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TREE SPECIES CLASSIFICATION USING WORLDVIEW-2 SATELLITE IMAGES AND LASER SCANNING DATA IN A NATURAL URBAN FOREST

KLASIFIKACIJA VRSTA DRVEĆA U PRIRODNOJ URBANOJ ŠUMI KORISTEĆI WORLDVIEW-2 SATELITSKE SNIMKE I LIDAR

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Summary:

A detailed tree species inventory is needed to sustainably manage a natural, mixed, heterogeneous urban forest. An object-based image analysis of a combination of high-resolution WorldView-2 multi-spectral satellite imagery and airborne laser scanning (LiDAR) data was tested for classification of individual tree crowns of five different tree species. The model training data were obtained from a systematic grid of plots in the forest. In total, 304 coniferous (Norway spruce and Scots pine) and 270 deciduous (European beech, Sessile and Pedunculate oak (combined), and Sweet chestnut) trees were identified in the field. The classification was performed by applying the support vector machine model. An accuracy assessment was performed by calculating a confusion matrix to evaluate the accuracy of the classification output by comparing the classification result to the independent test data. The overall accuracy of the classification was 58 %.

KEY WORDS: green infrastructure; ground truth data; spectral signature; tree species mapping; tree species inventory; forest monitoring

1. Introduction
Uvod

Maintaining a tree species inventory is one of the key forest management tasks. Specifically, for a close-to-nature managed natural urban forest for multiple ecosystem services, detailed information on tree species diversity and distribution is needed to assure its protection and conservation over large areas (Parviainen, 2005; Alvey, 2006; Benko and Balenović, 2011). Such a detailed information is valuable for example for protection of certain tree species or animals that inhabit them or to monitor health status of individual trees along official forest (Jurc et al., 2014) trails to prevent parts – or whole non-vital trees falling down and harming visitors.

In some European countries (e.g. Slovenia, Croatia), close-to-nature management of natural urban forest for multiple services such as nature preservation, recreation, climate mi-

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tigation, has been a long-term practice (Hladnik and Pirnat, 2011), often with selective thinning. The results are mixed heterogeneous forests stands, with high tree species and stand structure diversity, where field survey approach cannot assess detailed information on tree species distribution over large areas, because it is difficult to identify representative sampling locations. Moreover, such detailed information for a large forest area can highlight important areas, such as minority species presence or locations of a forest health concern (Jurc et al., 2014). Therefore, the use of remotely sensed data seems a promising tool to assess such information in close-to-nature managed urban forests.

Many studies used both multispectral data and laser scanning data for either automated tree isolation or segmentation and classification of tree species, what was found also in a recent review of the aerial laser scanning (ALS) application in the South-East European forestry by Balenović et al. (2013). Leckie et al. (2003) evaluated a combination of high spatial resolution (8.5 cm) multispectral aerial imagery and laser scanning data for isolation of individual trees in even-aged Douglas-fir stands in Canada. Applying a valley-following approach, automated tree isolations of the multispectral imagery achieved 80-90 % consistency with the ground data and the isolation with the lidar data produced 59 % of perfect crown outline delineations. Their main argument was that both types of data could be used to complement each other in order to achieve better automated isolations of individual trees. However, they suggested that research in various forest conditions was needed to improve the method. Popescu and Wynne (2004) used LiDAR data and ATLAS multispectral (visible, near-IR and mid-IR bands) optical data with spatial resolution of 4 m for measuring the heights of individual tress in pine and deciduous stands in Appomattox-Buckingham State Forest in Virginia, United States. They showed that combined multispectral imagery and LiDAR data are able to accurately predict tree heights of interest for forest inventory and assessment. Ali et al. (2008) tested feature-level fusion for modelling individual trees by applying marker-controlled watershed segmentation – using user-specific markers to define local tree-crown tops, and subsequent classification, using tree heights and tree crown signatures derived from light detection and ranging (LiDAR) data and multispectral imagery. Fused data of LiDAR derived height layer, original four-band spectral data and bands created by principal component analysis from original four bands (brightness, redness, greenness, and blue-yellowness), were classified. Classification with only the original four spectral bands had an overall accuracy of 63 % and with a fused ten band image the overall accuracy increased to 86 % due to the LiDAR data and newly derived bands from the multispectral imagery. Voss (2008) analysed the seasonal effect on differentiating tree species in a flat environment of the University of Northern Iowa campus, USA, where trees did not grow in dense conditions and were easily distinguished. They used multi-temporal hyperspectral data, LiDAR data, and ground truth tree species data. Overall hyperspectral data classification accuracy did not defer significantly between summer and autumn data (57 % and 56 %, respectively). The accuracy was increased by 19 % when LiDAR data was applied. Author gives credit to the reduction of the shadow effect (false 'tree-crowns' in segmentation process caused by shadows of actual tree-crowns on the ground in-between trees) and the addition of vegetation elevation data to separate low and high vegetation. Puttonen et al. (2009) tested a method called Illumination Dependent Colour Channels (IDCC) to improve individual tree species classification. The method used multispectral data from aerial imagery and LiDAR data dividing sunlit and shaded parts of the crowns and then included calculated indices from the spectral values of those parts to use them for classification using quadratic, linear, and Mahalanobis distance based discrimination functions. The highest overall accuracy achieved was 70.8 % using the linear discriminant analysis function.

Nagendra (2001) evaluated 'the potential of remote sensing for assessing species diversity'. He concluded that delineation of a large number of species by using spectral data was not yet possible a decade ago. However, in 2009 WorldView-2 (WV2) satellite was launched (DigitalGlobe, 2010), providing 2 m spatial resolution for 8 multispectral bands (Coastal, Blue, Green, Yellow, Red, Red-Edge, near infrared (NIR) – 1 and NIR – 2) and 0.5 m spatial resolution for panchromatic band. This could facilitate tree species classification also in mixed close-to-nature managed natural urban forests with great diversity of tree species.

