly-over, resulting with the reduction of time and costs of ALS.

ALS provides researchers, among other, with a novel approach in obtaining the information on the vertical structure of the forest stands at large areas and with high-density, making the ALS technology suitable for application in forestry [85], primarily in forest inventory [37]. Both, of the two methods (AB and ITB) for deriving forest information from ALS data described in this paper, have their advantages and disadvantages. In comparison with the ITB method, the AB method requires a larger quantity of referential terrestrial data necessary to calibrate ALS data [17, 39, 104], but is financially favourable and has been applied in practical forest inventory (e.g. in Norway since 2002) [105, 106]. The ITB methods provide more detailed information on forest stands and, unlike AB methods, on individual trees. However, they still have no practical use, mainly due to greater costs and more complex procedures of data processing.

Although our review of the existing researches showed that the ALS technology might have a significant potential for application in forestry, the majority of the reviewed papers, focus on pure, even-aged stands and/or forest cultures. At the same time, the researches of ALS application in natural, or close to nature deciduous forests, are rare, and in most cases an emphasis is made on the difficulties in retrieval of information due to the complexity of deciduous tree morphology and forest stand structure [68-70]. Tree species interpretation still presents one of the greatest challenges in application of ALS, particularly in mixed or deciduous stands [90, 91, 93]. Addressing this problem will probably require an improvement in ALS technology (i.e. decrease of survey costs), novel data processing algorithms for species recognition as well as improved integration of ALS data with other remotely sensed data.

Since 95% of Croatian forests are natural or semi-natural stands of various origins, cultivation, and structural forms, and over 60% are mixed stands [107], the conclusion may not be forwarded that the application of ALS technology would be justified for operational forestry purposes, either in Croatia or other countries of the region with similar forests. Therefore, it would be necessary to initiate ALS research in the South-east Europe region. In our opinion, at this stage the research should primarily focus on testing the potential for the use of ALS technology in forest inventory and forest management. However, since the ALS technology enables the measuring of the stand's vertical structure (understory layer, bush, ground vegetation), besides the application in the classic forest inventory, the other useful research directions could be the estimation of the biomass quantity, carbon stock, combustible matter, etc.

Research of distribution and quantity of combustible matter is particularly important in the Mediterranean region. During the last few years, the number of forest fires and burnt surfaces in the wider Mediterranean area, as well as in Croatia, has increased [108]. Recent report by IPCC [109] states that under the high emission scenario (RPC8.5) there is "*high confidence* in *likely* surface drying" by the end of this century. This might result in increased tree mortality and higher risk of forest fire in general.

Thus, one of the potential areas to apply the ALS technology in Croatia, as well as all the countries and areas of the Mediterranean, is the estimation of combustible matter (dense, low shrub, coppice, maquis, etc) in forest stands which are usually not measured under the commercial forest management. The mapped data on the quantity of combustible matter, combined with precise DTM from ALS data offering an insight into the area configuration (limestone pavements, sinkholes…), may serve as the basis in fire risk assessment, as well as valuable asset in fire-fighting routes planning and prevention of forest fires.

Due to the expected advancement of the ALS technology, we may assume that ALS data will probably have important role in forestry in the future. Naturally, in times of a financial crisis, especially evident in the countries of the SEE, an important factor for the application of the ALS technology is the financial one. Therefore, we would recommend that any new research, which would address the application of ALS in forestry of the South-East European countries, should also have a part addressing economic aspects of ALS application.

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Comparison of Different Wood Species as Raw Materials for Bioenergy

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Abstract

Background and Purpose: Most projections of the global energy use predict that biomass will be an important component of primary energy sources in the coming decades. Short rotation plantations have the potential to become an important source of renewable energy in Europe because of the high biomass yields, a good combustion quality as solid fuel, ecological advantages and comparatively low biomass production costs.

Materials and Methods: In this study, the wood of black locust *Robinia pseudoacacia*, white willow *Salix alba* L., poplars *Populus deltoides* and *Populus x euramericana* cl.I-214, aged eight years were examined. Immediately after the felling, sample discs were taken to assess moisture content, ash content, the width of growth rings, wood densities and calorific values, according to the standard methodology.

Results: The mean values of willow, poplar and black locust wood density were 341 kg/m^3, 336 kg/m^3 and 602 kg/m^3, respectively. The average heating values of willow poplar and black locust wood were 18.599 MJ/kg, 18.564 MJ/kg and 21.196 MJ/kg, respectively. The FVI index (average values) was higher for black locust (17.186) than for poplar and willow clones, which were similar: 11.312 and 11.422 respectively.

Conclusions: Black locust wood with a higher density, calorific value and ash content compared to poplar and willow wood proved to be a more suitable raw material as RES. However, it is very important, from the aspect of the application of wood of these tree species as RES, to also consider the influence of the biomass yield per unit area of the plantations established as "energy plantations".

Keywords: Poplar, willow, black locust, growth ring width, ash content, wood density, calorific value, FVI

INTRODUCTION

Using renewable energies, such as biomass, which are by definition carbon neutral, may drastically reduce greenhouse gas emissions. Forest products act as substitutes for politically, socially and environmentally insecure fossil fuels. In the climate change context, agricultural greenhouse gas sinks may be instrumental in removing carbon from the atmosphere by changing the vegetation cover and improving management, switching from the conventional agricultural crops to forests [1].

In terms of using wood biomass for bioenergy and biofuels, it is important to consider not only the total yield but also the composition of biomass in relation to different energy conversion technologies. Compared with annual and perennial grasses, wood biomass in general has a higher content of lignin, lower cellulose and hemicelluloses contents, a higher energy value, a lower ash content and lower concentrations of problem elements such as K, Na, Cl, Si, and S [2]. These characteristics favour wood biomass for combustion, pyrolysis and gasification but suggest it is a less favourable feedstock for biological conversion to biofuels.

In order to use wood biomass as renewable energy sources it is necessary to provide adequate support of the state, as well as an adequately formulated national strategy, particularly in regard to the issue of using biomass as a renewable energy source.

In order to encourage the use of biomass for energy production, the Government of Serbia adopted the Action Plan for Biomass in 2010, which defined the strategy for the use of biomass as renewable energy sources, taking into account the potential of national strategies, legislation and European directives. The Action Plan was defined as a document which should determine the measures for promoting biomass in heat production and electricity generation and transport, followed by the subsequent actions related to the common problems of biomass supply, financing and research.

Serbia, as a country with large areas of arable land and forests, has a great potential for biomass production. Biomass accounts for 63% of the total potential of RES (Renewable Energy Sources). Forests cover approx. 30% of the territory, and approx. 55% of the territory is arable land. The total energy potential of biomass in the Republic of Serbia is estimated at 2.7 million toe (tonnes of oil equivalent), and it consists of residues in forestry and wood processing industry (approx. 1.5 million toe), and the rest in farming, livestock breeding, fruit growing, growing and primary processing of fruit (about 1.7 million toe).

It is evident that approx. 80% of wood biomass is used as firewood, while the remaining 20% represents wood residues from forests and the wood processing industry. Unfortunately, Serbia still lacks significantly large areas intended for "production" of the renewable biomass for energy needs.

The technical potential for short rotation energy crops production in Croatia [4] was estimated as forest area suitable for energy crops of 46 850 ha, producing in total

TABLE 1. The possibility of energy production from biomass in Serbia – the biomass energy potential (according to FAO [3])

Biomass source	Quantity (m^3)	Share (%)	Biomass potential (toe)
Wood biomass	**6 840 958**	**100.0**	**1 527 678**
Firewood	5 521 758	80.7	1 150 000
Forest residue	572 000	8.4	163 760
Wood process.industry residue	627 200	9.2	179 563
Wood from trees outside the forest	120 000	1.7	34 355
Agricultural biomass			**1 670 240**
Total biomass			**3 389 223**

1 toe = 41.868 GJ or 11.63 MWh

430 000 tDM/y, or 7.9PJ, and agricultural areas with moderately suitable soils, and limited soil suitability of 235 650 ha, producing of 2 827 800 tDM/y, or 52.1PJ.

Therefore, the aim of this paper was to compare wood calorific values (heating values) of several clones of poplar, willow and black locust, which also represent the most promising species for plantations with a large number of plants per unit area in Serbia. The establishment of "energy plantations" with relatively short rotation cycles may, in relatively short time, produce very significant quantities of wood as a renewable resource for energy production. The results pertaining to determination of calorific value of wood, and also FVI index, which takes into account values of wood density, wood ash and moisture content used for obtaining heat energy, are quoted in this paper. In that way, a more realistic picture on the energy produced from biomass defined by the volume (m^3), as it is common in our forest practice, was obtained.

MATERIALS AND METHODS

In this study, the wood of 4 clones of black locust Robinia pseudoacacia, 11 clones of white willow *Salix alba* L., 7 clones of *Populus deltoides* and *Populus x euramericana* cl.I-214, aged eight years were examined. After the selection of the characteristic sample trees (three trees in each clone) the measured parameters of growth elements were determined and the trees were felled. Sample trees were chosen as average plants based on the average diameter and height on the experimental plot. Immediately after the felling, samples discs (discs cut at breast height - 130 cm) were taken to assess moisture content, ash content, width of growth rings and wood density. After the natural seasoning of samples for one month at room temperature, wood was ground into wood flour suitable for pellet pressing.

The wood density was determined on the basis of the oven-dry weight per green volume of an individual disk segment. Green volumes were obtained by soaking disk segments in water for 10 days until a constant volume was achieved. Excess moisture was removed from the surface of the sample, and each sample's water displacement (volume) was measured. The sample was then oven-dried to the constant weight at 1040C and weighed to determine the dry weight, i.e. to determine moisture content of wood samples,according to TAPPI standards T 12 wd-82. Ash content was determined by burning 5g of a oven-dried and grounded sample in a platinum crucible in a muffle furnace at 5500C±250C, (TAPPI standards, T211 m-58). All analyses were done in duplicate and the results were expressed on a dry weight basis.

Calorific value was determined for ground air-dried samples. according to ASTM E870-82 standard. The samples were combusted in the C200 IKA Werke calorimeter. However, calorific values were corrected for the moisture regained during storage. There were three replications for each sample.

Also FVI (fuel value index) was determined by the formula [5]:

$$FVI = \frac{\text{Calorific value(kJ/g) x Density(g/cm}^3\text{)}}{\text{Ash content(g/g) x Moisture content(g/g)}}$$

RESULTS AND DISCUSSION

The results of the analysis of variances regarding the width of the growth rings for all studied species are given in Table 2. As expected, the highest average values were recorded for all poplar clones, because the total average value was 13.51±1.54 mm. The value of the average width of growth rings for all willow clones was somewhat lower: 9.50±1.98 mm, while all black locust clones had the slowest growth, since the average width of the ring growth was 6.14±0.75 mm. Differences in the width of growth rings between the clones measured within one wood species varied considerably, especially for poplar, while the differences for black locust were less significant, i.e.

TABLE 2. The width of the growth rings in the examined wood species

Species	Width of growth rings (mm)	Min value (mm)	Max value (mm)	Significance between clones
Willow	9.50 ± 1.98	5.44	13.15	$F > F_{99.9}$ (***)
Black locust	6.14 ± 0.75	4.25	7.43	ns
Poplar	13.51 ± 1.54	10.78	17.12	$F > F_{99}$ (**)

the growth was uniform for all black locust clones. The variations between replications were statistically not significant, and there were no significant differences. These values were expected, and they were in accordance with our previous results [6, 7, 8].

The analysis of variances of wood density in the studied clones is given in Table 3. According to ANOVA test, variation between replications are statistically not significant The mean values of willow wood density ranged from 308 kg/m^3 to 390 kg/m^3, that of poplar from 284 kg/m^3 to 375 kg/m^3, while the mean value of black locust was 602±32 kg/m^3. Differences between the clones within individual tree species were significant for poplar at the level of P= 0.001.

The results obtained in this study for willow wood were in accordance with our previous studies [6, 9, 10]. According to the data mentioned by Tharakan [11], the values of the specific gravity of willow wood ranged from 0.33 to 0.48. Leclerq [12], also the quoted data for specific gravity ranging from 0.337 to 0.454. According to Monteoliva [13], the values of wood density of the 13-year-old willow wood ranged from 364 kg/m^3 to 455 kg/m^3. Earlier investigtains in Croatia [14] concerning production of willow biomass in short rotations indicate that biomass share above the ground increased with the age, and the most productive trispecies hybrid had the most favourable relation between the plant underground and above the ground parts.

The values of wood density of black locust were in accordance with our previous results [7, 8, 15]. According to the literature, the specific gravity of black locust was approx. 0.69 [16, 17, 18]. Geyer and Walawender [19] determined the values of the specific gravity for 7-year-old black locust wood to be 0.58. It was also in accordance with the results of Hernea [20], who found that the average values of several black locust clones ranged from 532 kg/m^3 to 648 kg/m^3 (basic wood density).

The values of poplar wood density were in good correlation with the studies carried out on a continual basis by the Institute of Lowland Forestry and Environment at Novi Sad. As it is well-known, the values of the wood density for the clone I-214 were the lowest (approx. 300 kg/m^3), while the clones of *P. deltoides* had significantly higher values of wood density [21, 22]. The results of the research conducted in Croatia [23] confirm that even at such a young plantation age (5 to 7 years), the quality of particular habitat of some poplar clones has conditioned modifications in average clone

TABLE 3. The wood density results of the examined wood species samples

Species	Wood density (kg/m^3)	Min value (kg/m^3)	Max value (kg/m^3)	Significance between clones
Willow	336 ± 17.386	308	390	$F>F_{99}$ (**)
Black locust	602 ± 32.603	543	659	$F>F_{99}$ (**)
Poplar	341 ± 23.864	284	375	$F>F_{99.9}$ (***)

TABLE 4. The ash content of the examined wood species

Species	Ash content (%)	Min value (%)	Max value (%)	Significance between clones
Willow	0.56 ± 0.08	0.45	0.72	$F>F_{99.9}$ (***)
Black locust	0.77 ± 0.05	0.69	0.89	$F>F_{99}$ (**)
Poplar	0.59 ± 0.04	0.52	0.69	$F>F_{99}$ (**)

values of growing stock and survival. They also indicate the amount of production to be expected from the mixture of these clones or from the cultivation of particular clone.

