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Izdajanje revije sofinancira Javna agencija za raziskovalno dejavnost Republike Slovenije (ARRS)
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LES/WOOD

UVODNIK / EDITORIAL

Za uredništvo / For the editorial board
Katarina Čufar, Jože Kropivšek

Ta številka revije Les/Wood je posebna iz več razlogov. Večji del aktivnosti z njenim nastajanjem je bil namreč izveden v času zapore inštitucij zaradi pandemije korona virusa Covid19, kar je za naše avtorice in avtorje, recenzentke in recenzente ter uredniški odbor predstavljalo svojevrsten izziv. Ne glede na to pa so se reviji oz. njenemu uredniškemu odboru pridružili ugledni znanstveniki iz tujine. Med njimi so prof. dr. Manuela Romagnoli, Department of Innovation of Biological Systems, Food and Forestry DIBAF, Tuscia University, Viterbo, Italija, prof. dr. Denis Jelačić, Šumarski fakultet, Sveučilište u Zagrebu, Hrvaška, dr. Krishna K. Pandey, Institute of Wood Science & Technology, Indian Council of Forestry Research and Education, Bangalore, Indija, in dr. Alan Crivellaro, Department of Geography, University of Cambridge, Velika Britanija. Zelo smo veseli, da so sprejeli naše povabilo, obetamo si dobro sodelovanje. Za mednarodno prepoznavnost revije Les/Wood je to nedvomno zelo pomembno.

V tokratni številki revije objavljamo sedem znanstvenih člankov, od tega so štirje v angleščini. Posebej nas veseli, da je med avtoricami in avtorji spet veliko novih imen. Tokrat bi radi predstavili mlade avtorice in avtorja. Dva sta pridobila prestižne projekte, dve pa sta na začetku doktorskega študija in sta tokrat prvič objavili članek v znanstveni reviji.

Dr. Kavyashree Srinivasa iz Indije je pridobila projekt (NewSiest-867451) v okviru raziskovalno inovacijskega programa EU H2020, MSC-IF = Marie Skłodowska-Curie – Individual Fellowships, kar dokazuje izjemno odličnost njene raziskovalne poti. V okviru tega projekta, ki traja 2 leti, je trenutno zaposlena na Oddelku za lesarstvo, Biotehniške fakultete, Univerze v Ljubljani, kjer pod mentorstvom prof. dr. Marka Petriča izvaja poglobljene podoktorske raziskave. Zaključila je magisterij iz kemije in doktorirala na Inštitutu za lesarstvo (Institute of Wood Science & Technology) v kraju Bangalore (FRI DU, Dehradun) v Indiji. Leta 2013 je prejela nagrado Ron Cockcroft, ki jo podeljuje Mednarodna raziskovalna skupina za zaščito lesa (IRG-WP).

Dr. Arnaud Maxime Cheumani Yona prihaja iz Kameruna in je pridobil projekt „SilWoodCoat", ki nosi »Pečat odličnosti« in je financiran s strani ARRS, kar dokazuje raziskovalno odličnost projekta in kandidata, ki se je tudi zaposlil na Oddelku za lesarstvo, Biotehniške fakultete, kjer pod mentorstvom prof. dr. Marka Petriča razvija premaze za les na osnovi silikatov. Po osnovni izobrazbi je kemik, njegovo raziskovalno delo pa vključuje predvsem lesarstvo, polimere in polimerne kompozite. Doktoriral je leta 2009 na Univerzi v Bordeauxu-Francija in je docent na Univerzi Yaoundé 1, v kraju Yaoundé, Kamerun. Pred tem je delal na več raziskovalnih projektih, kjer se je ukvarjal z lesno-cementnimi kompoziti, utekočinjenim lesom, razvojem premazov za les, modifikacijo lesa s poli(mlečno kislino) in s kompoziti iz naravnih vlaknen polimerov.