In the recent years, several studies have applied WV2 imagery for tree species analyses. The potential of the WV2 for identifying and mapping urban tree species/groups was explored e.g. in the city of Tampa, FL, USA (Pu and Landry, 2012). In comparison to IKONOS satellite imagery, the accuracy of mapping six tree species/groups increased by 16–18% with WV2 imagery. However, the study covered trees/groups in a dense, urban environment, with sparse vegetation, rather than in a forest. Carter (2013) used multitemporal data from two WV2 images – from June and September 2010 – to classify ash, maple, oak, beech, evergreen and six other tree classification classes in a mixed deciduous forest in Upstate New York. Statistically reducing the dimensionality of multispectral data set and combining ash and maple classes increased classification accuracy to almost 90%. However, training samples were GPS points and not objects (polygons) such as tree crowns. A study by Latif et al. (2012) assessed the potential of WV2 imagery in determining tree species in the Bukit Nanas Forest Reserve, Kuala Lumpur. They compared tree-level spectra extracted by a spectrometer on the ground and spectral data from WV2. The main difficulty they encountered was the delineation of trees of different species growing in a group being of approximately the same height, which is a common situation in a natural mixed forest. The number of studies where WV2 data was used for forest tree species mapping in heterogeneous temperate European forests is very limited. Immitzer et al. (2012) tested the suitability of WV2 data for mapping of 10 tree species in a mid-European mixed forest in Austria. With the use of a non-parametric Random Forests (Breiman, 2001) analyses, the overall accuracy of 82% was reached, which demonstrates the high use potential of WV2 data for forest tree species recognition. Moreover, the new WV2 bands improved classification when a larger number of tree species were analysed. However, they selected training samples by selecting pixels on the sun-lit parts of crowns to read spectral information and not whole crowns to add more complex texture information. Heumann (2011) demonstrated the use of the WV2 sensor, Object-based image analysis (OBIA), and support vector machine (SVM) classification for the classification of mangrove in the Galapagos Archipelago, Ecuador. The overall accuracy achieved for discriminating true mangroves from other vegetation was more than 90%. Similarly, Seletković et al. (2008) used a form of object-based image analyses – features extraction, in a supervised process analysing IKONOS imagery covering an area where a large pedunculate oak forest was situated. They concluded, however, that using IKONOS imagery visual interpretation gains favourable results in comparison to digital interpretation. Moreover, authors warned the time required for visual interpretation and concluded that that specific imagery did not guarantee significant reduction of time and cost needed for the analyses.

Because the satellite multispectral imagery has not yet provided enough spatial detail, for example, to distinguish the texture details of crowns of different tree species, a fusion with airborne laser scanning (LiDAR) data was applied to improve the segmentation and classification process (Ali et al., 2008; Zhang et al., 2012). It has been shown that combining LiDAR with multispectral imagery is a very useful method for monitoring of forest stands and even for individual tree crown mapping (Leckie et al., 2003; Blaschke et al., 2011; Jakubowski et al., 2013).

The review of previous research published in peer-reviewed literature revealed that more research was needed on the application of WV2 imagery for mapping individual tree species in heterogeneous, mixed urban forests of temperate climate, where trees of different species and of different ages often grow very close to each other with their crowns intertwining. Furthermore, a fusion of WV2 and laser scanning data has not been applied for individual tree classification in natural urban forests.

Therefore, this study was aimed toward closing this gap by exploring whether a straightforward method of object-ba-

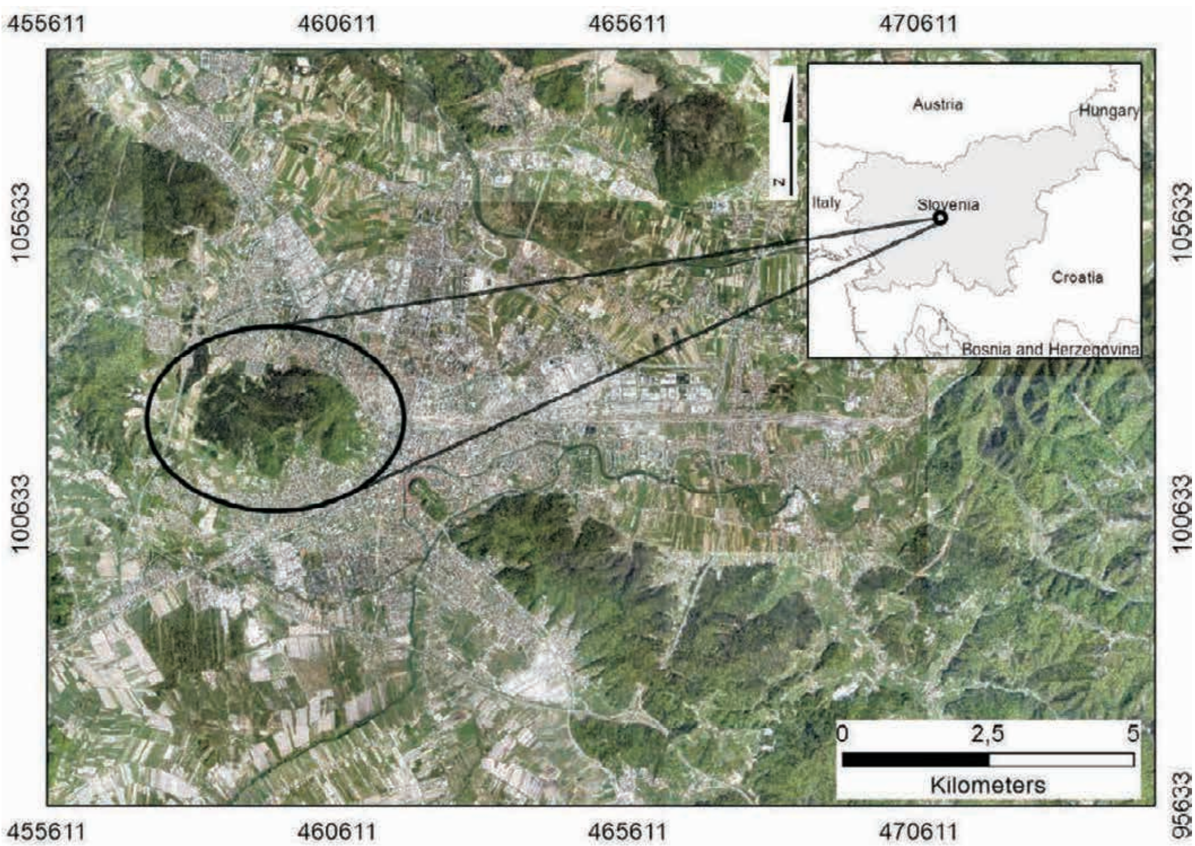

Figure 1. Study area. Location is marked with the black ellipse.
Slika 1. Područje istraživanja. Lokacija je opisana crnom elipsom.