Since the ash content of wood is very significant if wood is used as fuel, all the studied clones were analysed to determine their ash content. Although it is known that the content of the inorganic compounds of wood in the mentioned tree species is low (generally does not exceed 1%), for the calculation of the FVI index accurate values were needed, which are given in Table 4.

Significant differences in values of observed wood characteristics between the studied clones were analysed and proven for all studied tree species, while the differences between replications within the same clone were statistically insignificant. The ash content of the black locust tree was higher compared to that of poplar and willow, which influenced the values of the FVI index of the studied tree species.

The energy yield is a relevant criterion for using biomass as fuel. In relation to the harvested biomass, the energy yield was mainly determined by the contents of energy-rich compounds, such as lignin, resin or cellulose. The mean energy content related to the dry matter of biomass is, therefore, a stable feature within a particular type of biomass and more or less independent of external factors. The average heating values of the analysed poplar clones (Table 5), ranged in a very narrow interval from 18.254 MJ/kg (clone S6-36) to 18,812 MJ/kg (clone S1-7). This corresponded fully with the values of our previous research [6, 20], and the values reported by Ciria et al. [24] for the heating values of poplar wood (3–5-year-old stem and branches) 18.1MJ/kg to 18.3 MJ/kg. Benetka et al. [25] for the 1 to 3-year-old poplar clones (wood at breast height and the basal part, and branches) reported heating values from 18.60 MJ/kg to 19.27 MJ/kg.

The calorific values of willow wood were very similar and ranged from 18.028 MJ/kg (clone 347) to 18.993MJ/kg for the NS-73/6 clone (on average 18.599 MJ/kg). These values were in accordance with the values from our previous studies [7, 9], and with the values obtained by Szczukowski et al. [26], and Tharakan et al.,[27], approx. 19 MJ/kg. Higher heating values for black locust ranging from 20.396 MJ/kg to 21.956 MJ/kg significantly differed among the clones (P=0.001), and were somewhat higher than the cited in references: 19.578 MJ/kg [14]; 18.858 MJ/kg [19] for 7-year-old trees, i.e. from 17.72 MJ/kg to 18.14 MJ/kg [28] .

TABLE 5. The calorific values of the examined wood species samples

Species	Calorific value (MJ/kg)	Min value (MJ/kg)	Max value (MJ/kg)	Significance between clones
Willow	18.599 ± 0.282	18.028	18.993	ns
Black locust	21.19 6± 0.315	20.396	21.956	$F>F_{99}$ (***)
Poplar	18.564 ± 0.151	18.254	18.812	$F>F_{99.9}$ (***)

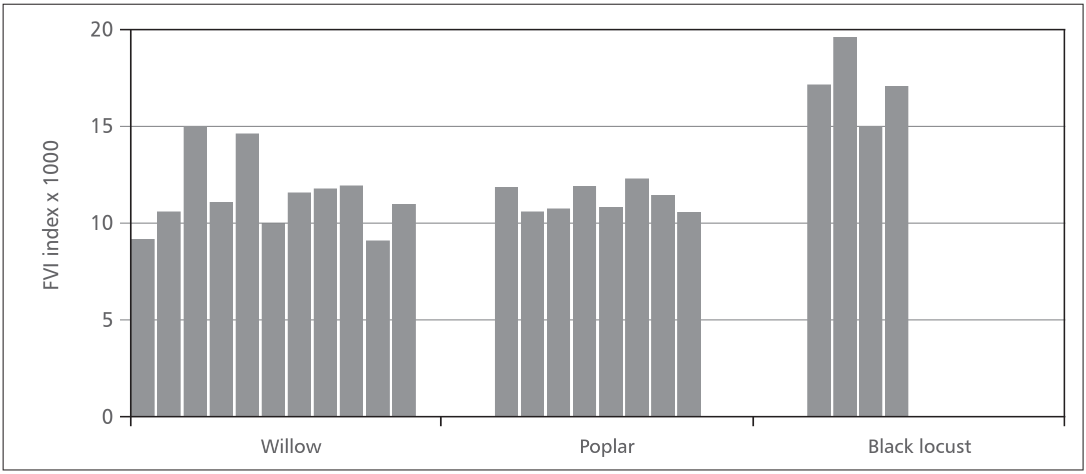

FIGURE 1. The FVI index values of the examined tree species

The FVI index (average values) was higher for black locust (17.186) than for poplar and willow clones, which were similar: 11.312 and 11.422 respectively. The statistical analysis of FVI index values for willow clones showed significant interclonal differences (P=0.001), and the values (Figure 1) ranged from 9.110 (min) for the clone NS 79/2 to 14.648 (max) for the clone 107/65-7. The values of the FVI index for the tested poplar clones ranged from 10.646 (clone S6-36) to 12.322 (clone S1-7) with interclonal difference at P=0.01 probability.

FVI index values of black locust tree shown in Figure 1 were significantly higher compared to the values of poplar and willow and ranging from 14.931 (clone R113) to 19.630 (clone R56). This is quite logical since the FVI index takes into account the values of wood density and ash content. A high ash content is less desirable for fuel wood as it non-combustible and reduces the heat of combustion. The results of the calculated FVI indexes indicated that a higher value of wood density may contribute to the heating value of wood combustion. In fact, although the ash content of black locust was higher compared to that of poplar and willow, the higher calorific value and black locust wood density had a decisive influence.

CONCLUSIONS

Black locust wood with a higher density, a higher calorific value and a higher ash content compared to poplar and willow wood proved to be the more suitable raw material that may be used as a renewable energy source, regarding the production of heat energy (by combustion) per biomass weight (kg).

However, it is very important, from the aspect of the application of wood of these tree species as renewable raw materials for energy, to also consider the influence of the biomass annual yield per unit area of the plantations established as “energy plantations”.

In fact, although the three studied wood species belong to the group of fast growing deciduous species, it is necessary to determine the yield of biomass per hectare and to estimate the quantity of energy that may be produced by a comparative analysis. The stands may be established on the same soil types, under similar technological conditions – the type of planting material, stand density (the number of plants per hectare), the duration of the rotation cycle, the number of cycles, the way of stand regeneration after felling, supplementary nutrition and protection regimes, etc. Only after such a comprehensive analysis an assessment of the suitability of certain wood species as energy raw materials may be given.

Wood density and calorific value may be used as useful parameters for determining harvest rotation cycles, particularly for short rotation plantations. However, decisions would be specific for each wood species on a given site. Both the biomass production and soil quality are important considerations to determine the optimum cutting age for fast growing energy plantations. These results indicate the possibility of energy production from whole very young trees from short rotation plantations, chipped together with branches and bark, which would significantly increase the energy potential due to the relatively large share of the bark and its high calorific value Based on the testing and research conducted in Croatia [4], considerable potential for short rotation energy crops production recognized. Currently a very small ammount of the avaliable area is utilised, and issues and problems to be addressed in order to increase this production include a change in policy approach.

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Box Tree Moth (*Cydalima perspectalis*, Lepidoptera; Crambidae), New Invasive Insect Pest in Croatia

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MATOŠEVIĆ D 2013 Box Tree Moth (*Cydalima perspectalis*, Lepidoptera; Crambidae), New Invasive Insect Pest in Croatia. *South-East Eur For* 4 (2): 89-94

Abstract

Background and purpose: Alien invasive species have been described as an outstanding global problem. Hundreds of species are intentionally and unintentionally moved worldwide and and numbers of introductions to new habitats have been accelerated all over the world due to the increasing mobility of people and goods over the past decades. Numerous alien insect species, many of them introduced only in the last 20 years, have become successfully established in various ecosystems in Croatia. Box tree moth (*Cydalima perspectalis*, Lepidoptera; Crambidae) is an invasive pest recently introduced to Europe causing serious damage to ornamental box (*Buxus* sp.) shrubs and trees. The aim of this paper is to describe the biology of box tree moth with prognosis of its future spread and damages in Croatia.

Material and methods: Young larvae (first and second larval stage) and adults of box tree moth were collected in August and September 2013 in Arboretum Opeka and in Varaždin. They were brought to the entomological laboratory of Croatian Forest Research Institute where they were reared to pupae and then to moths.

Results and Conclusions: The box tree moth was recorded for the first time in North Croatia in August 2013. Larvae were found defoliating box plants (*B. sempervirens*) in Arboretum Opeka, Vinica and they have been identified as *C. prespectalis*. According to damages it can be assumed that the pest has been introduced to the region earlier (in 2011 or 2012) and that the primary infection has not been detected. At least two generations per year could be assumed in Croatia in 2013. The damage done to box tree plants on the locality of study is serious. The plants have been defoliated, particularly in the lower parts. The defoliation reduced the amenity value of plants. This is the first record of this pest and its damages in Northern Croatia and it can be expected that the pest will rapidly spread to other parts of Croatia seriously damaging box plants, becoming threat to gardens and parks in Croatia.

Keywords: invasive species, damage, defoliation, biology of Box tree moth

INTRODUCTION

Alien species are considered as one of the major threats to biodiversity after habitat destruction [1, 2] causing enormous damage to ecosystems and economies [2, 3, 4]. As a result, they have been described as an outstanding global problem [5]. Alien species can significantly impact the functional properties of ecosystems, disrupt food webs, displace indigenous species, even threaten food and water supplies [6]. Hundreds of species are intentionally and unintentionally moved worldwide [7] and these introductions have been accelerated all over the world due to the increasing mobility of people and goods over the past decades [8] with varied modes of entry and transportation routes [9]. Numerous alien insect species, many introduced only in the last 20 years, have become successfully established in various ecosystems in Croatia [10].

While a certain number of alien insect species have little impact and are thus rarely noticed, some cause substantial damage to plants and the environment, and may have catastrophic effects on biodiversity. Box tree moth (*Cydalima perspectalis* Walker, 1859; Lepidoptera; Crambidae) is one of the most recent introductions to Europe [11] as well as to Croatia [12] causing serious damage to ornamental box (*Buxus* sp.) shrubs and trees.

Box tree moth was introduced to Europe in 2006 initially in Germany and Netherlands [13], and then it quickly spread to other European countries: Switzerland [14], England [15], France [16], Czech Republic [17], Italy [18], Slovakia [18], Austria [19], Slovenia [20], Hungary [21], Turkey [22], Romania [23] and Belgium [18]. The species is native to eastern Asia (India, China, Korea, Japan) [11] and feeds on every one of the most frequently planted box-tree species and varieties in Central Europe [24]. This rapid spread and establishment in European countries can be attributed to the ornamental plant trade as in particular box plants (*Buxus sempervirens* L.) are very popular ornamental garden plants. It is thought that the species was originally introduced with imports from China [11]. The larvae of the box tree moth are defoliating the plants posing a serious threat to these popular ornamentals especially in historical and formal gardens, hedging and topiary [11, 25].

The aim of this paper is to describe the biology of box tree moth with prognosis of its future spread and damages in Croatia.

MATERIALS AND METHODS

Young larvae (first and second instars) of box tree moth were collected in August and September 2013 in Arboretum Opeka, Vinica near Varaždin (coordinates N 46.327017; E 16.14747) and adults were collected in Varaždin (N 46.31551, E 16.316509). They were brought to entomological laboratory, Croatian Forest Research Institute and reared to pupae and moths. All developmental stages were photographed with Olympus camera E30 and Olympus stereo microscope SZ X7 (0,5x). The adults were identified according to Mally and Nuss 2010 [26].

RESULTS

The box tree moth was recorded for the first time in North Croatia in August 2013 when larvae were found defoliating box plants (*B. sempervirens*) in Arboretum Opeka, Vinica (Figure 1). The larvae and moths were identified as *C. prespectalis.* According to

FIGURE 1. Defoliated box plants (*Buxus sempervirens*) in Arboretum Vinica, Croatia (25 September 2013)

damages it can be assumed that the pest has been introduced to the region earlier (in 2011 or 2012) and that the primary infection has been undetected.

Newly hatched larvae were found on box trees (from eggs laid on the underside of box leaves), they are greenish yellow with black heads (Figure 2). Mature larvae have the green ground colour with a pattern of thick black and thin white stripes along the length of the body, with large black dots outlined in white on the dorsal side (Figure 3). They are up to 4 cm in length, and have 6 larval stages.

FIGURE 2. Newly hatched larvae, excrement and webbing of box tree moth (*Cydalima perspectali*) (26 September 2013)

FIGURE 3. Mature larvae of box tree moth (photo György Csoka)

The pupae are between 1.5 and 2.0 cm long. They are initially green with dark stripes on the dorsal surface, while older pupae turn brown. They are concealed in a cocoon of white webbing among the leaves and twigs of box trees.

FIGURE 4. Adult of box tree moth (photo György Csoka)

Adults have a wingspan of around 4 cm with a thick dark brown border of uneven width around the edges of white-coloured wings (Figure 4). The moths are iridescent when looked from different angles. The body is white, with a dark brown head and posterior end of the abdomen.

During this research we could not define the exact number of generations as first damages were visible in August but at least two generations per year could be assumed in Croatia in 2013. The box tree moth has two to three generations per year in Europe, while in the native range up to 5 generations per year are possible [19]. It overwinters as larva, spinning a cocoon between box leaves in autumn and completing its development the following spring.