Nina Škrk je od jeseni 2019 mlada raziskovalka v okviru programa MR+ na Oddelku za lesarstvo Biotehniške fakultete Univerze v Ljubljani pod mentorstvom prof. dr. Katarine Čufar. Vpisana je na doktorski študij Bioznanosti, Les in biokompoziti. Njeno delo je usmerjeno v raziskave dreves in lesa z vidika posledic sprememb klime v 21. stoletju, ki so zabeležene v zgradbi lesa. To je njena prva objava znanstvenega članka v reviji.

Irena Sochová je od novembra 2019 doktorska študentka na Univerzi Mendel v Brnu, Republika Češka, na programu Predelava in tehnologije lesa s poudarkom na dendrokronologiji. Tema njene disertacije je sestava standardne kronologije širin branik hrasta za dendro-arheološke analize na območju Zahodne Ukrajine. Trenutno je zaposlena tudi na inštitutu CAS, Global Change Research Institute na Češkem. To je njena prva objava znanstvenega članka v reviji.

Posebnost te številke revije je tudi to, da prvič uvajamo prakso vodilnih znanstvenih revij v svetu glede odprtega dostopa do raziskovalnih podatkov, ki so podlaga (empiričnim) znanstvenim člankom. Vključili smo se v aktivnosti RDA (Research Data Alliance) vozlišča Slovenije, ki ga s podporo projekta RDA EU 4.0 koordinira Arhiv družboslovnih podatkov. Tako enega izmed člankov v tej številki revije (Škrk et al., 2020) spremlja objava znanstvenih podatkov (fotografij), ki so na ta način prosto dostopni preko Repozitorija Univerze v Ljubljani (RUL). Pri objavi podatkov so nas vodili dr. Mojca Kotar (Univerzitetna služba za knjižnično dejavnost, Univerza v Ljubljani), doc. dr. Janez Štebe (Fakulteta za družbene vede, Univerza v Ljubljani), doc. dr. Sebastian Dahle (Oddelek za lesarstvo, Biotehniška fakulteta, Univerza v Ljubljani) in Darja Vranjek (INDOK, Oddelek za lesarstvo, Biotehniška fakulteta, Univerza v Ljubljani). Vsem lepa hvala.

Posebej se zahvaljujemo vsem recenzentkam in recenzentom revije Les/Wood, ki so spet opravili odlično delo v praviloma zelo kratkem času. Zahvaljujemo se tudi ekipi, ki skrbi za tehnično podporo revije, lektorja Paul Steed in Darja Vranjek, bibliotekarka Maja Valič, tehnični urednik Anton Zupančič in oblikovalci iz podjetja DECOP d.o.o., Železniki.

This issue of the journal *Les/Wood* is special for several reasons. Most of the related activities were carried out during the Covid-19 lockdown, which was very challenging for our authors, reviewers and editorial board. However, despite all the inconveniences caused by the pandemic, four eminent scholars from abroad joined the journal and its editorial board. Among them are: Prof. Manuela Romagnoli, PhD, Department of Innovation of Biological Systems, Food and Forestry DIBAF, Tuscia University, Viterbo, Italy; Prof. Denis Jelačić, PhD, Faculty of Forestry, University of Zagreb, Croatia; Krishna K. Pandey, PhD., Institute of Wood Science & Technology, Indian Council of Forestry Research and Education, Bangalore, India; and Alan Crivellaro, PhD, Department of Geography, University of Cambridge, UK. We are glad that they accepted our invitation, and we hope for fruitful further cooperation, which is undoubtedly very important for the international recognition of the journal.

In this issue we are publishing seven scientific articles, four of them in English. We are especially pleased that there are new names among the authors, and young authors in particular. Two of them have already acquired prestigious projects, while another two are at the beginning of their PhD studies and publishing articles in a scientific journal for the first time.

Kavyashree Srinivasa, PhD from India has obtained a project (NewSiest-867451) under the EU research innovation programme H2020, MSC-IF (Marie Skłodowska-Curie – Individual Fellowship), which proves the excellence of her research. As part of the two-year project, she is currently employed at the Department of Wood Science and Technology, Biotechnical Faculty, University of Ljubljana, pursuing detailed post-doctoral research under the mentorship of Prof. Marko Petrič, PhD. She completed a master's degree in chemistry and obtained her PhD from the Institute of Wood Science & Technology in Bangalore (FRI DU, Dehradun), India. She was a recipient of the Ron Cockcroft award from the International Research Group on Wood Conservation (IRG-WP) in 2013.