sed image analysis (OBIA) (Blaschke, 2010) with a combination of WV2 imagery and LiDAR data allows for successful classification of individual crowns of five different tree species in the dominant layer of natural, mixed, heterogeneous urban forest in Ljubljana, Slovenia. The forest in this research is facing various macro and micro scale conflicts due to its general conservation status (Odlok, 1984, 2010a), protected habitat locations (ZGS, 2007), intensive and various recreation versatile (Verlič and Pirnat, 2010; Smrekar et al., 2011) as well as small-scale (mostly) private ownership (ZGS, 2007).

2. MATERIALS AND METHODS
Materijali i metode

2.1. Study area – Područje istraživanja

More than 60 % of urban forests within the City of Ljubljana are primal forests and have continuously offered a natural forest ecosystem experience to the citizens (Hladnik and Pirnat, 2011). Since 2010 most of the forest area is protected (Odlok, 2010b), due to its highly emphasized social and ecological forest functions. This protected remnant of natural mixed forest lies within the Tivoli, Rožnik and Šišenski Hill Landscape Park (Fig. 1) located in the city centre. In 1984, the 459 hectare area was declared a natural landmark (Odlok, 1984). A study conducted in 2010 (Smrekar et al., 2011) estimated 1,750,000 visits to this forest per year.

Geological substratum is predominantly of Permo-Carbonian shales and sandstones, where dystric brown soil, ranker and luvisols developed. The highest peaks are the Rožnik area (394 meters above sea level) and Šišenski hill (429 meters above sea level).

On the whole area of Rožnik there are three prevailing forest communities: *Blechno-Fagetum* (mixed forests dominated by beech, oak and chestnut, thriving mainly on northern and eastern slopes, where the soil is deeper and humid; *Vaccinio-Pinetum* (acidophilic pine forest covers in particular sunny exposures, in the southern and western slopes); *Alnetum glutinosae* (alder located on the marshy part of the valley on the north and northwest side) (Marinček and Čarni, 2002). According to the share of the growing stock of the forest management unit Ljubljana is dominated by the following tree species: Scots pine (*Pinus sylvestris)* (22 %), Sessile and Pedunculate oak (*Quercus petraea* and *Quercus robur*) (15 %), European beech (*Fagus sylvatica*) (21 %), Norway spruce (*Picea abies*) (19 %) and Sweet chestnut (*Castanea sativa*) (8 %) (ZGS, 2007).

2.2. Remote sensing data – Podaci dobiveni daljinskim istraživanjima

The acquisition of data was guided by phenological stages of the forest tree species and recommendations by some prior studies, which tested seasonal differences for classification for tree species (e.g. (Voss, 2008)). Aerial imagery and laser scanning data were recorded simultaneously on 24.3.2011 from a helicopter on a windless day to avoid errors in fused images due to moving tree crowns, as warranted by Puttonen et al. (2009). The time of data acquisition was before the full unfolding of tree leaves, which was a compromise between scanning tree crowns and penetration to the ground (Đurić, 2011). Additional aerial images were taken in summer, when tree leaves were fully leafed-out and thus enabled a visual distinction among the tree species. The images were processed into a true orthophoto imagery which was used in the field work for detailed identification of individual trees, in the manual digitisation of tree-crown polygons of trees selected in the field, as well as for the visual verification of the classification results.

The distance between ten flight lines was 250 m, which provided sufficient overlap of aerial images along and across the flight lines. Furthermore, because the width of individual lidar strips is approximately 550 m, it also doubled the density of laser points of a combined dataset from 10 pts/m2 to about 20 pts/m2 (Đurić, 2011), with 0.33 m average point spacing in a single flight line. A Riegl LMS-Q560 laser scanner was used.

A digital elevation model (DEM) with the 0.5 m resolution was obtained through a combination of adaptive triangulated irregular network densification – ATIN ((Axelsson, 2000); as implemented in Terrasolid Terrascan 11) and repetitive interpolation – REIN (Kobler et al., 2007). The REIN algorithm uses a two-step approach to calculate a raster DEM. It was developed for steep forested terrain and was considered most suitable for the model area of this study. The first phase employs a geomorphological filter to eliminate all echo points that lie under the terrain and most, but not necessarily all above terrain points. The second phase removes the remaining non-terrain points and computes a raster elevation model. We have modified the procedure by replacing the first phase, i.e. the geomorphological filter, with ATIN filtering, because it has a big advantage in non-continuous surfaces characteristic for urban areas (Sithole and Vosselman, 2004). By doing so, we combined the benefits of both algorithms – effective operation in build-up areas (ATIN) and on sloped forested terrains (REIN). A raster DEM produced via repetitive triangulation is also superior for further spatial analyses compared to directly rasterized DEM, as REIN uses several estimations of elevation values at a certain raster pixel. REIN was also used to calculate the digital canopy model (DCM, (Fig. 2)).