The damage caused on box tree plants at the locality of research was found to be serious. Young larvae feed in the lower surfaces of the leaves only and leave the upper epidermis intact, whereas older larval stages feed inside the webbing, leaving only the midribs intact (Figure 5), they also eat green bark of the young twigs. Younger larval instars feed sheltered between two spun leaves and later instars rest during the day in loosely spun webbing where they also overwinter. Webbing and larval excrement were found between leaves and twigs. After overwintering, the larvae continue feeding until the end of March and when fully grown, they pupate and the moths of first generation appear

FIGURE 5. Total defoliation of box leaves, only midribs are left (September 2013)

[11]. The damaged box plants lose their amenity value as garden plant since defoliation is visible particularly on lower branches (Figure 1).

DISCUSSION AND CONCLUSIONS

Almost 90% of alien invertebrates in Europe were introduced unintentionally through human activities, mostly as contaminants of a commodity [27]. The main pathway of introduction of alien and invasive insect species on trees and shrubs is trade of ornamental plants [28]. In Europe, ornamental plant trade contributes significantly more than forestry products to the invasion of alien forest insects [9]. More than 80% of alien insect species in Croatia (57% on agricultural lands and 28% in parks and gardens) have been established in man-made habitats [14]. Box tree moth is another invasive species introduced to Europe and Croatia with ornamental plants, establishing and quickly spreading in a new habitat [11]. Ornamental plants and flowers are transported also very rapidly around the globe allowing alien insects to survive during transport and established themselves in new environment. There is a strong suspicion that ornamental plants are one of main pathways of introduction of alien insects to Croatia due to the increase of the imported volumes from year to year [10]. Box tree hedges have an important value in historical gardens and are essential element of gardens and parks [14].

Ways of spreading

It is likely that the box tree moth reached Europe on horticultural box tree plants imported from China [11]. Eggs and small larvae are difficult to detect and are easily dispersed with contaminated plants. The box tree moth is a good flyer, so it can also disperse naturally (5 km/year) [18], with several generations per year and good flying abilities it has a relatively high self spread potential. It easily spreads from contaminated areas as its host plant is extensively traded all over Europe being one of the most popular and widely planted ornamental plants.

Damage and control measures

The defoliation reduces the amenity value and repeated severe defoliation can result in the death of plants [11]. First signs of box tree moth presence are the following:

- moths (from May/June and in August) and larvae (from March until October),
- first partially devoured leaf epidermis and later whole leaves and green bark eaten by larvae,
- webbing and light coloured excrements can be found between leaves and twigs

The plants should be checked in the middle as box shrubs are usually very thick and when the infection starts the larvae live well protected inside the plants. If larvae, pupae or moths are found on box plants they cannot be misidentified for another species as this is the only one so far that makes such visible and characteristic damage. Ecological impact and damage may become particularly important when this pest reaches the main areas of natural distribution of *Buxus* spp. in Europe such as France, the Pyrenees, Montenegro and F.Y.R.O.M. where the European box tree is an essential component of unique forest ecosystems [11, 29].

Cultivated box trees can be protected by chemical insecticides or the ones based on *Bacillus thuringiensis* (Bt). In private gardens and on smaller plants, the moth may be controlled by hand picking caterpillars, by shaking trees or by spraying with water [19].

No natural enemies have been recorded in Europe so far [11] while it is neither attacked by predators (birds) because of the toxicity of the host plant [14]. Given all these circumstances this invasive pest has very favourable conditions (no natural enemies, favourable climate, widely available host plant) for spreading and establishing in new areas.

Forecast of box tree moth spreading in Croatia

Seven years after the first introduction, the pest has either naturally spread or been introduced multiple times and consequently it is now established widely across Europe [11].

This is the first record of this pest in Northern Croatia and, based on its potential, it can be expected that the pest will rapidly spread to other parts of Croatia damaging seriously box plants and thus becoming threat to gardens and parks in Croatia.

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Preliminary communication

Natural Regeneration of Beech Forests in the Strict Protected Area of the Plitvice Lakes National Park

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Abstract

Background and Purpose: The study presents the results of an investigation of regeneration processes, growth, development and survival of young growth by field measurement and three-dimensional visualization of horizontal and vertical structure. The results are based on the ten-year investigation (1998-2009) on a permanent experimental plot in a mountain beech forest with dead nettle tree (*Lamio orvale - Fagetum sylvaticae* Ht. 1938) in conditions of passive protection.

Materials and Methods: Basic structural indicators were measured (diameter at breast height and height), structural crown elements (size and shape, ground cover crowns) and the occurrence and survival of young growth as the basic conditions of natural regeneration. Particular emphasis in the investigation was paid to the development of crown structures and the process of natural regeneration during the 10 year period.

Results and Conclusions: Investigation indicates the occurrence of young growth regeneration cores arising as a result of the die-back of one dominant beech tree with horizontal crown projections of 145 m^2 which initiated the possibility of natural regeneration. The greatest change occurred in the beech seedling count, whose numbers increased fourfold from 3556 plants per hectare in 1998 to 12694 plants per hectare in 2009. The share of beech seedlings increased from 8.7% to 22.6% of all species of young growth and shrubs. Thus beech became dominant among the tree species regeneration. However, the majority of the young plants of beech are of poor quality and thus their further development in conditions of passive protection is questionable. The investigations also showed the possibility of a new approach to the study of the dynamics of crown structures and the process of natural regeneration by methods of three-dimensional visualization of horizontal and vertical structures. The methods presented offer a more graphic illustration of the development of stands and high quality presentation of the obtained results. For a long-term scientifically based plan, with the aim of reaching the most favourable decisions on the future of forest stands in protected areas, particularly in today's conditions of climatic changes, continuous improvement and expansion of monitoring methods by means of a network of permanent experimental plots in all protected forest areas is necessary.

Keywords: forest reserve, passive protection, close-to-nature-forestry, crown structure, natural regeneration, beech (*Fagus sylvatica* L.).

INTRODUCTION

Almost half of the continental territory of the Republic of Croatia (48%) is covered by forests. Of the total forest areas approximately 56% consists of beech dominated forests, beech forests with sporadic sessile flowered oak, and mixed beech-fir forests [1]. In contrast to many countries, where the natural composition of the forest has been significantly changed by the activity of man, in Croatia a large part of the forests have retained its natural characteristics mainly due to the endeavours of the foresters and the nature of forest management based on the principles of sustainable development. This determined the stability and conservation of forest ecosystems and offered the possibility of establishing national parks during the middle and second half of the past century, in which the main, or one of the main, basic natural phenomena are the forests. The Plitvice Lakes National Park, one of eight national parks in Croatia, was established in 1949 for the protection of the hydrologic system of the lakes, forests and other ecosystems, and natural phenomena. In recognition of the great importance of the forest for the future of the Plitvice Lakes National Park, employees of the Croatian Forest Institute (formerly Forest Institute, Jastrebarsko) established four forest reserves with a total surface area of 1 347 ha: Medveđak (1976), Čorkova uvala-Čudinka (1977), Kik-Visibaba (1979) and Rječica-Javornik (1981). The basic objective of establishing forest reserves was to determine the basic (zero) condition of vegetation, determine structural relations and to monitor the further growth and development of forest ecosystems, particularly the condition and possibility of their natural regeneration as the basic factor for permanent forest ecosystem sustainability and survival.

This problem has been studied by many forest experts in Croatia. Seventy years ago prof. I. Horvat began the first systematic phytocoenological investigation in the Risnjak National Park. The start of forestry scientific research in virgin forests of Croatia can be attributed to the investigations of Čorkova uvala in the Plitvice Lakes National Park, which were commenced by academician Milan Anić in 1957. With the object of monitoring the development of forests in natural conditions in the area of the Plitvice Lakes National Park the investigation of Cestar et al. [2] should be mentioned, who, after carrying out typological investigations, showed that the method of performed management did not encourage the occurrence of young growth, particularly of beech. Hren [3] investigated the structure of the beech virgin forest "Ramino korito", and Prpić [4] investigated the characteristics of the beech-fir virgin forest "Čorkova uvala" in the Plitvice Lakes National Park. Klepac [5, 6] advocated active protection of the forests in the Plitvice Lakes National Park, and in 1994 proposed ecological management of the forests with emphasis on the need to enable permanent natural regeneration of forests. In his investigation Novotny et al. [7] pointed to the growth and development of basic structural elements and elements of regeneration in the Plitvice Lakes National Park.

These investigations, with periodic measurements on permanent experimental plots, carried out by employees of the Croatian Forest Research Institute (basic structural elements, indicators of growth structures and development of tree crowns, including the number and quality of young growth), indicate that the possibility of satisfactory natural regeneration in national parks is questionable [8-14]. The aforementioned investigations showed that, although nature is continuously active, we cannot be satisfied only with its activity. Long-term study has shown that passive protection clearly does not give the expected results.

This study aimed to investigate regeneration processes, growth, development and survival of young growth in a mountain beech forest with dead nettle tree (*Lamio orvale - Fagetum sylvaticae* Ht. 1938) in conditions of passive protection. For that purpose field measurements on a permanent experimental plot in 1998 and 2009 were conducted as well three-dimensional visualization of horizontal and vertical structure.

MATERIALS AND METHODS

Study Area

The investigation was performed in the "Medveđak" Forest Reserve on a permanent experimental plot in a natural stand of mountain beech forest with dead nettle (*Lamio orvale-Fagetum sylvaticae* Ht.1938) 570 m above sea level (Figure 1). The reserve is situated within a larger forest complex of beech forests, in the north-eastern part of the "Plitvice Lakes" National Park. The reserve comprises three compartments with a total area of 156.3 ha. The highest point of the reserve is 875 m, and the lowest 580 m above sea level. The reserve is located on a geological base of limestone with three soil types. On the high positions and on the ridges is humus (black soil) on limestone (10%), on the steep slopes shallow brown soil on limestone (20%), on the less steep slopes moderately deep brown soil on limestone (40%), and in karst sinkholes is loessial soil or illimerised soil (30%) [9]. Inclination ranges from 10^0 to 25^0. In the south-eastern lowest part of the reserve are karst sinkholes, from which the terrain rises up towards the north-east up to the highest point, and again over the ridge descends towards the north and north-east.

FIGURE 1. Beech stand in the Medveđak Forest Reserve

Data Collection

In 1998 a permanent experimental plot was established, 1 ha in size (plot coordinates: N=44^0 53′ 09″; E=15^0 38′ 01″) according to the method of Dubravac and Novotny [15] as a part of a network of permanent experimental plots established in the national parks of Croatia (Risnjak, Plitvice Lakes, Paklenica, Mljet, Brijuni). The plots were established with the aim of monitoring the dynamics of forest ecosystems in conditions of strict protection of nature. The age of the stand at the time of the establishment of the plot was 147 years. All trees with diameter at breast height (DBH) greater than 7.5 cm were marked and their basic characteristics measured (DBH, tree height and stem length). In the most homogenous part of the plot a sub-plot was set up, 60m x 60m in size, on which the spatial arrangement of the trees was recorded, their horizontal crown projections were mapped. Furthermore, elevation data of each tree were recorded, according to which a digital terrain model (DTM) was created (Figure 2). In three

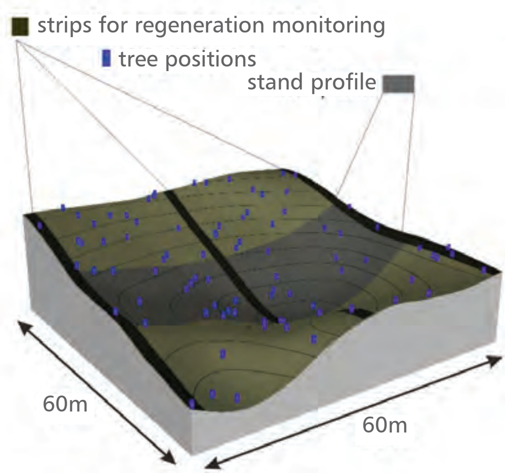

FIGURE 2. Digital terrain model (DTM) of the experimental plot with basic measuring elements

strips, 2 m x 60 m (total surface area 360 m^2), the height structure of young growth and shrub layer was recorded and they were grouped into the height classes (<30 cm; 31-60 cm; 61-130 cm; 131-150 cm; 151-200 cm; 201-250 cm). Ten years later (2009) DBH and height of all trees were measured again, and on the strips the structure of young growth and shrub layer was recorded according to height classes and species. The horizontal projections of crowns were measured on the trees on the part of the plot (20 m x 60 m), for comparison with the changes in the vertical profile of the stand between the two measurements. More information on data collection procedure could be found in earlier authors' works [9, 10, 12, 16]. On the two occasions (1998 and 2009) dimensions of young growth which developed after the die-back of one of the dominant beech were also recorded and it was grouped into already mentioned height classes. ArcMap programme was used for digitalization of horizontal crown projections and production of the DTM. For preparation and analysis of data MS Excel was used and for visualization of stands and vertical profile Stand Visualization System and EnVision (USDA Forest Service, USA) programmes were used.

RESULTS

Basic structural characteristics of the experimental plot are shown in Table 1. Comparing the obtained data with growth and yield tables [17] which have volume on I. cite class of 646 $m^3 \cdot ha^{-1}$, it may be seen that the obtained volume of the researched stand is considerably higher, mainly due to passive protection of the stand and absence of the management activities. More details on the stand structure elements and comparison between two measurements (1998 and 2009) may be found in the paper of Novotny et al. [7].