Arnaud Maxime Cheumani, PhD from Cameroon has acquired the project "SilWoodCoat", which bears the "Seal of Excellence" and is funded by the ARRS, a testament to the outstanding nature of both the researcher and the project. He currently works at the Department of Wood Science and Technology, Biotechnical Faculty, University of Ljubljana under the mentorship of Prof. Marko Petrič, PhD., developing silicate-based wood coatings. He is a chemist by basic education, but in his research focusses mainly on polymers and polymer composites connected to wood science. He obtained his PhD from the University of Bordeaux-France in 2009, and is an assistant professor at the University of Yaoundé 1 in Yaoundé in Cameroon. Prior to this he worked on several research projects dealing with wood-cement composites, liquefied wood, development of wood coatings, wood modification with poly (lactic acid) and composites made of natural polymer fibres.

Nina Škrk has been working as a young researcher under the mentorship of Prof. Katarina Čufar, PhD at the Department of Wood Science and Technology, Biotechnical Faculty, University of Ljubljana since the autumn of 2019. She is enrolled in the PhD study of Biosciences, Wood and Biocomposites. In her research she focuses on the effects of climate change in the 21st century on trees and wood. This is her first publication of a scientific article in a scientific journal.

Irena Sochová has been a PhD student at Mendel University in Brno, Czech Republic since November 2019. She works within the Wood Processing and Timber Technology programme with a focus on dendrochronology. The main topic of her dissertation is the oak tree-ring standard chronology as a tool for dendro-archaeological analyses in the Western Ukraine. Currently she is also employed at CAS, the Global Change Research Institute in the Czech Republic. This is her first publication of a scientific article in a scientific journal.

The main feature of this issue is the introduction of the practice of the world's leading scientific journals regarding open access of their research data, which is basis for (empirical) scientific articles. We joined the activities of the RDA (Research Data Alliance) of the Slovenian hub, which is coordinated by the Social Science Data Archive with the support of the RDA EU 4.0 project. Thus, one of the articles in this issue (Škrk et al., 2020) is accompanied by the publication of the scientific data (photographs), which are freely available through the Repository of the University of Ljubljana (RUL). In publishing the data we were guided by Mojca Kotar, PhD from University Library Services, University of Ljubljana, Janez Štrebe, PhD from the Faculty of Social Science, University of Ljubljana, by Sebastian Dahle, PhD from Department of Wood Science and Technology, University of Ljubljana, and by Darja Vranjek from INDOK, Department of Wood Science and Technology, Biotechnical Faculty, University of Ljubljana. Thank you all for your work, we truly appreciate your efforts.

Special thanks go to all the reviewers of the *Les/Wood* journal, who did excellent job once again in a very short time. In addition, we would like to thank the technical support team, proof-readers Paul Steed and Darja Vranjek, librarian Maja Valič, technical editor Anton Zupančič and designers from DECOP d.o.o., Železniki.

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PHENOLOGY OF LEAF DEVELOPMENT IN EUROPEAN BEECH (*FAGUS SYLVATICA*) ON A SITE IN LJUBLJANA, SLOVENIA IN 2020

FENOLOGIJA RAZVOJA LISTOV NAVADNE BUKVE (*FAGUS SYLVATICA*) NA RASTIŠČU V LJUBLJANI V LETU 2020

Nina Škrk[1*], Zalika Črepinšek[2], Katarina Čufar[1]

UDK 630*181.8:630:176.1 *Fagus sylvatica*
Original scientific article / Izvirni znanstveni članek