The WorldView-2 (WV2) satellite image used in the study was acquired on August 1, 2010, in the peak of vegetation period. Obviously, the satellite imagery and aerial data were not from the same period; however this compromise had

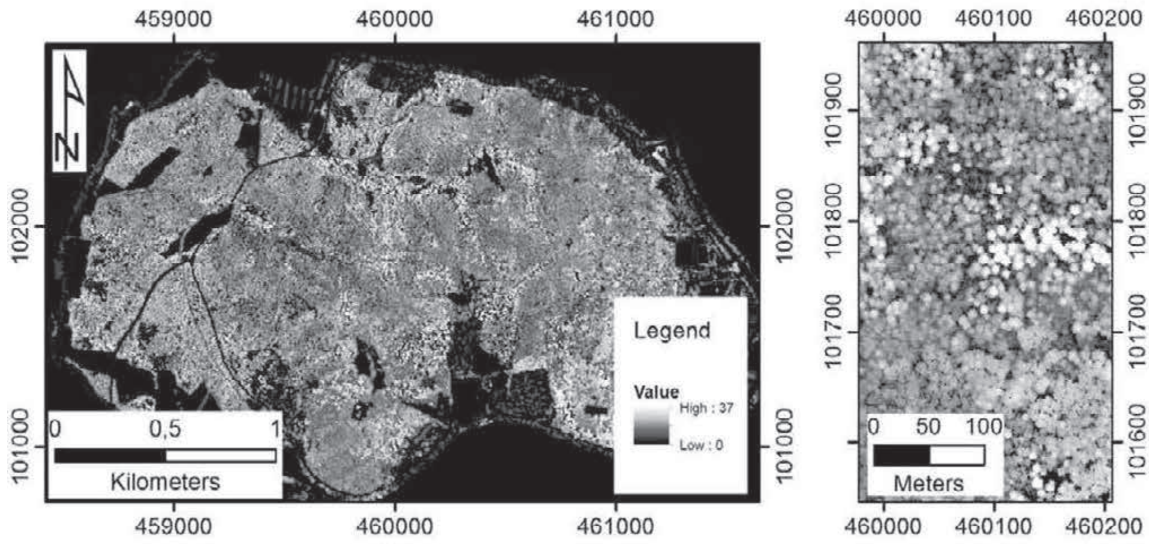

Figure 2. Digital Canopy Model (DCM).
Slika 2. Digitalni model krošanja

to be taken into account due to the availability of the imagery for this research project.

The satellite imagery consists of an 8-band multispectral image with resolution of approximately 2 meters and a panchromatic image with 0.5 m resolution (Tab. 1). They contained only basic radiometric and sensor correction, which means that they were not projected onto a plane using map projection (level 1B). Metadata with information on the satellite orbit, camera properties and rational polynomial coefficients (RPC) were supplied by the image provider. The panchromatic and multispectral images were first orthorectified using RPC and an accurate laser scanning digital surface model (with 1 m resolution). The orthoimages were generated only where the laser scanning digital surface model (DSM) was available. Then to maintain the high spatial resolution of the panchromatic images and the high spectral resolution of multispectral images, they were combined into a pansharpened image with a resolution of 1 m using the modified Intensity-Hue-Saturation (IHS) method (Švab and Oštir, 2006). The pansharpened image was then used for classification.

Table 1. The spectral bands and their minima and maxima wavelengths (DigitalGlobe, 2010).
Tablica 1. Spektralni kanali i njihove minimalne i maksimalne valne duljine (DigitalGlobe, 2010).

Spectral band *Spektralni kanal*	Minimum lower band edge (nm) *Minimalni donji rub (nm)*	Maximum upper band edge (nm) *Maksimalni gornji rub (nm)*
Panchromatic *Pankromatski*	447	808
Coastal Blue *Obalno plavi*	400	450
Blue *Plavi*	450	510
Green *Zeleni*	510	580
Yellow *Žuti*	585	625
Red *Crveni*	630	690
Red-Edge *Rubno crveni*	705	745
NIR-1 *NIR-1*	770	895
NIR-2 NIR-2	860	1040

2.3. Tree data – Podaci o drveću

The tree data for tree species classification were obtained from a virtual network of circular 2000 m2 plots in a 100 x 100 meter grid in the forest. On each of the 332 plots, a coniferous and a deciduous tree were recorded. Only dominant and co-dominant trees were selected to maximize the sunlit parts of the crowns and to be distinguishable from surrounding trees on images.

A field manual (Fig. 3) for each plot was prepared for locating each plot in the field. It contained a section of the true orthophoto image, DCM and a digital model of terrain (DMT) derived from laser scanning data. DCM shows stand canopy model and DMT shows a detailed ground relief model. Plots were located using the LEICA one 10 GNSS receiver with interchangeably displayed true orthophoto,

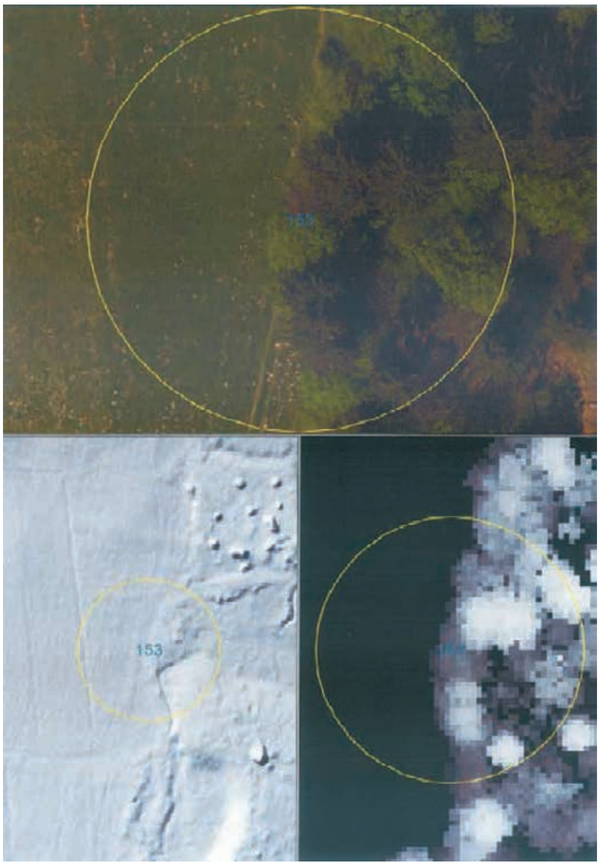

Figure 3. Field manual (example for the plot number 153). On top is a true orthophoto image (spatial resolution 10 cm), below left is a digital model of terrain (spatial resolution 50 cm) and below-right is a digital canopy model (spatial resolution 1 m); the yellow circle represents the optical boundary of the 2000 m2 sample plot, where one conifer and one deciduous tree (if present) were selected in the sample.

Slika 3. Terenski manual (primjer manuala za plohu 153). Na vrhu je ortofoto snimak prostorne rezolucije 10 cm, ispod lijevo digitalni model reljefa prostorne rezolucije 50 cm, dolje desno digitalni model krošanja prostorne rezolucije 1 m; žuti krug predstavlja optičku granicu plohe veličine 2000 m^2, gdje su odabrani jedno stablo četinjače i jedno stablo listače.