Crown structure

From the layout of horizontal projections of crowns in the first measurement in 1998, it was determined that the crown cover of ground amounted to 96%. Mean area of a horizontal crown projection amounted to 53.67 m^2 ranging from 5.94 to 158.36 m^2. Crown projection area of trees exhibits a non-linear relationship with the DBH, in the form of the power function (Figure 4).

In the left lower quadrant of the experimental plot an advanced regeneration was found in the opening of the stand canopy, which had resulted from the die-back of one dominant beech tree from the upper canopy layer prior to the establishment of the plot. From the DBH of the dead tree, the area of the horizontal crown projection was estimated to be 145 m^2. The opening created in the canopy layer stimulated the occurrence of the advanced regeneration. In order to estimate the growth dynamics of the crown structure development between the two measurements, two stand profiles were set up on a part of the plot, 20 m x 60 m in size (Figure 5). In the first measurement the total area of the horizontal crown projections of 27 trees in the profile amounted to 1,492.24 m^2, with the average size of projection area for one tree at 55.27 m^2. Prior to the second measurement die-back occurred in 3 trees of the total area of the horizontal crown projection of 69.27 m^2. However, an increase occurred in the mean

TABLE 1. Basic stand structure elements (stem number – N, basal area – BA, volume – V) and average values (diameter at breast height – DBH, height – h, basal area – ba, volume – v) of the beech trees of the experimental plots in 2009

Measurement year	N trees·ha^{-1}	BA $m^2 \cdot ha^{-1}$	V $m^3 \cdot ha^{-1}$	DBH cm	h m	ba m^2	v m^3
2009	291	45.68	803.07	41.1	27.1	0.15	2.46

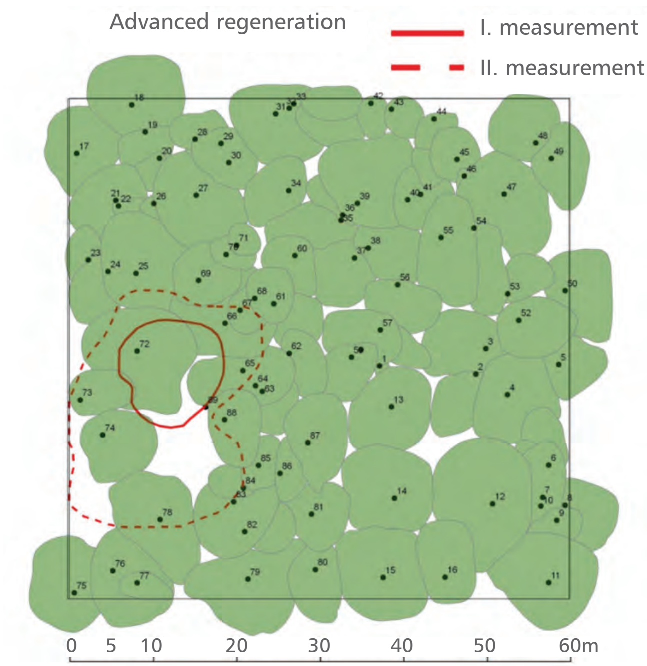

FIGURE 3. Horizontal projections of crowns (first measurement 1998) with advanced regeneration (1998 full line, 2009 broken line)

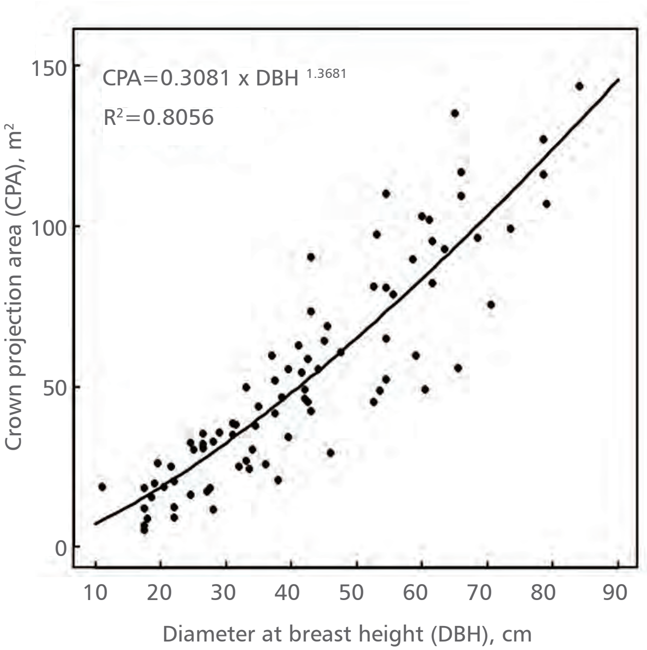

FIGURE 4. Relationship of the crown projection area (CPA) and the DBH

area of crown projection per tree of 63.04 m^2 (+ 7.77 m^2), and increase also occurred in the total area of the of horizontal crown projections of 1,512.89 m^2 (+ 20.65 m^2). In the period between the two measurements no more significant changes occurred in the vertical canopy, regardless of the 3 missing trees.

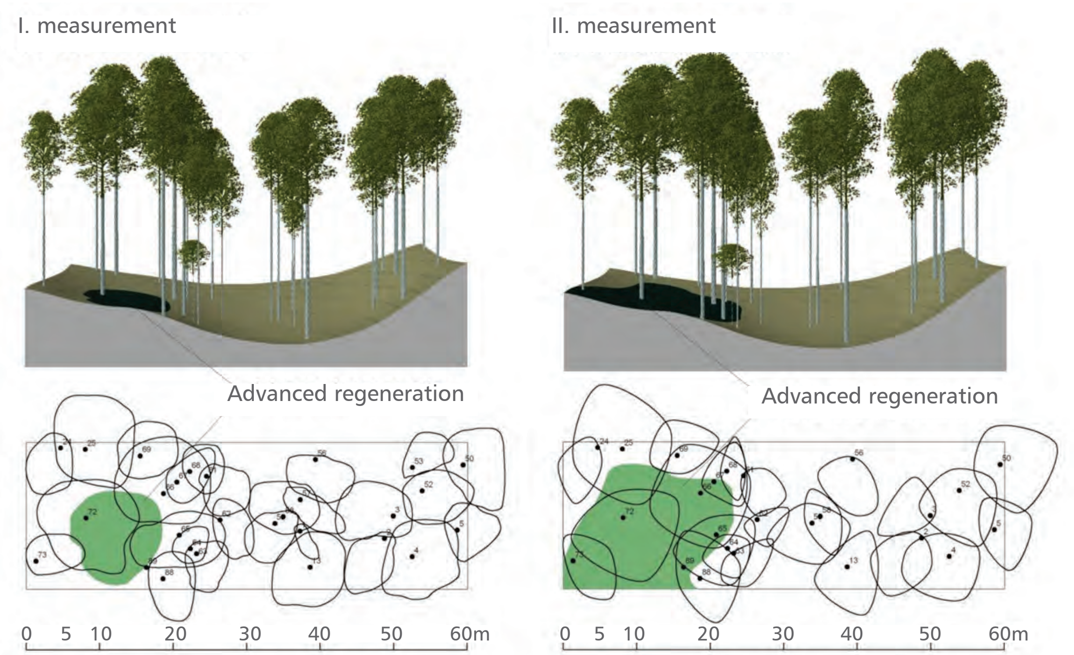

FIGURE 5. Scheme of the development of initiated advanced regeneration between two measurements

Process of natural regeneration

As has already been stated that the process of natural regeneration was mainly influenced by the opening of the canopy due to the die-back of one dominant beech tree and by development of advanced regeneration (Figure 5). The area of the advanced regeneration in 1998 amounted to 124.7 m^2 which increased fourfold in the second measurement, to 512.2 m^2. By measuring the numbers of the regeneration and shrubs on three strips (Figure 2) on total area of 360 m^2 in 1998 and 2009, an increase in the overall number of plants from 40.8 to 56.2 plants per hectare, was determined (Table 2). The greatest changes occurred in the share of beech seedlings, the number of which increased fourfold from 3,556 plants per hectare in 1998 to 12,694 plants per hectare in the second measuring. In the percentage share common beech increased from 8.7% to 22.6% of all plants of young growth and shrubs, and took a dominant role among the young crop of trees. With regard to the height structure of the young beech trees, their increased number is most visible in height class up to 30 cm (Figure 6). The majority of the young beech plants is of poor quality and it is questionable how they will continue their further development in the conditions of passive protection.

Today, information on stand structure (spatial arrangement of trees, tree measurements, and particularly crown measurements) may be visually presented by means of one of numerous computer programmes. On the basis of a digital model of tree-crown projections, measured values in the field (tree heights, stem length, length and width of crowns) and standard bases, a three-dimensional photo-realistic digital model of a stand was produced. In the production of the model the spatial arrangement of trees and phenotype of crown forms were taken into account [18]. In this investigation stand structure is visualized in the programme packet EnVision (USDA Forest Service, USA) which is shown in Figure 7.

TABLE 2. Number of seedlings, saplings and shrubs per hectare in two measurements
* *Acer pseudoplatanus* L., , *Picea abies* (L,) H.Karst, *Fraxinus excelsior* L.
** *Sambucus nigra* L, *Daphne mezereum* L., *Corylus avellana* L. and others

Height class (cm)	Beech		Other tree species*		Shrubs**		Total	
	1998	2009	1998	2009	1998	2009	1998	2009
to 30	1528	10194	1556	1028	28167	36194	31250	47417
31-60	1417	1111	1056	1306	5500	3917	7972	6333
61-130	556	1139	361	611	361	222	1278	1972
131-150	28	139	56	28			83	167
151-200	28	83	167	111		56	194	250
201-250		28	28	83			28	111
Total	3556	12694	3222	3167	34028	40389	40806	56250

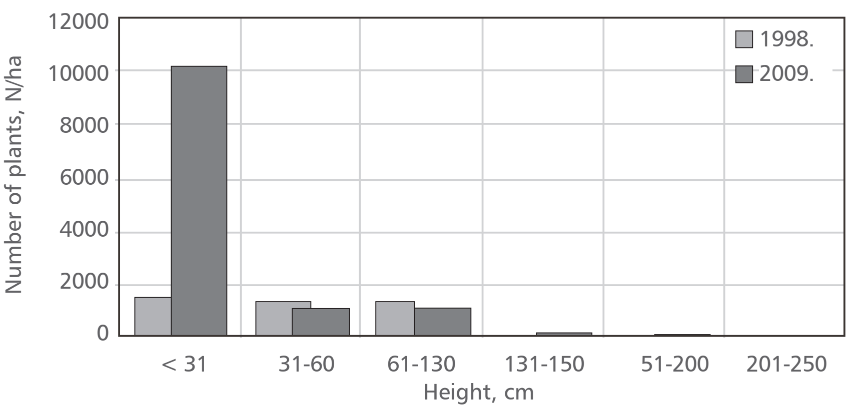

FIGURE 6. Height structure of young beech growth

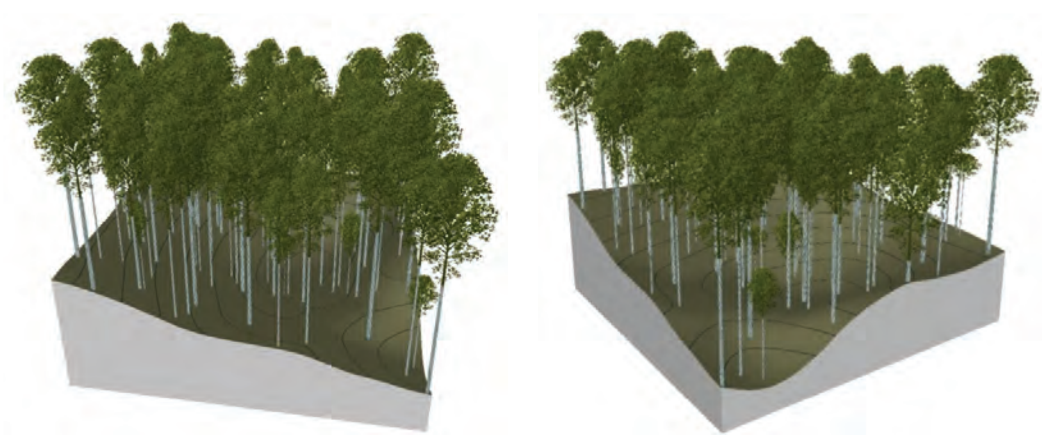

FIGURE 7. Visualization of beech stand on the experimental plot (En Vision), two views

DISCUSSION

Although the observation was carried out in a relatively short period of time (10 years), the methods and results of this investigation present new contributions to understanding crown structure dynamics and the process of natural regeneration of pure beech stands in conditions of passive protection. Investigations so far [e.g. 19-24], also confirmed in this study, indicate that natural regeneration should be carried out on initiated regenerative cores, by opening the canopy in small areas and groups. Similar to this research, results of the research conducted by Rugani et al. [25] showed that gaps smaller than 500 m^2 are the dominant driving force of stand development. Therefore, we think that opening canopy in small areas present the best form of regeneration for nature, especially in protected forest ecosystem. In order to attain scientifically based plans for deciding on the future of forest stands of protected areas, particularly in conditions of climatic changes today, it is necessary to constantly improve and broaden methods of monitoring by means of a network of permanent experimental plots in all protected forest areas. The possibilities offered by modern computerised models for high quality presentation of obtained knowledge should not be ignored. Furthermore, modern remote sensing methods and data (e.g. airborne images, satellite images, LiDAR) may be used for characterising forest dynamics on large-scale areas. For instances, Hobi [26] founded that high resolution satellite images (WorlView-2) have a large potential for forest canopy modelling (for characterising forests' gap dynamics).