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Abstract / Izvleček

Abstract: *In spring of 2020 we observed leaf phenology in mature European beech (*Fagus sylvatica*) trees in Tivoli, Rožnik and Šišenski hrib Landscape Park in Ljubljana, Slovenia (46.05°N, 14.49°E, 310 m a. s. l.). A group of 11 trees was selected for daily monitoring of leaf development. We recorded seven phases from dormant buds, through leaf unfolding till development of mature leaves. At the same time, photos were taken to illustrate the leaf development. First developing leaves were observed on 4 April in one tree. General leaf unfolding, as defined by International Phenological Gardens (IPG), was observed in different trees between 7 and 25 April 2020. The occurrence and duration of individual phases of leaf development showed great variation within and between trees. General leaf unfolding of the tree included in the long-term monitoring program of the Environmental Agency of the Republic of Slovenia (ARSO) occurred on DOY 105 (14 April 2020), which is 4 days earlier than long-term average of the same tree/location, and this is ascribed to above average temperatures in the winter of 2019/2020.*

Keywords: *phenology, leaf development, variability, European beech (*Fagus sylvatica*), Slovenia*

Izvleček: *V Krajinskem parku Tivoli, Rožnik in Šišenski hrib v Ljubljani (46,05°S, 14,49°V, 310 m n. m.) smo spomladi leta 2020 opazovali fenologijo razvoja listov odraslih dreves navadne bukve (*Fagus sylvatica*). Izbrali smo skupino enajstih dreves za dnevno opazovanje, beleženje in fotografiranje razvoja listov. Razlikovali smo sedem faz od mirujočih brstov, preko različnih faz olistanja do zrelih listov. Prve razvijajoče se liste smo na enem drevesu opazili 4. aprila 2020. Fazo splošnega olistanja, kot jo določa metodologija Mednarodnih fenoloških vrtov, smo pri različnih drevesih beležili od 7. do 25. aprila 2020. Pri nastopu in trajanju različnih faz razvoja listov smo zabeležili velike razlike znotraj posameznega drevesa in med drevesi. Splošno olistanje pri drevesu, ki ga dolgotrajno opazuje Agencija RS za okolje (ARSO), je nastopilo na zaporedni dan 105 (14. aprila 2020), kar je 4 dni prej kot kaže dolgoletno povprečje za isto drevo/lokacijo. Slednje pripisujemo nadpovprečno visokim temperaturam v zimi 2019/2020.*

Ključne besede: *fenologija, razvoj listov, variabilnost, bukev (*Fagus sylvatica*), Slovenija*

1 INTRODUCTION
1 UVOD

Phenology is the study of cyclic and seasonal natural phenomena, especially in relation to climate and plant (or animal) life. In forest trees, we often observe the phenology of leaf development, wood and phloem production, cambium activity, or a combination of these (e.g. Prislan et al., 2013b; Žust, 2015; Gričar et al., 2017). Leaf phenology of forest trees is often studied in European beech (*Fagus sylvatica*) (e.g., Dittmar & Elling 2006; Donnelly et al., 2006; Vitasse et al., 2011; 2013; Wenden et al., 2019). It can be basically divided into early or spring phenology and autumn phenology. Spring phenology involves processes related to the interruption of winter dormancy and phases of leaf development from the dormant bud to fully developed and functional mature leaves (Meier, 1997). Leaf unfolding is one of the most visible signs of the reactivation of a tree's physiological activity after the winter dormancy (Žust, 2015). It is synchronised with reactivation of cambium and onset of wood and phloem formation, which are not visible unless we extract tissues from the tree for monitoring under a microscope (Čufar et al., 2008; Prislan et al., 2013a; 2013b).

Common beech is the most common tree species in Slovenia and represents one third (32.6% in

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2018) of the growing stock in the country (Poročilo Zavoda…, 2018). A recent national forest inventory by the Slovenian Forestry Institute showed that 208 million beech trees grow in Slovenia (Inventura gozda, 2018).