DCM and DMT. The receiver had a constant GPRS connection with the base station for real-time post processing of the location, which reached up to 40 cm accuracy. That was sufficient to determine the exact location of an individual tree. The crowns of selected trees were delineated by hand in the field manual, to assure the later identification in imagery for digital delineation. For each tree the tree species, diameter at breast height (DBH), within forest stand canopy position and any visible anomalies (illness, injury, dead tree, etc.) were recorded.

In total 608 trees of 15 different tree species were recorded. For further analysis 574 trees were selected – 304 coniferous trees and 270 deciduous trees of tree species whose sample consisted of more than 30 units (Baldeck and Asner, 2014), namely the Norway spruce, Scots pine, European beech, Sessile and Pedunculate oak and Sweet chestnut. Other tree species are sparsely represented in the forest and the method for sampling training tree data did not allow to include enough units for representative learning (Baldeck and Asner, 2014).

The crowns of selected training trees were manually delineated (Fig. 4) on the true orthophoto and DCM to create polygons for classification. The sample was randomly split in half. One half of the crowns were used in the supervised classification process – training data (292 units), and the other half in post-classification for classification accuracy assessment purposes – testing data (calculation of confusion matrix and user's and producer's accuracies) (290 units).

The classification polygons were converted into Regions of Interest (ROI) files in ENVI, creating ground truth ROIs for classification. Fig. 5 presents the mean spectral signatures of Norway spruce, Scots pine, European beech, Sessile and Pedunculate oak and Sweet chestnut. The coniferous

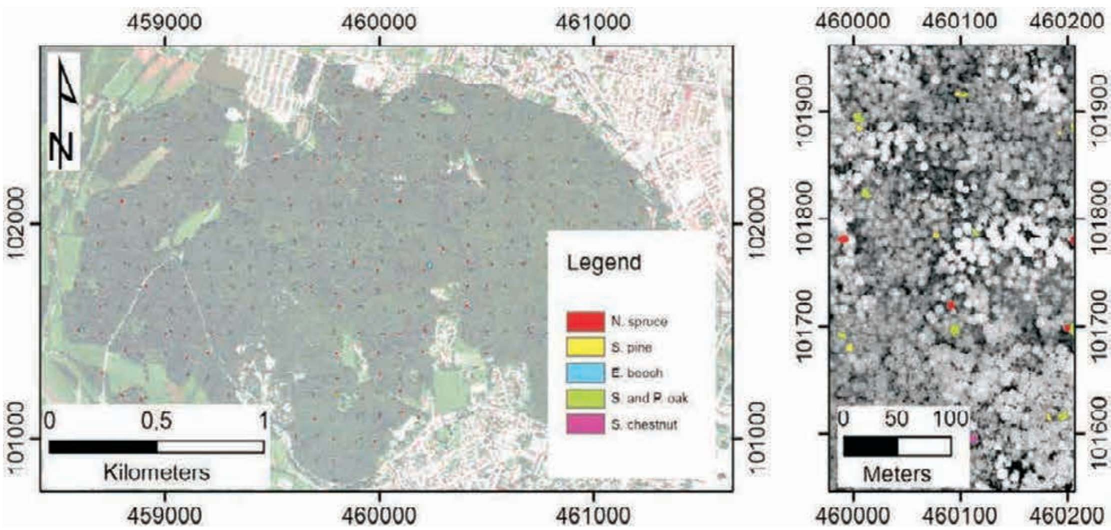

Figure 4. All the tree species crown reference samples (5 tree species digitised in the left figure) on WorldView-2 image and close-up on Digital Canopy Model on the right figure.

Slika 4. Identificirane krošnje stabala (lijeva slika prikazuje pet vrsta drveća na WV2, slika desno prikazuje digitalni model krošanja izbliza)

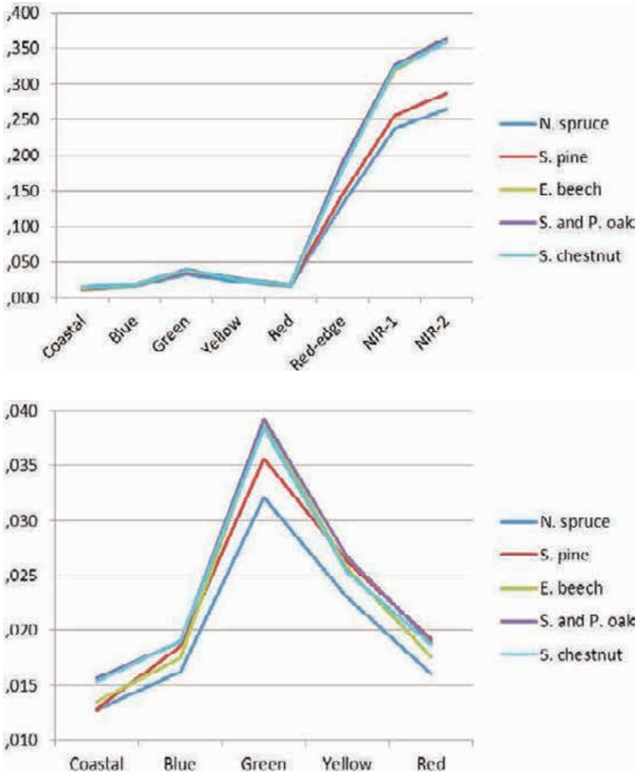

Figure 5. Mean spectral signatures of five tree species derived from the WorldView-2 bands using Regions of Interest; all 8 bands in the left figure and a detail of the signature in the visible bands in the right figure; (bands wavelengths are listed in Tab. 1).

Slika 5. Srednje spektralne vrijednosti za pet vrsta drveća na osnovi WV2 pojasa, koristeći područja interesa; svih kanali na lijevoj slici te detalj vrijednosti u vidljivom području na desnoj slici (valne duljine su navedene u Tablici 1).

species spectral signature differs especially in Red-Edge, NIR – 1 and NIR – 2 and in the Green band.