By acknowledging existing laws and provisions in areas which are not under a regime of strict protection, it is necessary to assist natural processes which are already in progress in the forest ecosystems. The aforementioned activities are the fundamental method for optimization of priority functions of the forests with specific assignment. Such work should include two important principles: 1) high-production forest is biologically the most stable forest, which offers the greatest generally useful functions and 2) professional silvicultural activities are at the same time the condition and only way in which we can, on the one hand utilize productive functions of the forest, and on the other hand ensure the protection and natural regeneration in these forests.

Knowledge of these problems clearly indicate that increased engagement of the forestry profession is necessary, particularly in those protected areas whose basic phenomena, and most recognized characteristics, are forest ecosystems. In such cases forest interventions should be adapted to the preservation and natural characteristics of the forest ecosystems on particular sites. This is also confirmed by other researches conducted in the 'Medveđak' forest reserve [20, 24, 27]. Therefore, so called 'close-to-nature-forestry' silvicultural approach [19, 23, 28], with existed but reduced human activities, which is accepted in most of the Central European countries may be adapted in forest managing of Croatian Natural Parks, as well.

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Preliminary communication

Habitat Characteristics of Bracken-Covered Areas Intended for Afforestation in Ličko Sredogorje

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Abstract

Background and Purpose: Forest cultures in continental part of Croatia are mainly based on bracken-covered areas and moors on deserted agriculture soils and pastures. Successful afforestation i.e. establishment of forest cultures depends among other things on the understanding of habitats and ecology of forest trees. The choice of best species of forest trees for afforestation needs to be based on the research in soil and climate characteristics of target habitats. The aims of this research were to show mesoclimatic characteristics of Ličko sredogorje and microclimatic and pedological characteristics of Ličko polje. Also, based on habitat characteristics and ecology of forest trees, the aim was to determine species of forest trees suitable for afforestation of bracken-covered areas.

Materials and Methods: Climate, microclimate, pedological and plant nutrition researches were done at the area of Lika highlands. Climate analysis was done according to air temperatures, amount of precipitation, relative air humidity and other climate elements and appearances. Composite soil samples were taken from the depth of 0-30 cm in order to determine plant nutrition potential. Samples were prepared for further analysis in the laboratory.

Results: The highest average annual air temperature of 9.6 °C was found at weather station Gračac and the lowest at Korenica station (8.1 °C). Average amount of precipitation for this region was around 1500 mm. Monthly rain factors were ranging from arid to perhumid. Considering thermal character of the climate, the area has moderately warm climate. Average volumetric soil humidity is 14.2 %. Soil has strong acid reaction, is very humus, good to richly supplied with total nitrogen, content of physiologically active phosphorus and potassium is low, and C/N ration normal.

Conclusions: According to habitat characteristics in the area of Ličko sredogorje and ecological demands of forest tree species, forest cultures of Common birch (*Betula pendula* Roth.), Common spruce (*Picea abies* Karst.), Eastern white pine (*Pinus strubus* L.), Black pine (*Pinus nigra* subsp. *austriaca* Asch i Gr.), Common pine (*Pinus sylvestris* L.) and European trembling aspen (*Populus tremula* L.) can be established.

Keywords: habitat, climate, soil, afforestation, ecology of forest trees

INTRODUCTION

Planned and organized works on the establishment of cultures of conifers in the continental part of Croatia started around 1960. The first afforestations were mostly done by sowing the seeds, particularly in the karst areas, and later it was done with seedlings produced in forest nurseries. Pedological, ecological and plant nutrition researches have been done with a goal to choose the most suitable species, that is, the provenance for sowing on certain habitats and such researches have until 1992 encompassed an area of over 25 000 ha [1].

Forest cultures of conifers are being established with different goals. They can have a determined purpose, ex. production of trees for cellulose and thinner technical timber, for soil protection against erosion, for enriching the landscape and for increasing forest functions of general benefit, for the production of Christmas trees, and lately for the production of biomass for energy purposes.

Others are established as pre-cultures with the goal of establishing conditions for the return of indigenous forest trees, and consequently, of forming a natural forest eco-system.

According to Čavlović [2] Croatia has 33 070 ha of evergreen and 10 080 ha of deciduous plantations. Forest conifer cultures in the continental part of Croatia are mostly established on bracken-covered areas and moors on deserted agriculture soils and pastures.

It is estimated that Croatia has around 300 000 ha of such area. Conifer cultures of the continental part of Croatia are divided as follows Common spruce 55 %, Common pine 20 %, Eastern white pine 5 %, European larch 4 % and other conifer types 1 %.

The first conifer cultures in Lika have been established between 1856 and 1896 and they have included Scots pine and Austrian black pine on the territory "Vujnović brdo" on the surface of 120 ha. The Municipality of Otočac has in 1896 afforested Laudonov gaj on quicksand soil with Common pine and Black pine. Between 1964 and 1968 on the territory of Medak and Žitnik, 114.88 ha of plantations and 1102.26 ha of intensive fast growing conifers have been established which included Common pine (483 ha), Eastern white pine (142 ha), European larch (256 ha), Common spruce (314 ha) and Black pine (20 ha).

According to Komlenović [3] before establishing forest cultures every surface requires a detailed research and special attention needs to be dedicated to soil reactions.

The goal of this research is to show the mesoclimatic characteristics of Ličko sredogorje as well as micro-climatic and pedological characteristics of Ličo polje and based on the habitat's characteristics and the ecology of forest trees, to determine types of forest trees for afforestation of forest land covered with bracken.

MATERIALS AND METHODS

Climate analysis on the territory of Ličko sredogorje was done according to air temperatures, amount of precipitation, relative air humidity and some other climate elements and appearances received from the weather stations in Gospić, Gračac and Korenica for the period 1981 – 2010.

The site Medačke staze was selected for additional micro-climate and plant nutrition research due to the need for afforestation of that area. Micro climate research was done in 2010 and 2011 on the territory of Ličko polje, management unit "Medačke staze", subcompartments 39a, 51a and 63, of the Forest office Gospić. Measurements were executed in a time interval of one hour using a micro-climate station "Spectrum". The measurements included measuring air temperature (°C) at the height of 1 m and soil temperature (°C) at the depth of 10 cm, as well as volumetric soil humidity VWC (%) up to a depth of 20 cm.

Composite soil samples were taken from the same sites from the depth of 1-30Cm for the reason of determining plant nutrition soil potential. The samples were consequently taken to the laboratory where they were air-dried, chopped up, sieved through a mesh with 2 mm wide holes and in such a way prepared for further analysis [4]. The samples were then analysed for the pH in water and 1MKCl [5], the total content of nitrogen was determined in the elementary analyser Leco CNS 2000 [6], the humus content according to Tjurin [4], and the physiological active phosphor and potassium according to Egnér, Riehm and Domingo [7]. Soil analysis was done in the Laboratory for physical-chemical testing of the Croatian Forest Research Institute.

The data was processed in the programmes KlimaSoft 2.0 [8], SpecWare 8.0 [9] and Statistica 7.1. [10].

RESULTS

Air temperature

Looking at the average annual air temperatures in Table 1 for the listed weather stations, we notice a temperature difference between stations. Maximal average annual air temperature of 9.6 °C was measured in the Gračac station, and the minimal of 8.1 °C in Korenica. According to many authors, average air temperatures for the vegetative period (April-September) has a much greater significance for the development of vegetation than average annual air temperatures which in certain years depends significantly on the air temperature during the winter period. Average temperatures for the vegetative period were: Korenica 14.1 °C, Gospić 15.2 °C and Gračac 15.6 °C. Once again, Gračac stands out with the hottest vegetative period.

Absolute maximal and minimal air temperatures show realistic and total temperature differences in a specific area. They can frequently be a limiting factor for the incoming, development and survival of a species [11]. Good indentation, and particularly relief factors such as height above sea level and inclination, very often influence on significant deviations even in the air temperature extremes. The lowest air temperature on the weather station Gračac was 34.6 °C. On the Gospić and Korenica territory, the minimal air temperatures were 27.3 °C, respectively, -27.6 °C. The absolute maximal air temperatures were also very high for this climate type. The weather station in Gračac registered the absolute maximal air temperature of 38.3 °C. On the Gospić and Korenica territory, the maximal air temperatures were 37.0 °C, res-pectively, 36.8 °C.

Precipitation

Average amount of precipitation for this area was around 1500 mm. Table 1 shows the monthly and annual amount of precipitation for the observed weather stations. The researched area has a maritime precipitation regime. The biggest part of precipitation occurs during the colder part of the year, except on the weather station in Korenica. Maximal monthly amount of precipitation occurs in late autumn or in the beginning of winter, while July is a month with the minimal amount of precipitation.

The percentage of precipitation in the vegetative period is the highest on the territory of Korenica and it was 50.3 %. The percentage of precipitation for the weather station in Gračac is least favourable and it was 36.4 %, and it is followed by Gospić with 43.1 %. The most favourable precipitation regime is in Korenica where the precipitation is equally distributed during the whole year. The highest number of rainy days was measured on the Gospić area (143 days), then Gračac (128 days) and the lowest on the Korenica territory (105 days). During the vegetative period, a surplus of water in the soil was noticed on the Ličko sredogorje territory. The values of potential evapotranspiration were less than the amount of rainfall (Figure 1).

Monthly rain factors shifted from arid to perhumid. Considering the heat character of

TABLE 1. Monthly and annual rain factors, humidity and heat character of the climate according to M. Gračanin (1981 – 2010)

Met. station	Climate indexes	Months												Year
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Gospić	Precipi. (mm)	103.2	99.2	95.2	104.5	100.1	92.8	51.2	80.6	148.7	150.1	177.7	151.3	1354.6
	Air temp.(°C)	-0.9	0.3	4.3	8.6	13.7	17.0	19.3	18.7	13.9	9.7	4.5	0.4	9.1
	Rain factor	102.3	330.7	22.1	12.2	7.3	5.5	2.7	4.3	10.7	15.5	39.5	378.2	148.9
	Humidity	ph	ph	ph	h	h	sh	a	sa	h	ph	ph	ph	h
	Heat character	n	n	uhl	ut	t	t	t	t	t	ut	uhl	n	ut
Gračac	Precipi. (mm)	186.9	168.5	160.3	154.0	128.5	90.7	57.5	82.7	153.8	157.2	244.9	257.8	1837.0
	Air temp. (°C)	-0.1	0.8	4.8	8.9	13.9	17.1	19.6	19.0	14.2	10.3	5.3	1.2	9.6
	Rain factor	186.8	210.6	33.4	17.3	9.2	5.3	2.9	4.4	10.8	15.3	46.2	214.8	191.4
	Humidity	ph	ph	ph	ph	h	sh	a	sa	h	ph	ph	ph	ph
	Heat character	n	hl	uhl	ut	t	t	t	t	t	ut	uhl	hl	ut
Korenica	Precipi. (mm)	99.4	71.5	94.9	120.0	101.9	88.4	52.0	72.2	142.9	103.8	138.9	140.4	1186.8
	Air temp. (°C)	-1.9	-0.9	3.1	7.7	12.7	16.0	18.0	17.4	12.8	9.0	3.9	-0.4	8.1
	Rain factor	97.5	70.6	30.6	15.5	8.0	5.5	2.9	4.1	11.2	11.5	35.6	140	146.5
	Humidity	ph	ph	ph	ph	h	sh	a	sa	h	h	ph	ph	h
	Heat character	n	n	h	uh	t	t	t	t	t	ut	h	n	ut

Climate humidity character:
a – arid
sa – semiarid
sh – semi-humid
h – humid
ph – perhumid

Climate thermicity character:
h - hot
th – temperately hot
tc – temperately cold
hl - cold
n - nival

the climate, the weather stations are located on the territory of moderately warm climate. Hot months were not registered on any of the weather stations. Considering the heat character of the climate, during the year we have registered 5 hot months (h), from one to three months with snowfall (s), one to two temperately cold and cold months (tc and c), one to two temperately hot months (th). Temperately cold months (tc) occurred one on the territory of Gospić and Korenica, and two such months occurred on the Gračac territory (Table 1).

Air humidity

In the period from 1981 to 2010, on the three observed weather stations in Ličko sredogorje, maximal relative air humidity values were measured in December (rarely in November), except from the weather station Korenica where its peak was measured in April. The minimal values were measured in July.

In the observed period, the listed weather stations did not measure extremely humid or extremely dry air because the average annual value of air humidity was not higher than 90 % or lower than 40 % except for the weather station in Korenica, where February, March, April, May, November and December were extremely humid. The average annual air humidity level was temperate (Gospić and Gračac 78 %) up to very high (Korenica 89 %).

Climate indexes

Table 2 shows some of the climate indexes which determine the climate of the researched territory. The Ličko sredogorje territory, considering the value of the Lang annual rain factor, belongs to perhumid and humid climate. Considering the Martonne's index of aridity, which varied from 67.7 (Korenica) to 94.1 (Gračac), these are considered to be humid areas.

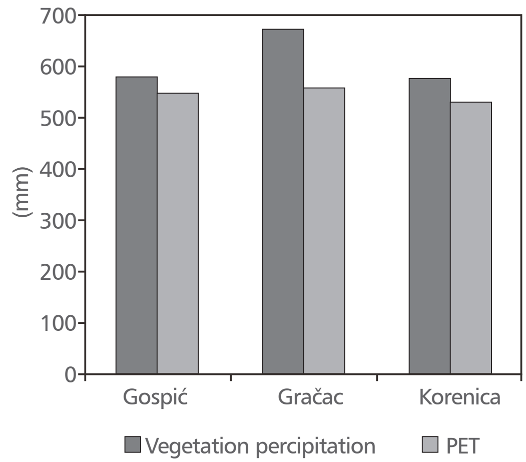

FIGURE 1. Relation between precipitation amount and potential evapotranspiration (PET)

Considering the value of the index of continentality, the study area has continental climate. According to the value of the thermal coefficient (from 5.4 for Gospić to 7.1 for Gračac), weather stations are located on the area characterized by temperate continental climate (Table 2).