Beech is one of twelve tree species included in the Slovenian National Phenological Network of the Environmental Agency of the Republic of Slovenia (ARSO) within the Ministry of the Environment and Spatial Planning, which has conducted systematic monitoring since 1951 (Žust, 2015). The Slovenian National Phenological Network is also a part of the International Phenological Gardens (IPG), which has monitored genetically identical trees (clones) on ca. 90 localities all over Europe since 1957, with large latitudinal gradient, from Portugal ~41°N to Norway ~63°N (The international…, 2020; Chmielewski et al., 2013). Observation of genetically identical trees limits the bias in leaf phenology caused by possible genetic variation, which is known to affect this (Kraj & Sztorc, 2009). Long-term phenological data are a rich source of information on the response of trees to climate change (e.g., Menzel et al., 2006; Fu et al., 2019).

The leaf phenology monitoring of beech by ARSO records general leaf unfolding, defined as the phase BBCH11 when 50% of the leaves have unfolded completely (Meier, 1997; ARSO, 2020). In Slovenia it is considered that the leafing of beech marks the real beginning of spring, while the ripened fruits indicate the beginning of true autumn (Žust, 2015). General leaf yellowing (BBCH94), which occurs when more than half of the leaves turn yellow in autumn, and leaf fall (BBCH93-10% of leaves fell down from trees to the ground to BBCH97-100% of leaves fell down from trees to the ground) are also monitored (Žust, 2015; Lukasova et al., 2019).

Spring phenology and the mechanisms driving leaf development are generally better understood than the autumn ones. Beech has thinly pointed leaf buds that are already visible on the tree in the autumn before the tree enters winter dormancy, when growth is inhibited even if seemingly favourable environmental conditions (a warm winter) occur. Leaf development can start in spring when the buds are able to respond to warmer forcing temperatures (Caffarra & Donnelly, 2011; Wenden et al., 2020). However, this is only possible if the tree previously experienced adequate chilling and if the photoperiod is sufficiently long (Vitasse & Basler, 2013; Dantec et al., 2014). Such requirements are species and site specific (Wenden et al., 2020).

A study based on the leaf unfolding and leaf colouring data for beech obtained by ARSO from 47 localities all over Slovenia (altitudes 55 to 1,050 m a.s.l.), in the period 1955-2007 showed that the average day of the year (DOY) of the leaf unfolding varied from 14 April (DOY 104) to 13 May (DOY 133) (Čufar et al., 2012), and was delayed for 2.6 days as the altitude rose 100 m. Year-to-year variation of leaf unfolding was mainly driven by March and April temperatures, whereas the temperatures in March had greater effect at lower elevations and those in the April at higher elevations. During 1955-2007, March and April temperatures showed a slightly positive trend and leaf unfolding occurred 1.52 days earlier per decade at 1,000 m a.s.l. and 0.67 days earlier at 500 m a.s.l., which showed that climate change particularly affects phenological behaviour at higher altitudes. However, leaf colouring occurred from 2 October till 29 October and was earlier at higher altitudes (1.9 days earlier for every 100 m). Colouring proved to be positively correlated to August and September temperatures, whereas the long-term trends and relation to altitude were not statistically significant (Čufar et al., 2012). It was also shown that leaf unfolding approximately agrees with the onset of wood production by the cambium, although the climatic drivers of both processes are different (Čufar et al., 2008). Variability in leaf phenology generally cannot be directly correlated with variations in radial tree-ring growth (Čufar et al., 2015), and the extension of the growing season due to climate change does not necessarily increase tree-ring width (Kolar et al., 2016).

As organization and implementation of ground observations is demanding, it has been discussed whether ground monitoring of leaf phenology and the condition of leaves could be replaced by other techniques, like modelling (e.g., Vilhar et al., 2018) or satellite imagery (e.g., Allevato et al., 2019; Lukasova et al., 2019). Research into beech canopy parameters all over Slovenia between 2001 and 2017 based on analyses of crown features derived from the satellite Moderate Resolution Imaging Spectroradiometer (MODIS) and calculating the remotely sensed Enhanced Vegetation Index (EVI) shows that the resolution and frequency of satellite images hamper the precise reconstruction of leaf phenology. However, it is possible to reconstruct spatio-temporal leaf and canopy damage due to extreme weather events like heat waves, ice storms and spring frosts recorded in changes of the EVI (Decuyper et al., 2020).