The box-and-whiskers plots in Fig. 6 show the spectral variability among and within the five tree species. The difference between deciduous and coniferous species is clearly visible in Red-Edge, NIR – 1 and NIR – 2 and in Green band. Moreover, there were not as many outliers in Red-Edge, NIR – 1 and NIR – 2 bands.

2.4. Object-based image analyses – Analiza snimaka

Example-based Feature Extraction was performed in Exelis VIS ENVI 5 software applying support vector machine model (SVM). After a trial and error with various combinations, the optimal parameters of the segmentation were set.

In addition to the original 8 bands, Red-Edge normalized difference vegetation index (Red-Edge NDVI) calculated from Red-Edge and Red band, and DMC layer were stacked into a 10-band image for the five tree species supervised classification. In the first step of classification the area on the image was masked by laser scanning height data to include only areas with heights between 15 and 50 m to remove the lower (also ground) vegetation influence and reduce the abundance of data, as suggested by some previous studies (e.g. (Leckie et al., 2003)). In the second step, training samples of the five tree species were included as a reference.

Post-classification was performed by calculating a confusion matrix (Tab. 3) in Exelis VIS ENVI Classic software to assess the accuracy of a classification output by compa-

Table 2. Principal Component Analysis derived bands.

Tablica 2. Vrijednosti dobivene analizom glavnih elemenata (engl. Principal component analysis).

Eigenvector	Coastal	Blue	Green	Yellow	Red	Red-Edge	NIR-1	NIR-2	Eigenvalue	Cumulative (%)
Band 1	0.054	0.060	0.104	0.082	0.070	0.364	0.611	0.683	0.0705	93.49
Band 2	–0.336	-0.382	–0.395	–0.487	–0.535	–0.115	0.148	0.162	0.0042	99.06
Band 3	–0.113	–0.074	0.030	–0.003	–0.031	0.383	0.578	–0.707	0.0003	99.41

The PCA results in Tab. 2 show that most of the variability was explain by Red – Edge, NIR – 1 and NIR – 2 spectral bands

Table 3. Confusion matrix for the 5 main tree species.

Tablica 3. Matrica pogrešaka pri klasifikaciji za pet glavnih vrsta drveća.

Ground Truth (Percent)						
Class	N. spruce	S. pine	E. beech	Oak	S. chestnut	Total
Unclassified	0	0	0	0	0	0
N. spruce	80	26	11	11	5	31
S. pine	4	50	4	7	15	11
E. beech	7	2	38	12	7	17
Oak	9	22	47	70	73	41
S. chestnut	0	0	0	0	0	0
Total	100	100	100	100	100	100

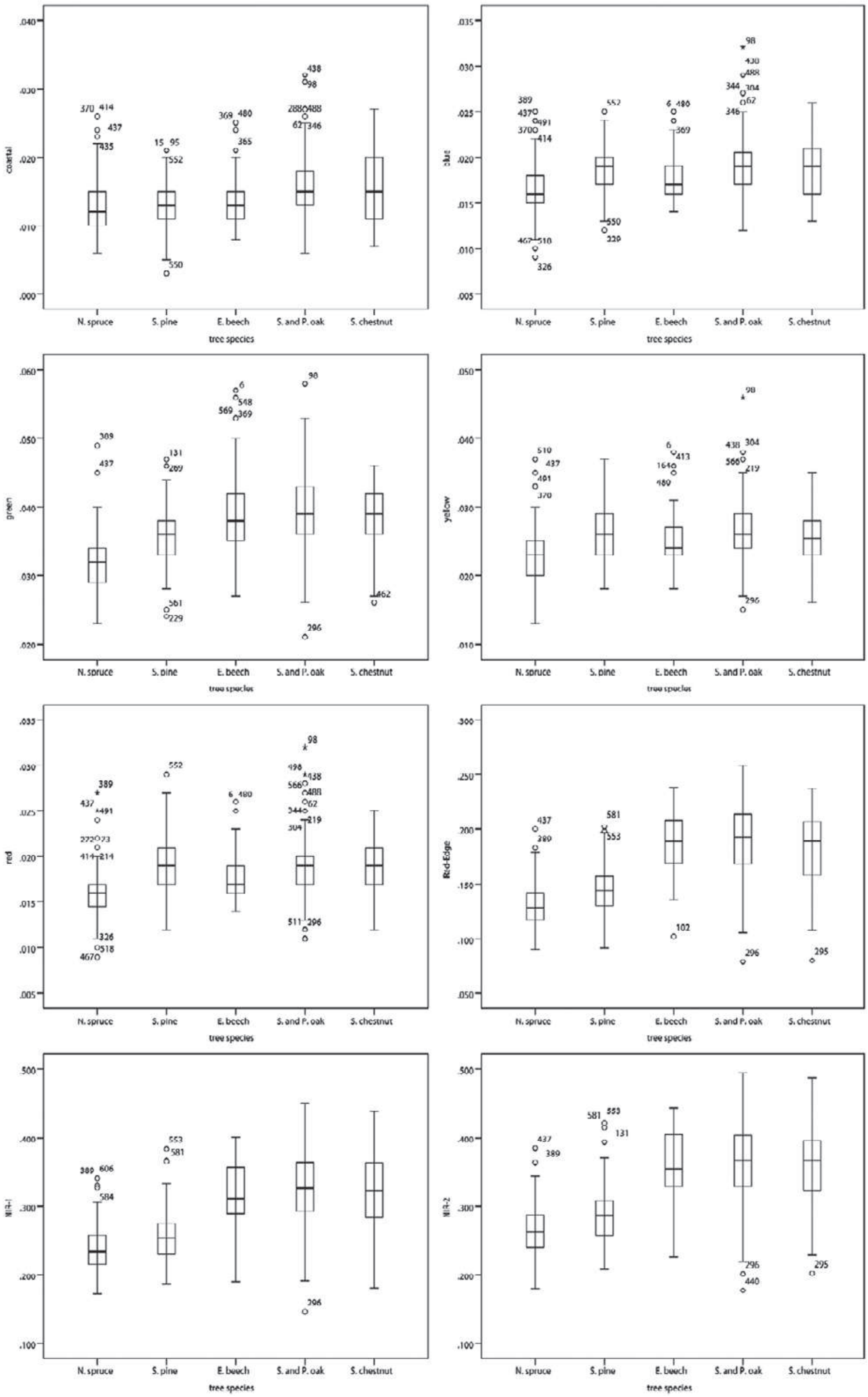

Figure 6. Mean spectral values within each of the WorldView-2 bands for the Regions of Interest of the five tree species.
Slika 6. Srednje spektralne vrijednosti unutar pojedinih WV2 kanala za područja interesa svih pet vrsta drveća.