Climate appearance

On the territory of Ličko sredogorje frost appears frequently. Fog is also frequent but also very interesting and important from the ecological point of view because it increases the total value of air humidity and creates additional amounts of precipitation.

According to the number of days with snow (≥ 1 cm), the first places holds the weather

TABLE 2. Climate factors and indexes of weather stations Gospić, Gračac and Korenica (1981 - 2010)

Met. station	Lang's rain factor	Martonn's aridity index	Emberger's Pluviotermic quotient	Konrad's index of continentality	Krener's thermic quotient
Gospić	148.9	70.8	205.1	51.3	5.4
Gračac	191.4	94.1	253.8	49.7	7.1
Korenica	146.5	67.7	205.6	61.4	6.5

TABLE 3. Descriptive statistics of microclimate in Ličko polje in 2011

Microclimatics elements	N	Mean	Min.	Max.	Std. Dev.
Air temperature (°C)	8025	10.5	-10.3	37.3	7.38
Soil temperature (°C)	8025	11.3	2.7	22.1	5.91
Volumetric water content (%)	8025	14.2	0.8	26.2	3.67

station Korenica with 165 days, it is followed by Gospić with 117 days and finally Gračac with 72 days. According to the documented amount of snowfall, Gračac stands out with 135 cm, it is followed by Korenica with 128 cm and Gospić with 117 cm of snow on the ground.

Microclimate

Average annual air temperature on the Ličkog polje area was 10.5 °C, and the soil temperature was 11.3 °C. The volumetric soil humidity had an average value of 14.2 %. The absolute maximum in the fluctuation of air temperature was 47.6 °C, then, of the soil temperature 19.4 °C, while the least absolute fluctuation was noticeable in the volumetric soil humidity for a value of 25.4 % (Table 3).

Basic substrate, soil types, soil chemical properties

Data about the geological and lithological structure was taken from the basic geological map Gospić [12], and the basic geological map Udbina [13]. The geological map of Ličko sredogorje iz characterized by layers from different age, from the Late and Middle Triassic, Jurassic, Late and Early Cretaceous, followed by Tertiary and Palaeocene, and Holocene.

In the geological-lithological as well as in the pedogenic sense the most significant rocks and basic substrates was limestone (Cretaceous and Jurassic) as well as limestone and dolomite (Jurassic), including limestone shale, conglomerates and limestone (Tertiary), limestone dolomites and shale (Cretaceous), limestone and dolomitic limestone (Jurassic) as well as sandstone and schist.

Data about the soil was taken from the basic pedogenic maps sheet Gospić 3 [14], Novigrad 1 and Novigrad 2 [15]. The central part of the Ličko sredogorje consists of a series of soils from calco-cambisol deep, calco-melanosol organic-mineral and brown variety and in a smaller amount from terra rossa deep and black soil organic-mineral and organic. On the territory of Medak, Bilaj, Ribnik, Počitelj and Plantaža there is a distric brown podsolic and typical soil, podsolic typical, and brown soil on limestone, deep. In a smaller amount, certain anthropogenic soils can also be found here. On a wider area around Gračac and Bruvno there are brown soils on limestone and dolomite, typical and podsolic, and shallow, medium deep and deep, then limestone dolomitic black soil, organic-mineral, organic and browned. The area around Ličko sredogorje also has limestone dolomitic black soil and alluvial and colluvial soil in a smaller area.

Based on the chemical analysis of the soil (Table 4) we can conclude that the studied soils have the same chemical content: the soil has a very acid reaction, it is very humus-like, it is good to richly supplied with total nitrogen, the

TABLE 4. Chemical analyses of soil in the area of Ličko polje

Subcompartment	pH		P_2O_5	K_2O	N	Humus	C	C/N
	H_2O	1MKCl	mg/100 g tla		%	%	%	
39a	5.53	4.18	1.21	5.8	0.28	7.31	4.23	15.18
51a	5.35	4.12	1.32	6.2	0.30	7.56	4.40	14.67
63	5.54	4.13	0.88	4.4	0.18	5.20	3.02	16.78

content of physiologically active phosphorus and potassium is low, and C/N ration normal.

DISCUSSION

The Lika territory, considering the available soil types, is among one of the most optimal areas for the production of intensive cultures of fast-growing conifers. [16]. All pine cultures in Lika (classic and intensive) have been planted on Ličko and Krbavsko polje and in their surroundings. According to Vukelić [16] these areas are in the areal of the plant community of Illyrian forest of Sessile oak and hornbeam (*Epimedio-Carpinetum betuli* /Ht.1938/Borh. 1963) where the dominant forms are moors and bracken (*Genisto-callenetum*).

Apart from the air temperature which is dependant of the amount of clouds and air insolation, the amount of precipitation has the dominant effect on the growth of the vegetation because that is the main source of soil humidity. Lack of precipitation and high air temperatures weaken the resilience of forest trees because due to an increased transpiration, a large amount of water is being used [17]. The success of afforestation, that is, of establishing forest cultures, among other things, also depends on the understanding of the forest trees' habitats.

With afforestation it is necessary to consider the priority functions of the future forest cultures, and adjust accordingly the choice of tree types suitable for such climate, and consequently respect the soil characteristics. It is necessary to know the relation between what the plant requires and what the habitat can provide.

In today's conditions of climate change and the fluctuation of climate elements, it is also necessary to pay attention at the choice of afforestation species for a specific bio climate due to the survival of seedlings, as well as, due to the particular species' relation towards the climate change. The territory of Ličko sredogorje as well as the whole Lika territory has many contrast areas from the point of view of ecology and habitats which need to be considered when choosing the afforestation tree types.

Atmospheric drought is influenced by the lack of water steam. If the relative air humidity decreases significantly, transpiration increases. Terrestrial plants mostly receive water from the roots, although they sometimes also water from the atmosphere [18]. Vajda [19] says that the soil humidity factor is extremely important for the development of Common spruce. He also says that every tree type in the hotter provenance area requires a high level of humidity both in the air and the soil for its good development and growth than it would require in the colder and more humid area, and vice-versa. Therefore, he considers humidity to be the eliminating factor in many karst habitats which influences on the lack of spruce, especially if the expositions are under the influence of strong wind. According to the results of Oršanić and others [20] the soil humidity is statically conditioned with the air temperature, the dew point and the amount of precipitation in a significant way. It is well known that the relative air humidity has a big ecological significance for the supply of superficial soil layers by water condensation. Young cultures of common pine on the moor and bracken covered soils have showed their best development of the soils with the maximal quantity of the available water in the soil profile [21]. The same authors say that weather conditions in particular years have a very pronounced influence on the growing height of common pine. On the other hand, the results of Martinović and others [22] have showed that the existing differences in the growth of common pine are mostly derived from the differences in the productive value of soils.

With planning and afforestation implementation, among other factors, it is also important to respect a determined production order of the soil for specific tree types [23].

According to the results in Table 4, particularly considering the pronounced soil acidity we can conclude that the soil is more suitable for the growth and development of conifers, and for their good development, it is important to make the basic fertilization with unit phosphorus and potassium fertilizer. According to the research made by Komlenović and Rastovski [24] it is visible that the fertilization had a positive effect

Komlenović and others [25] have showed the positive effect of fertilization on the increased concentration of biogenic elements in the needles as well as on the increased volume of this year's needles.

Looking at their characteristics, the cultures are not forest ecosystems with an established dynamic of elements circulation, and therefore, for their good development it is necessary to fertilize "for the supply" with phosphorous and potassium, because due to their features (slow shift in the soil profile) the subsequent interventions are not possible or they are poorly used. In forest plantations and in horticulture, foliar treatment of plants can be combined with the application of protective measures while with forest cultures this is difficult to implement. This fact shows the importance of doing research on the areas which are intended for the establishment of forest cultures and plantations as well as the importance of selcting a suitable species [3].

According to the research of Vukelić [16] on the Ličko polje territory, the best results were obtained with Eastern white pine, than common spruce and common pine. The poorest results were obtained with the European larch. According to Martinović [23] acid brown soils on a relic terra rossa soil under common pine and spruce have a high forest productivity value. The author further concluded that the natural productivity potential of acid brown soils on the relic terra rossa soil is used better by growing common spruce than by growing common pine. Orlić and Ocvirek [26] have concluded that common spruce deserves the best attention and has rightfully been used on our territory for the afforestation of moors and bracken covered areas.

According to the data provided by Martinović [23] black pine has the highest productivity on terra rossa soils, and lower and equal on brown soil on limestone and on rendzina on flysch. Significant differences are evident in the diameter and volume at breast height and they can be attributed to the edaphic conditions. According to Martinović [23] with the establishment of conifer cultures in the bio climate of sessile oak and common hornbeam, bigger attention should be given to common pine than to black pine, while the priority for afforestation when looking at the soil productivity should be given to distric brown soil on relic terra rossa.

Based on the ecology demands of individual forest tree species with pioneer character [27, 28] and on habitat characteristics of the studied area, for the afforestation of un-grown forest land of the Ličko sredogorje territory we recommend the following forest tree species: Common birch (*Betula pendula* Roth.), European larch (*Larix decidua* Mill.), Common spruce (*Picea abies* Karst.), Eastern white pine (*Pinus stroubus* L.), Black pine (*Pinus nigra* subsp. *austriaca* Asch i Gr.), Common pine (*Pinus sylvestris* L.), European trembling aspen (*Populus tremula* L.).

CONCLUSIONS

Climate and soil are the factors that determine the habitat and which need to be taken into consideration during the selection of forest trees species for afforestation.

Average annual air temperatures on Ličko sredogorje territory have been between 8.1 °C and 9.6 °C. Absolute minimal and absolute maximal air temperatures have been between -34.6 °C and +38.3 °C. Average annual amount of precipitation were around 1 500 mm and the percentage of precipitation in the vegetative period was between 36.4 % and 50.3 %. Soil humidity during the whole year is sufficient. The water balance of the soil has a positive prefix all year round. When establishing the cultures, it is essential to implement agro-technical measures, namely fertilization, all accordingly to the results of chemical analysis.

For the afforestation of the un-grown forest land in the Ličko sredogorje area we recommend the following forest trees' species: Common birch (*Betula pendula* Roth.), Common spruce (*Picea abies* Karst.), Eastern white pine (*Pinus stroubus* L.), Black pine (*Pinus nigra subsp. austriaca* Asch i Gr.), Common pine (*Pinus sylvestris* L.) and European trembling aspen (*Populus tremula* L.).

During the selection of afforestation species it should be considered that different authors have obtained different results regarding the growth and development of specific species in the forest cultures of Lika territory, the reason for which could be traced back to the mosaic characteristic of soil, differences in the micro-climate conditions and to forest cultures' management.

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Ecological and Economic Advantages of Using Polypropylene Tree Shelters in Lowland Oak Forests

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Abstract

Background and Purpose: The process of joining the market competition by the company "Croatian Forests", managing state forests in Croatia, is related to the transformation of the company into a trading company. This means that beside the biological and ecological goals in managing forests, the special attention is to be paid to business operations with the highest economic outputs, reduced costs and increased income. In order to enhance the regeneration of pedunculate oak forests in present day changing ecological and challenging economic conditions, as our proposal, is implementation of one of the artificial methods of regeneration pedunculate oak forests by planting seedlings protected with polypropylene tree shelters.

Materials and Methods: The paper deal with existing knowledge about the conditions and characteristics of two methods of oak stand regeneration and analyzed data of current norms, standards and prices for each of these methods. The analysis compared the two methods: method of regeneration with unprotected seedlings, and seedlings protected with polypropylene tree shelters.

Results and Conclusions: The research results showed that in comparison to the common seedling planting method, this method of pedunculate oak stand regeneration on difficult terrains with complex stand conditions is ecologically and economically more beneficial.

Keywords: forest stands regeneration, polypropylene tree shelters, ecological and economic advantages

INTRODUCTION

Two words that are now often used in forestry, as a positive conservative branch of the economy, are ecology and economics (the latter term actually means relating to forestry under the rules and laws of competition). The process of "ecologization" of Forestry is emphasized by the certification of forests, which imposes a rather demanding standard in the application of pesticides, and requires, instead of environmentally harmful chemical protection of forests, the use of integrated mechanical, biological, biotechnological and other environmentally friendly materials and measures to protect forest ecosystems. Further process acceleration is gained through rising public awareness about the need for sustainable development and the protection of biodiversity and nature.

The process of joining the market competition by the company Croatian Forests Ltd., managing state forests in Croatia, is related to the transformation of the company into a trading company. This means that beside the biological and ecological goals in managing forests, special attention is to be paid to business operations with the highest economic outputs, reduced costs and increased income.

At the first glance it seems that these two terms are incompatible, that is, that the ecologically acceptable protection measures raise the price of the final product, making it thus less competitive on the market. That this is not the case is evident on the example of polypropylene tree shelters.

Polypropylene shelters were introduced by the English forester, Graham Tuley, in 1979. The shelters are pipes made of two-layered polypropylene in various light color tones (Figure 1).

FIGURE 1. An experimental plot with polypropylene tree shelters (Forest Office Kutina, Kutina Lowland Forests management unit, June 1996)

Polypropylene, unlike the polyvinylchloride (PVC), the material also used to produce plastics, has several important advantages in the sense of ecological acceptability:

- during manufacturing (unlike PVC) no dioxins are neither created, nor released, which are among the most poisonous chemicals known today. They are carcenogenous and disturb the immunological and hormonal systems.
- polypropylene, unlike the PVC compounds, does not contain phthalates, very damaging additives that increase the PVC elasticity and disturb hormonal functions.
- when burning polypropylene no dioxins or any other poisonous compounds are created, and no additives are released on dump sites that may contaminate drinking water sources, which is a significant problem with PVC.