Any of the abovementioned methodologies needs to take into account the great variability of phenology, which varies within and among trees and sites. However, this is relatively difficult as we lack precise observations on representative numbers of trees on a daily scale (e.g., Lukasova et al., 2019).

The aim of this study was to select beech trees on a site in Ljubljana, Slovenia, and in the spring of 2020 monitor different phases of their leaf development daily, from dormant buds to the development of mature leaves, to establish a photo-gallery of temporal variability of leaf development, and to relate the leaf development to air temperature and precipitation. Finally, general leaf unfolding in individual trees in 2020 was compared with long-term data (1951-2020) for beech in Ljubljana collected by ARSO.

2 MATERIALS AND METHODS

2 MATERIAL IN METODE

2.1 STUDY SITE AND TREES

2.1 OPAZOVANA PLOSKEV IN DREVESA

The selected study area was Tivoli, Rožnik and Šiška Hill Landscape Park in Ljubljana which was declared a Natural Site of Special Interest in 1984 (Odlok o razglasitvi..., 2020). Forest management is allowed in the park. The stand with selected trees has 428 m^3/ha of average growing stock, and the predominant forest community is *Blechno – Fagetum clamagrostidetosum*. These forests are site-silvicultural class suburban forests on acidic beech habitats. The prevailing tree species is beech (*Fagus sylvatica*) (49%), followed by sessile oak (*Quercus petraea*) (20%), spruce (*Picea abies*) (11%), large-leaved lime (*Tilia platyphyllos*) (11%) and other deciduous trees (Pregledovalnik ..., 2020).

At the forest foothills, along a transect of about 1.6 km (Figure 1), we selected adult dominant or codominant beech trees with diameters at breast height of 50 – 100 cm and heights over 30 m. We observed the trees on three locations: (1) trees 11-19 (where the first number indicates the location and the second the tree number) growing on the slope, along the pathway Pod Turnom, near the water reservoir, (2) one tree number 20 growing in the vicinity of trees 11-19 with the earliest leaf unfolding, and (3) one beech number 30, which grows near the Cekin Mansion (National Museum of Contemporary History) (Figure 1, Table 1).

Trees 11-20 grow in the abovementioned beech habitats, while the beech 30 grows in the park and is included in the long-term monitoring of the Slovenian National Phenological Network (*Fagus sylvatica* Hardegsen, identification number of the plant 221, year of planting 1969, origin Germany) of the Environmental Agency of the Republic of Slovenia (ARSO) within the Ministry of the Environment and Spatial Planning as a part of the International Phenological Gardens of Europe.

Figure 1. Locations of selected trees (red dots) in Tivoli, Rožnik and Šišenski hrib Landscape Park in Ljubljana, Slovenia.

Slika 1. Lokacije izbranih dreves (rdeče pike) v Krajinskem parku Tivoli, Rožnik in Šišenski hrib v Ljubljani.

Table 1. Geographical coordinates of the observed trees
Preglednica 1. Geografske koordinate opazovanih dreves

Tree numbers	Latitude	Longitude	Altitude
Številke dreves	Zemljepisna širina	Zemljepisna dolžina	Nadmorska višina
11-19	46.052585°	14.490125°	316 m
20	46.052697°	14.489115°	315 m
30	46.058247°	14.495366°	307 m

2.2 FIELD OBSERVATIONS OF LEAF PHENOLOGY
2.2 TERENSKA OPAZOVANJA RAZVOJA LISTOV

In the period from 4 till 27 April 2020, we visited and photographed the selected trees and recorded the phenological phases daily (Figure 2, Table 2), which indicated the progress of leaf development. In May 2020, we visited the trees at weekly intervals, because significant changes related to phenological phases were no longer happening on a daily basis. The observations were carried out in agreement with the criteria of the World Meteorological Organization (Guidelines ..., 2009).

Table 2. Descriptions of the main phenological phases of leaf development in beech.
Preglednica 2. Opis glavnih fenoloških faz razvoja listov pri bukvi.