Table 4. Classification accuracy assessment. Producer's and user's accuracies for the 5 tree species.
Tablica 4. Preciznost klasifikacije. Preciznost prema proizvođaču i korisniku za pet vrsta drveća

Overall Accuracy = (7280/12608) 58 % Kappa Coefficient = 0.431				
Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
N. spruce	80	69	2716/3395	2716/3932
S. pine	50	57	793/1591	793/1401
E. beech	38	64	1330/3466	1330/2072
Oak	70	47	2437/3498	2437/5169
S. chestnut	0	12	4/658	4/34

ring a classification result with the training data. The overall accuracy, Kappa coefficient and producer's and user's accuracies are reported in Tab. 4.

Principal component analysis (PCA) of the original 8 WV2 bands was used with the training dataset only to produce new output bands and to calculate variability between tree species classes explained by different spectral bands (Tab. 2).

3. Results
Rezultati

The confusion matrix (Tab. 3) compares the location and class of each pixel from the testing data set with the corresponding location and class in the classification image. Each of the five columns of the confusion matrix represents a training trees data class for the five tree species and the values in the column correspond to the classification image's labelling of the training trees data pixels in percent. As it can be seen, 80 % of the pixels of Norway spruce, 50 % of Scots pine, 38 % of European beech, 70 % of Sessile and Pedunculate oak and 1% of Sweet chestnut classes were classified correctly.

The overall accuracy of the classification was 58 % and Kappa Coefficient was 0.431 (Tab. 4). The highest accuracy was for Norway spruce, where producer's accuracy was 80 % and user's accuracy was 69 % (Tab. 4). Most S. chestnut crowns were misclassified as Oaks (73 %).

4. Discussion
Rasprava

The purpose of this study was to assess a straightforward method of object-based image analysis (OBIA) (Blaschke, 2010) with a combination of WV2 imagery and LiDAR data for successful classification of individual crowns of five different tree species in the dominant layer of natural, mixed, heterogeneous urban forest in Ljubljana, Slovenia.

Studies by Immitzer et al. (2012) and Puttonen et al. (2009) achieved higher overall accuracy. However, the method of collecting training samples was different. It seems that the approach of those studies was to achieve high classification accuracy with less attention to the practical applicability of the method for potential end-users, such as forest managers usually with significantly less knowledge about remote sensing analyses. For example, the method of collecting only

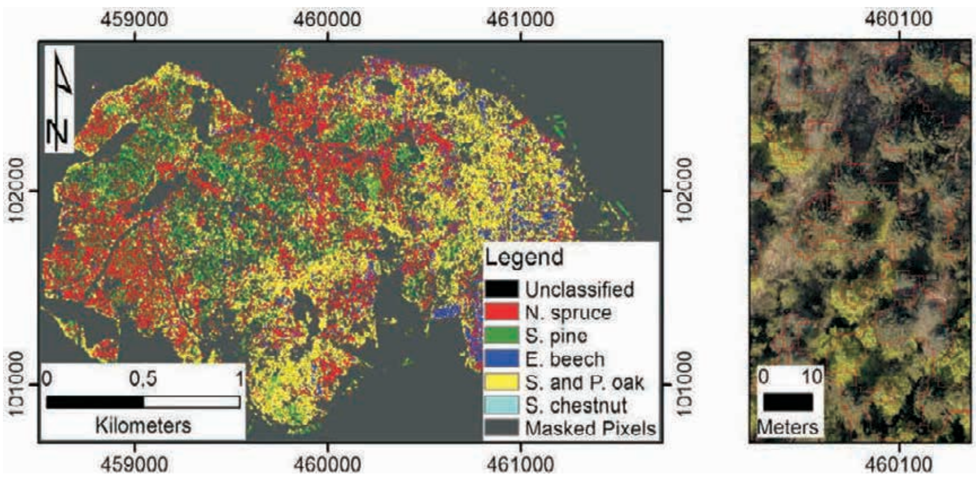

Figure 7. The result of the full-scene 10-band object-based image analysis on the left and segmentation part on the right.
Slika 7. Rezultati analize multispektralne snimke, gdje lijeva slika prikazuje cijelo područje, a desna samo jedan njegov dio.

sun-lit pixels of the crowns by Immitzer et al. (2012) requires more detailed knowledge of interpretation of satellite imagery. The second study (Puttonen et al., 2009) divided sunlit and shaded part of the crowns and included calculated indices from the spectral values of those parts to use them for classification. However, the results of Puttonen et al. (2009) should be compared with even extra caution due to different change in elevation (only 30 m), different geographical latitude causing different angles of the solar illumination, different forest type (not as dense and with fewer tree species) and not least – different type of spectral data. Krahwinkler and Rossmann (2013) achieved an average accuracy of more than 80 % by using laser scanning data, airborne red, green, and blue true colour imagery (RGB) and colour infrared data (CIR) imagery, SPOT and RapidEye satellite data for classification of trees in a mixed species forest, also using support vector machine classifier. However, the comparison is limited since their aerial imagery and laser scanning data had a sub-half meter spatial resolution and even the authors argue whether higher classification accuracy was caused by the multitemporal information, additional spectral bands, better suitability of the acquisition dates, or better homogeneity of the RapidEye and SPOT satellites data sets. According to Ke and Quackenbush (2011), lower classification accuracy could be caused by non-optimal segmentation of trees growing close to each other and often overlapping.