The upper rim of the shelter is slightly bent towards outside to avoid damaging the plants after they outgrow the shelter. Due to the more economical and easier transport and storing, the shelters are 5 in a package, one in the another, so that their diameters are between 8.3 and 10.8 cm. They are manufactured as 0.2 m in height due to the protection of rodents and up to 1.8 m against wildlife (deer). The shelter is placed next to the pole and fastened with two plastic ties.

The first shelters were sensitive to UV rays and atmospheric influences and fell apart in two to three years after planting (Figure 2).

The improved shelters with the UV ray inhibitors may last for up to 8 years and are capable to provide support to thin and long trunks even after the trees outgrow the shelters. Without support the trees would bend and be covered by weeds. The technology of producing shelters was improved in 1990 by introducing the weakening line along the shelter's length because previously they lasted for too long and stayed on the tree for 10 and more years (Figure 3). The line consists of holes along the shelter that allow the shelter to rip when the tree outgrows the shelter's diameter.

FIGURE 2. An inadequate structure and composition of the shelter causing their premature deterioration (September 2002)

FIGURE 3. A polypropylene tree shelter without a weakening line (August 2006)

The basic advantage of shelters is an accelerated growth of seedlings, as reported by many authors [1-6]. Liović [5] conducted the research on experimental plot near Kutina and found that six vegetation periods after the planting the medium height of the pedunculate oak (*Quercus robur* L.) seedlings was over 200 cm, while the heights of the unprotected seedlings was about 50 cm. Some protected seedlings grew up to the height of 4 m. Jeffrey and Stephens [7] reported that the wildlife gnawing on the unprotected seedlings of the black walnut (*Juglans nigra* L.) at the beginning of the planting was higher (34.0 cm) than three years later (28.2 cm) while the protected seedlings grew from 36.1 cm to 89.0 cm. The red oak (*Quercus rubra* L.) seedlings in shelters grew from 30.2 cm during three vegetations to 110.6 cm, while the control (unprotected) grew from the initial 31.1 cm only to 45.1 cm.

Liović [5] reported the increased growth and the lower mortality of protected seedlings, so that the mortality rate of sheltered seedlings after four vegetations was 6 %, while it was 24 % in unprotected seedlings. Jeffrey and Stephens [7] also reported the mortality of the seedlings protected by polypropylene shelters was significantly lower than in the control group. During three vegetation 8 % of the unprotected red oak seedlings withered, while only 2 % of the protected seedlings died. The same experiment reported the 8 % death of the unprotected black oak (*Quercus kelloggii* Newb.) seedlings, while all the protected seedlings survived. Placing the shelters in the shadow of old trees did not increase the survival of seedlings so this method of regeneration should be avoided [8]. Generally, the assistance (help) of polypropylene shelters would not be required at all if the regeneration cuttings on the entire oak forest areas in Croatia would be done successfully.

The deterioration of forests is a process that is especially frequently present in the lowland pedunculate oak forests. The increased intensity of forest decline lowers the number of young oak trees [9]. The areas with forest deterioration symptoms are increasing, so we may expect that the areas for artificial regeneration by planting seedlings or sowing acorns will keep increasing. The ever more frequent lack of acorns and/or the reduced acorn yields lately, improperly done regeneration cuttings and artificial regeneration by pedunculate oak seedlings, the flooding of forest areas, as well as other causes that often lead to increased weediness or turning areas intended for regeneration into marshes, make the artificial and natural regeneration more difficult and prevents natural regeneration. Artificial regeneration is more expensive than natural regeneration (this obligation is not questionable in normal conditions) so failure is not acceptable because the regeneration process would have to be repeated several times in some cases.

The newly founded clonal seed orchard of pedunculate oak trees will produce seeds that will have to be rationally handled due to their limited quantities. There are three clonal seed orchard in Croatia, with 119 clones on 103 ha [10]. Plant shelters offer the opportunity to regenerate forests artificially with seedlings from this seed and with the least loss. The most detrimental factors that decrease the survival of oak seedlings are weeds, powdery mildew (*Microsphaera alphitoides* Grif. et Maubl.) disease and wildlife. Thick weeds overgrow the seedlings fast, shadows them, reduce the intensity of photosynthesis and, at the same time, the lower vitality and the growth of the plants. Besides, weeds are seedlings' competition for water and nutrients. In winter, the dead over ground parts of weeds mechanically press and bend young oak trees. Kozarac [11] wrote about the detrimental influence of weeds in regenerating oak forests, because the condition of weeding gives a greater advantage to ash (*Fraxinus angustifolia* Vahl). Plant disease, powdery mildew, reduces the intensity of photosynthesis and wildlife bites off seedling tops which influences growth. The growth within the shelters shortens the time the plant spends in the weed competition zone, and the plant is not exposed to powdery mildew, wildlife and rodents in its most sensitive phase of development, and has a much larger probability of survival, as mentioned above. These are the reasons that in areas where natural regeneration failed and there are several negative factors preventing or burdening artificial regeneration, polypropylene shelters may be a good choice. The justification of such ideas may be supported by an example from German forestry quoted by Hammer [12]. He described how the problem of deforestation was successfully solved by planting seedlings protected by polypropylene shelters after the catastrophic consequences of the hurricane "Lothar" in the vicinity of Baden-Baden in the Schwartzwald area. The influence of the hurricane was recorded on more than 2,000 ha of forests. In order to resolve the problem, 350,000 polypropylene shelters were purchased to plant some 20 species of trees (49% of deciduous trees: oak, ash, wild fruit trees, etc.). Besides the planted 350,000 plants protected by polypropylene shelters (1 to 2 year seedlings), the area between the planted trees was left to regenerate to low vegetation left after the hurricane. Some plants were planted under the shade of undamaged trees. The author reported that today these are vital young stands created by a combined natural and artificial regeneration, and the "exceptionally high percentage of seedling survival if protected with polypropylene shelters". Hammer [12] also emphasized the advantages of planting seedlings in polypropylene shelters: smaller seedlings may be planted because they quickly outgrow the shelters and their roots develop better than large seedlings that are used to avoid the competitive high weeds (also more expensive). The economic advantages include a smaller number of seedlings, less manpower to plant the seedlings and no requirements for fences to protect against wildlife. As ecological advantage, Hammer [12] reported, that chemical as well as other forms of tending after two years are virtually unnecessary.

The purpose of this research is to determine the advantages of using polypropylene shelters for the protection of planted trees in artificial regeneration and/or founding new pedunculate oak stands in relation to using the common artificial regeneration method and planting unprotected seedlings, especially the advantages determinable through ecological and economical indicators of the applied methods.

MATERIALS AND METHODS

The research of the comparative elements included the cost analysis of all important actions, as well as costs of seedlings and other materials for regeneration and tending of pedunculate oak stands up to 5 years in case the stand is set on the weeded area without natural offspring. These costs depend on the applied regeneration method.

The research used the comparative method of evaluation the ecological and economic advantages, that is, the efficiency of the regeneration and tending of oak forest stands with the two methods applied. The common method of planting and tending of 10,000 pedunculate oak seedlings 2+0 per 1 ha, with the previous preparation of the entire site by filling up with seedlings 3+0 A and tending of young plants up to 5 years, was compared to the regeneration by polypropylene shelters and tending of young stands up to same age. It may be assumed that the regeneration method of applying polypropylene shelters will show certain advantages in relation to the common method (in the ecological and economical sense) because a significantly lesser number of seedlings is planted, the area for tending to young trees is smaller (financial cost, the necessary quantities of chemical compounds for tending and protection of young trees, etc.), and if necessary, the possibility is open to apply mechanical means for tending and regeneration.

The normative data of the preparatory silvicultural plan for the year 2011 (the IT package of the HS PPU software), plus the control methods of oak stand cultivation for Forest Administration Vinkovci and Forest Administration Zagreb was used for the comparison of work cost and material used with the common method of regenerating pedunculate oak stands.

The data for the elements of the pedunculate oak stand regeneration by applying polypropylene shelters was partially used from the same program package, and partially recorded as separate normative, due to the specificity of the method.

Besides determining the quantity of the applied (detrimental) chemical means (chemical tending, protection against powdery mildew, rodents) for the purposes of comparing the ecological advantages of the aforementioned methods, based on the appropriate norms and standards, as well as the planned prices for 2011, the important economical indicators of the regeneration and tending costs per 1 ha were to be determined.

The earlier research conducted by Liović and Ocvirek [4] showed that, due to the specific microclimate within the shelter, the plant disease powdery mildew on oak seedlings may be disregarded, while the unprotected seedlings were heavily damaged (it is necessary to protect the seedlings against powdery mildew). Liović [13] also quoted the results of another research when he determined that 15 % of the control group of unprotected plants were eaten by wood wasps (*Apethymus abdominalis* Lep.), while the seedlings protected by shelters remained undamaged. The results of both research indicate that the use of fungicides and insecticides for these purposes may be significantly reduced or completely excluded if pedunculate oak seedlings are regenerated by applying polypropylene shelters.

RESULTS AND DISCUSSION

Site Preparation

The costs of preparing the sites on open surfaces intended for pedunculate oak stand regeneration were higher with a common method of regeneration because mechanical and chemical preparation of the site is done on the entire area, while with the use of polypropylene shelters the unwanted plants were removed chemically only in the row where the seedlings protected with shelters were to be planted. The required quantity of chemicals for this purpose (the glyphosate herbicide) with the common method of regeneration was 101/ha, with machinery (tractor + atomizer), while the regeneration with polypropylene shelters only required 2 to 2.5 l of herbicide per 1 ha, using a portable nozzle or a smaller atomizer. The otherwise ecologically suitable herbicide with glyphosate as active ingredient became a large threat to the biological diversity. Namely, the application of total herbicide kills almost all plant organisms on the treated surface, both the frequent, but also those rare plant species that would hardly "return" to that area.

The presentation of costs when applying the two methods on Figure 5 shows the relations of compared cost variables indicating the advantages, that is, the acceptability in the economic and ecological sense.

Protection of Seedlings from Wildlife and Rodents

Setting up protective fences against **wildlife** and protective measures against **rodents** when applying the method of regeneration by using polypropylene shelters were not necessary, while the common method of regeneration almost always required the aforementioned measures to protect young stands (the total cost of 822.53 €/ha). Besides the financial benefit, the ecological advantage of this method was also important due to the left-out dangerous pesticides, which reduced the population of pest, but also negatively influenced all other animal species and presented a danger of soil infiltration and further detrimental influences.

Planting Seedlings and Filling

Although the unit price of an oak seedling **planted in a polypropylene shelter** (planting the seeding, purchasing, transport and setting of the polypropylene shelter and the supporting pole = 3.51 € per seedling) was significantly higher than the oak seedling **planed with a common method of regeneration** (planting - 0.66 € per seedling + filling 0.96 € per seedling), the total calculation, due to 7 times less required quantity of seedlings, shows that the planting by using the polypropylene shelters was economically significantly more beneficial:

a) common method:

planting seedlings - 10.000 pcs 2 + 0B	= 6,566.70 €/ha
+ filling - 5.000 pcs 3 + 0 A (to 10 % surface)	= 477.81 €/ha
Total: planting + filling	= 7,044.51 €/ha
b) planting with polypropylene shelters (1.500 pcs. 2 + 0 B)	= 5,259.55 €/ha

Due to the potential application of mechanization in protecting and tending, it was more beneficial to plant seedlings in rows, but they may be planted on the prepared area in no order with a certain distance in between to preserve the naturally regenerated forest appearance.

There may be an objection that a relatively small number of seedlings (up to 1500/ha) does not ensure a sufficient diversity. The fact is that larger areas are being regenerated so that the diversity is present on such a large area. Also, the selection of trees in tending, cleaning and thinning is done so that tall and straight trees are chosen (technically, the most perspective trees), so in that way, the selected trees in the natural regeneration do not completely represent a wide biological diversity within the species

.

Tending of Seedlings up to 5 Years

Due to the great growth and easy visibility of polypropylene shelters and protected plants, the tending of seedlings is significantly easier. With the common method of regeneration chemical tending includes the tractor atomizer with a norm of 0.17 working days per 1 ha and the 2.5 l of herbicide, meaning the total of 63.07 €/ha, unlike the polypropylene shelter method that spends the total of 49.43 €/ha with a portable nozzle in the area of 1 m around each shelter 2 to 3 years after planting. It is important to mention that the herbicides are applied by a portable nozzle and not by heavy machinery that stiffens the soil and often the access to the tending area is difficult. Hand mechanical tending with the common method of regeneration consists of the working norm of 10 workers day per 1 ha, which means with additional cost of tools the total of 666.49 €/ha, while the polypropylene shelter method requires 2 workers per 1 ha for hand tending and the cost of 132.43 €/ha. The fact is also that it will be increasingly more difficult to ensure a larger number of workers for this job and low pay in the future. The total difference in costs of tending seedlings is, therefore, 484.63 €/ha in favor of the polypropylene shelter regeneration method, which is the economic advantage of this method.

It should be also mentioned that on the basis of the experience of applying polypropylene shelters in Croatia for the purposes of assisted regeneration (the first research began some twenty years ago), that tending and cleaning, otherwise done in turn until the oak stands are 20 years old, is almost unnecessary (Figure 4).