Phase / Faza		Description	Opis faze
BBCH00	A	buds dormant	speči popki
BBCH02	B	buds swollen	popki napeti (nabrekli)
BBCH07	C	buds swollen, brown scales open, and the green colour of the developing leaves appears	popki nabrekli, rjave luske se razprejo in pojavi se zelena barva razvijajočih se listov
BBCH09	D	buds swollen and open	popki nabrekli in odprti
BBCH10	E	leaves partly unfolded, the petiole is not visible	listi delno razviti, vidna listna ploskev, listni pecelj ni viden
BBCH11	F	leaves unfolded, 10% of leaves have final shape, but not final size and colour, the petiole is visible	listi razviti, listna ploskev je odprta, 10 % listov je značilne oblike, ni še končne velikosti in barve, viden je listni pecelj
BBCH19	G	mature leaves, final size and colour	zreli listi, končne velikosti in barve

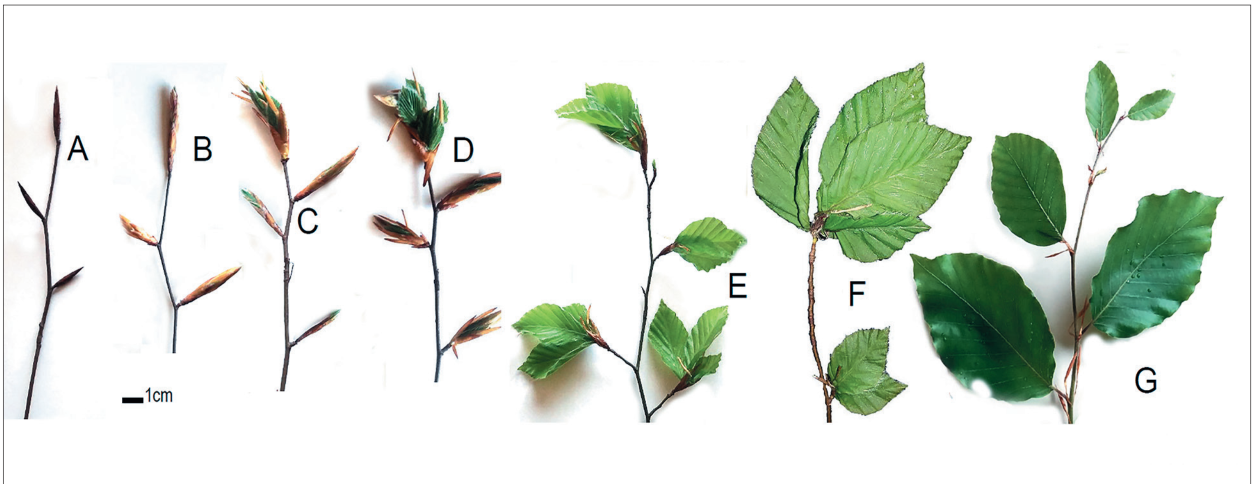

Figure 2. Phenological phases of leaf development in beech from (A) dormant bud to (G) mature leaves.
Slika 2. Fenološke faze razvoja listov bukve od (A) spečih popkov do (G) zrelih listov.

2.3 CLIMATIC AND PHENOLOGICAL DATA FOR COMPARISON
2.3 KLIMATSKI IN FENOLOŠKI PODATKI ZA PRIMERJAVO

To study the weather conditions during the observed leaf development we used the daily climatic data, minimum and maximum temperatures and sums of precipitation for Ljubljana for the period 1951-2020 obtained from the on-line meteorological archive ARSO METEO.

Current leaf development was compared with long-term phenological data, i.e. the data of general leaf unfolding for Ljubljana for the period 1951-2019 obtained from the database of the Slovenian National Phenological Network of ARSO (Žust, 2015).