Accuracy assessment made by inspecting the detailed true orthophoto image of the classified area showed that the object-based classification produced fair estimation of tree species distribution and composition in the park (Fig. 9). Distribution of the presence of the analysed cases of tree species was mainly consistent with the actual allocation in nature. The proportion of classified Norway spruce cases increases towards the southwest, Scots pine to the northwest, European beech was the most present in the south-eastern part, the oaks in the southern and eastern parts. According to forest management plans (ZGS, 2007) the eastern part has more diverse tree species composition, including planted non-autochthonous oak – *Quercus rubra*. Second, on average Sweet chestnut achieves the minimum height among all of the classified tree species in the study. Moreover, its crown is not as contrasting as those of the other four tree species. Isolating deciduous tree species also with LiDAR data remains difficult task due to their complex structure and overlapping of the crowns (Chen et al., 2012). Other likely causes for over-classification of the oaks in the eastern part and no classifications of Sweet chestnut are harder to explain.

5. CONCLUSIONS
Zaključci

The object-based image analysis method used in this study showed promising applicability of fused WorldView-2 and laser scanning data for dense, tree-species-rich, highly heterogeneous natural urban forest stands where crowns of trees often intertwine. However, the accuracy of the proportions of individual tree species that form the forest stand canopy was lower than in some other studies. The distinction between deciduous and coniferous tree species was the most reliable. This was expected based on the reports of previous studies and the spectral signatures of the reference sample data for this study. However, segmentation of individual tree crowns was (mostly) not achieved. Most of the segments were either parts of the crowns or conglomerates of parts of crowns and interspace.

Complete visible parts of the tree crowns were selected for ground-truth tree data. In this way, not just the spectral signature but also texture served as an attribute for classification. In a dense forest stand canopy – especially the one formed by the deciduous trees – the intertwining of adjacent crowns makes delineation of neighbouring tree crowns very difficult, both in manual digitization and automated segmentation and classification of objects.

This study offers new evidence on how the application of remote sensing data offers an opportunity to reduce the time of assessment of tree species inventory by using a straightforward method of object-based image analyses. The next project will compare this method using the same data for the same forest to remove the effect of variability of forest conditions which has a high impact on the accuracy of the results (Kaartinen et al., 2012).

We therefore recommend further research that would provide more evidence on the optimal combination of spectral, spatial and temporal resolution of the data to achieve the optimal cost – benefit ratio for forest management practice.

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Sažetak

Osnovni zadatak gospodarenja šumama je provedba inventure drveća. Posebno se to odnosi na blisko prirodi gospodarene urbane šume. Cilj ovog istraživanja je provjeriti može li se metoda analize snimaka (tzv. object-based image analysis – OBIA) kombinacijom WorldView-2 multispektralnih satelitskih snimaka visoke prostorne rezulocije i laserskog skeniranja (LiDAR-a) koristiti za uspješnu klasifikaciju krošanja pojedinačnih stabala različitih vrsta drveća u prirodnim, mješovitim i heterogenim urbanim šumama u Ljubljani (Slika 1).

Terenska klasifikacija vrsta drveća provedena je postavljanjem mreže kružnih ploha (100x100 m) veličine od 2000 m^2. Na svakoj od 332 plohe, registrirana su stabla iz dominantnog i kodominantnog sloja drveća. Ukupno je za analizu izdvojeno 574 stabala, od čega 304 stabla četinjača (obična smreka, obični bor) i 270 stabala listača (obična bukva, hrast lužnjak i kitnjak, pitomi kesten). Polovica uzorkovanih stabala tj. njihovih krošanja korišteno je kao probni set podataka u nadgledanoj klasifikaciji, dok je druga polovica uzorkovanih stabala korištena za ocjenu točnosti provedene klasifikacije (tzv. testni podaci).

Za klasifikaciju su korištene WorldView-2 multispektralne satelitske snimke (8-kanalne), tzv. 'Red-Edge' normalizirani razlikovni vegetacijski indeks (NDVI) izračunat pomoću rubnog crvenog i crvenog spektralnog kanala te digitalni model krošanja (tzv. Digital Canopy Model – DCM) dobiven iz LiDAR podataka. Prostorna rezolucija WorldView-2 satelitskih snimaka iznosila je 1 m.

Klasifikacija je provedena pomoću Exelis ENVI 5 kompjuterskog programa, primjenjujući tzv. pomoćni vektorski model. Preciznost procjene izračunata je na temelju izračunate matrice pogreške, uspoređujući rezultate klasifikacije s testnim podacima. Također je provedena analiza glavnih komponenata, koja je pokazala da je najveća varijabilnost (oko 85 %) objašnjena pomoću rubnog crvenog spektralnog kanala (705–745 nm), bližeg infracrvenog kanala – 1 (770–895 nm) te bližeg infracrvenog spektralnog kanala – 2 (860–1040 nm) WorldView-2 snimaka.

Metoda analize snimaka (OBIA) kombinacijom WorldView-2 satelitskih snimaka I LiDAR podataka korištena u ovom istraživanju pokazala je obećavajuće rezultate pri klasifikaciji vrsta drveća u gustim, mješovitim i heterogenim prirodnim urbanim šumama, u kojima često dolazi do isprepletanja krošanja. Najpouzdaniji dobiveni rezultati odnose se na razlikovanje četinjača i listača. Kod sastojina s gustim krošnjama, posebice kod listača kod kojih je teško napraviti delineaciju krošanja, otežana je i manualna i automatska delineacija (segmentacija) krošanja. Ovo istraživanje novi je dokaz kako se primjenom podataka dobivenih metodama daljinskih istraživanja pruža mogućnost uštede u vremenu pri inventarizaciji vrsta drveća.

Ukupna preciznost identifikacije iznosila je 58 %, a Kappa koeficijent je iznosio 0.421 (Tablica 4). Za svaku vrstu drveća izračunata je preciznost na osnovi razlike između preciznosti koju navodi proizvođač (postotak točno identificiranih piksela u odnosu na ukupan broj piksela na probnim podacima) i preciznosti korisnika. Rezultati tako dobivene preciznosti iznosili su 80 % za smreku, 70 % za hrastove lužnjak i kitnjak, 50 % za obični bor, 38 % za bukvu, te manje od 1 % za pitomi kesten.

KLJUČNE RIJEČI: zelena infrastruktura, zemaljski podaci, spektralni odraz, kartiranje šumskog drveća, izmjera šumskog drveća, monitoring u šumarstvu.