FIGURE 4. An experimental plot of the pedunculate oak forest stand regenerated 18 years ago by polypropylene tree shelters in the Kutina Lowland Forest management unit (Forest Office Kutina,30 March 2012)

Protecting Plants from Disease and Pests

The data on normative costs of protecting seedlings against plant diseases and pests it is evident that the cost per 1 ha for this purpose (fungicides + insecticides, without airborne treatments) is 333.31 €/ha, when the common regeneration method is used, while the application of the method with polypropylene shelters means no such financial cost, but also the cost of pesticides is low and rare. This fact also indicates the economic and ecological advantage of regenerating pedunculate oak stands with polypropylene shelters.

The Total Cost of Pedunculate Oak Stand Regeneration Depending on the Applied Method

Summing up all costs that include pedunculate oak tree stand regeneration on clean areas, as well as the tending of the young stands in the first five years (Figure 5), it is evident that the cost of the common method of regenerating pedunculate oak tree seedlings is the total of 9,697.74 €/ha, while the total cost for the same purpose when applying the polypropylene shelters is 6,160.21 €/ha, meaning the total difference of 3,537.53 €/ha less per 1 ha. Except this method being financially (economically) more beneficial by 36%, the success rate of regeneration with this method is very high (survival of seedlings) in relation to the common method [6, 14].

Similarly, the ecological advantages of this method should be emphasized, as determined through significantly reduced quantities of the required chemicals, whether herbicides, fungicides and/or insecticides, whose detrimental impact to the ecosystem, environment and health of people is difficult to evaluate, especially in financial terms.

Potential Applications of Polypropylene Tree Shelters to Protect Seedlings

1. Reforestation of weeded clearings or low bush plants (e.g. *Amorpha fruticosa* L., *Carex* sp., *Cornus sanguinea* L., etc.), with the terrain configuration that does not allow the application of technical equipment and the areas endangered by wildlife

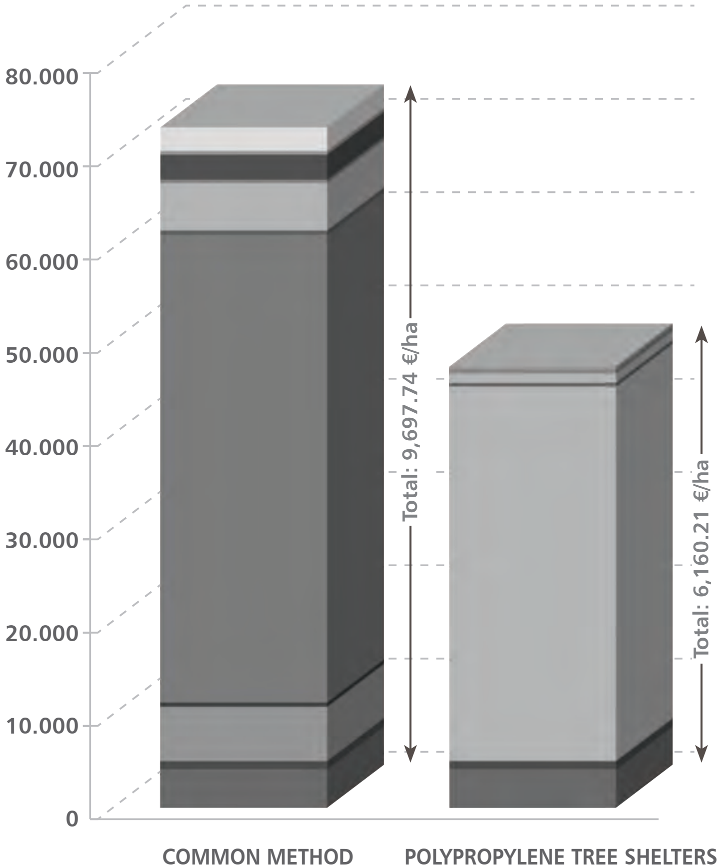

FIGURE 5. Comparison of the cost structure - cost per 1 ha in € of the pedunculate oak stand regeneration of the common method and with the help of the polypropylene tree shelter (middle rate published by the Croatian National Bank on 3rd January 2014, 1 € =7.626505 HRK)

- Site preparation - manually, habitually: 552.94 €/ha; with polypropylene tree shelters: 552.94 €/ha
- Site preparation - mechanized, habitually: 117.22 €/ha; with polypropylene tree shelters: 68.18 €/ha
- Installing of protection fence, habitually: 763.65 €/ha; with polypropylene tree shelters: 0 €/ha
- Rodent protection, habitually: 58.87 €/ha; with polypropylene tree shelters: 0 €/ha
- Supply, transport, planting and seedlings manipulation (10.000 pieces/ha seedlings of Querscus robur 2+0B) habitually: 6,566.70 €/ha; with polypropylene tree shelters: 0 €/ha
- "Supply, transport, and seedlings planting; Supply, transport, and setting of stakes (1500 pieces per hectare) (1.500 pieces/ha seedlings of QR 2+0B), habitually: 0 €/ha; with polypropylene tree shelters: 5,259.55 €/ha"
- Tending of young plants (applying of herbicides), habitually: 63.07 €/ha; with polypropylene tree shelters: 49.43 €/ha
- Tending of young plants (manually), habitually: 666.49 €/ha; with polypropylene tree shelters: 132.43 €/ha
- Establishing of silvicultural breaks (forestry mulcher 1,5 m), habitually: 47.33 €/ha; with polyp. tree shelters: 47.33 €/ha
- Filling-up with 5.000 seedlings/ha 3+0 A, habitually: 477.81 €/ha; with polypropylene tree shelters 0 €/ha
- Maintaining of silvicultural breaks (forestry mulcher 1,5 m), habitually: 50.35 €/ha; with pol. tree shelters: 50.35 €/ha
- Protection from plant deseases, habitually: 333.31 €/ha; with polypropylene tree shelters: 0 €/ha

With selected seedlings of economic species (phenotype, genotype) and no more than 1500 pcs/ha protected with polypropylene shelters, it is possible to regenerate such areas primarily due to the accelerated height growth of protected plants. This enables the planting of other species of the same phytocenosis at the same time, without protection and not more than 1000 pcs/ha.

For oak and ash stands it may be done in the way of planting seedlings in rows 2.5 m distant with 4.0 m between the seedlings, provided that every other row is planted by oak and ash alternatively. In the rows between the protected seedlings it is advisable to plant a certain number of currently financially more valuable species (e.g. wild cherry - *Prunus avium* L., checker tree - *Sorbus torminalis* L., etc). Naturally, should the stand conditions allow that.

2. Assistance to Regeneration

In the areas already regenerated (with seedlings), with young trees and especially endangered by wildlife teeth, or parts of areas (generally micro depressions) where young ash trees endanger oak trees, it is possible to use protection assisted by polypropylene shelters to obtain quality mixed stands.

3. Improving the Stand's Quality

The poorly regenerated stands in the sapling phase may be significantly improved in the biological and financial quality by introducing seedlings of faster growing trees (e.g. ash, wild cherry, black walnut, oak, etc) protected by polypropylene shelters. Pure black locust (*Robinia pseudoacacia* L.) stands of up to 15 years may be transformed into significantly more valuable mixed stands of oak, wild cherry and black locust stands without waiting for the end of pollination and by using protective pipes.

4. Raising Clonal Seed Orchards – grafts protection

5. Application in Nursery Production

6. Protection of the Existing Young Plants

7. Forest Renovation by Seeds from Clonal Seed Orchards, with the Highest Exploitation Rate

CONCLUSIONS

Based on the research results, it was determined that the method of artificial stand regeneration by using polypropylene shelters is environmentally more beneficial than the method of planting unprotected seedlings (the common method), because instead of preparing the site by spraying the vegetation with herbicides on the entire area, it requires the spraying of stripes of only about 1 m wide.

Similarly, the use of shelters in tending young plants does not exclude the use of herbicides up to two years after planting, but they are used in significantly lesser quantities, because the entire area is not sprayed, but only a 1 m diameter circle around each shelter. Besides the financial benefits, this is also the ecologically better method to prepare the site, for regeneration and tending, because the quantities of herbicides are reduced and a larger area is left intact to preserve biodiversity of the future stand (wild fruit trees and other species that do not endanger the pedunculate oaks).

It bears repeating that this is the regeneration on the weeded area without young trees, that is, the area where for certain reasons the natural regeneration of oak stands is not possible.

The presented method of pedunculate oak stand regeneration by using measures to protect the seedlings against competitive weeds, wildlife, plant diseases and pests, is not to be taken as a replacement for the natural regeneration of pedunculate oak stands. This method of artificial regeneration is recommended primarily for the terrains where natural regeneration is not possible by the well-known principles of forest nursing due to various reasons (the calamities damaging the vitality of the forest stand that, in some more difficult cases, may cause their deterioration, flooded terrains at times after the final cutting, the failed natural regeneration and weediness of the entire terrain with problematic weeds and so on). Similarly, although such a method of forest stand regeneration may be objected to be copied from fruit tree nursing and is not common for the nursing methods in Croatian forestry, we have to mention that this method has been successfully used for a long time in the forestry of many countries with developed forestry as an economic branch. The negative climatic changes and the results of their influence on ecosystems that seriously change the ecological and stand conditions in forest stands, as well as the changed economic circumstances, lead to the necessity of different ways of thinking, that is, the application of new solutions and technologies in order to overcome the consequences of these events that are inevitable today. In this sense, such thinking is reasonable when considering the ways and possibilities of overcoming the negative consequences of the changed ecological and economic conditions, as one more recent research on this issue confirms the aforementioned claims: "...to take into consideration that many norms, rules, regulations, expertise, tradition, work dynamics and the usual economic actions, that used to be applicable in managing pedunculate oak forests in normal conditions, should be adjusted to the actual stand, structural and site conditions" [15].

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- papers written in the language other than English (e.g. German, Russian, Croatian, Serbian, etc.) should be translated into English.

3. MARJANOVIĆ H, OSTROGOVIĆ MZ, ALBERTI G, BALENOVIĆ I, PALADINIĆ E, INDIR K, PERESSOTTI A, VULETIĆ D 2011 Carbon Dynamics in younger Stands of Pedunculate Oak during two Vegetation Periods (*in Croatian with English summary*). *Sumar list* 134 (11-12): 59-73

- papers in journals with DOI number:

4. VULETIĆ D, POTOČIĆ N, KRAJTER S, SELETKOVIĆ I, FÜRST C, MAKESCHIN F, GALIĆ Z, LORZ C, at al. 2009 How Socio-Economic Conditions Influence Forest Policy Development in Central and South-East Europe. *Environ Manage* 46 (6): 931-940. DOI: http://dx.doi.org/10.1007/s00267-010-9566-3

- Early View papers (published online, waiting to be published in print version):

5. MATOŠEVIĆ D 2013 Box Tree Moth (*Cydalima perspectalis*, Lepidoptera; Crambidae), New Invasive Insect Pest in Croatia. *South-East Eur For* 4 (2): (early view). URL: http://www.seefor.eu/36-vol4-no2-matosevic.html (20 December 2013)

- or (if doi number is available):

6. ANČIĆ M, PERNAR R, BAJIĆ M, SELETKOVIĆ A, KOLIĆ J 2013 Detecting mistletoe infestation on Silver fir using hyperspectral images. *iForest* (early view). DOI: http://dx.doi.org/10.3832/ifor1035-006

b) *Paper in Proceedings:*

7. BALENOVIĆ I, SELETKOVIĆ A, PERNAR R, MARJANOVIĆ H, VULETIĆ D, BENKO M 2012 Comparison of Classical Terrestrial and Photogrammetric Method in Creating Management Division. *In*: Pentek T, Poršinsky T, Šporčić M (*eds*) Forest Engineering - Concern, Knowledge and Accountability in Today's Environment, Proceedings of 45th International Symposium on Forestry Mechanization, Dubrovnik, Croatia, 8-12 October 2012. Forestry Faculty of University Zagreb, Zagreb, Croatia, pp 1-13

c) *Book:*

8. VAN LAAR A, AKÇA A 2007 Forest Mensuration. Springer, Berlin, Germany, 383 p

d) *Chapter in a book:*

9. CURTIS PS 2008 Estimating Aboveground Carbon in Live and Standing Dead Trees. *In*: Hoover CM (*ed*) Field Measurements for Forest Carbon Monitoring. Springer, New York, NY, USA, pp 39-44

e) *Thesis:*

10. OSTROGOVIĆ MZ 2013 Carbon stocks and carbon balance of an even-aged Pedunculate Oak (*Quercus robur* L.) forest in Kupa river basin (*in Croatian with English summary*). PhD thesis, University of Zagreb, Faculty of Forestry, Zagreb, Croatia, 130 p

f) *Non-scientific literature:*

- Paper in online magazine:

11. LEMMENS M 2011 Digital Photogrammetric Workstations, Status and Features. *GIM International* 25 (12). URL: http://www.gim-international.com/issues/articles/id1797-Digital_Photogrammetric_Workstations.html (20 November 2012)

- Professional and other web pages:

12. CROATIAN FORESTS LTD 2013 Forests in Croatia. URL: http://portal.hrsume.hr/index.php/en/forests/general/forests-in-croatia (14 December 2013)

- Manuals, Reports and other documents from web pages:

13. DOBBERTIN M, NEUMANN M 2010 Tree Growth. Manual Part V. *In*: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. UNECE ICP Forests Programme Co-ordinating Centre, Hamburg, Germany, 29 p. URL: http://www.icp-forests.org/Manual.htm (12 December 2013)

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- Legislations, Regulations:

15. THE MINISTRY OF AGRICULTURE, FORESTRY AND WATER MANAGEMENT 2006 Regulation on forest management (*in Croatian*). *Official Gazette* 111/06, Zagreb, Croatia. URL: http://narodne-novine.nn.hr/clanci/sluzbeni/128205.html (10 December 2013)

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