3 RESULTS AND DISCUSSION
3 REZULTATI IN RAZPRAVA

3.1 DYNAMICS OF LEAF DEVELOPMENT IN SPRING 2020
3.1 DINAMIKA RAZVOJA LISTOV SPOMLADI 2020

On the first day of observation, 4 April 2020 (DOY 95), we inspected all mature dominant and co-dominant beech trees along the 1.6 km long pathway to select the trees for observation (Figure 1, 3). Tree number 20 already had partly unfolded leaves (phase E), whereas all other trees had dormant or swelling buds (phases A, B) and showed no leaf emergence yet (Figures 4, 5, 6). The crown of tree 30 (included in the IPG) still had abundant dry leaves from the previous year.

*Figure 3. Study site and trees: (A) Tivoli, Rožnik forest as seen from Ljubljana Castle on 3 May 2020 (DOY 124) with the locations of the monitored trees, and (B) the observed trees before general leaf unfolding. Trees 11-20 belong to a beech forest site, while tree 30 grows in the park and is a clone (*Fagus sylvatica* Hardegsen) included in the International Phenological Gardens.*

*Slika 3. Opazovano območje in drevesa: (A) gozd Tivoli Rožnik, fotografiran z Ljubljanskega gradu 3. maja 2020 (DOY 124) z mesti opazovanih dreves in (B) drevesa pred splošnim olistanjem. Drevesa 11–20 rastejo v pretežno bukovem gozdu, drevo 30 pa v parkovnem delu in je kot klon (*Fagus sylvatica* Hardegsen) vključeno v Mednarodni fenološki vrt.*

Date	Datum	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
DOY	Dan	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
Tree No. / Drevo	20	E	E	F	F*	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	G	G	G	G
	12	A, B	C	E	E	F	F*	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
	13	A	A	B	B	B	B	C	C	D	E	E	F	F*	F	F	F	F	F	F	F	F	F	F	F
	14	A	A	A	A	B	B	B	B	B	B	B	B	C	C	C	C	C	E	E	E	F	F*	F	F
	19	A	A	A	A	B	B	B	C	C	D	D	D	E	E	E	E	E	F	F*	F	F	F	F	F
	30	A	A, B	A, B	C	D	D	D	D	E	F	F*	F	F	F	F	F	F	F	F	F	F	F	F	F

Legend / Legenda

A	B	C	D	E	F	G

Figure 4. Phenological phases of most typical trees, showing different timing and dynamics of leaf development; A-G indicate leaf development phases (see Figure 2). Phase F in the frame indicates the day of general leaf unfolding when 50% of the leaves have unfolded completely. "Date" indicates the day in April 2020 and DOY indicates the day of the year.*

Slika 4. Fenološke faze najbolj tipičnih dreves, ki prikazujejo različen čas nastopa posameznih faz in različno dinamiko razvoja listov; oznake A-G označujejo faze razvoja listov (glej sliko 2). Faza F v okviru nakazuje dan splošnega olistanja za opazovano drevo, ko je bilo 50 % listov popolnoma razvitih. Datum predstavlja dan v aprilu 2020 in DOY predstavlja zaporedni dan v letu.*

Tree 12 already showed numerous buds which started to open (phase C) on 5 April 2020 (DOY 96); phase C was observed in tree 30 on 7 April 2020 (DOY 98), and in trees 13, 19, and 14 on 10, 11 and 16 April (DOY 101, 102, 107), respectively. Phase C was quickly followed by the first leaf emergence (phase E) and unfolding (F). General leaf unfolding (F*), as defined by IPG (when 50% of the leaves have unfolded completely) was first observed in tree 20 (7 April, DOY 98), slightly later in tree 12 (9 April, DOY 100), and in tree 30 on 14 April (DOY 105). In tree 19 general leaf unfolding appeared much later, on 22 April (DOY 113), and in tree 14 on 25 April (DOY 116). The first mature leaves, phase G, were observed on 24 April (DOY 115) in tree 20. In all other trees the leaves remained light green and soft till 27 April 2020, the last day of daily monitoring. However, monitoring of the trees on 3 May (DOY 124) showed that the colour of the leaves was dark green in most of the trees (Figure 3A). The described phases were documented on photos of the entire trees that were taken every day (Figures 5, 6).

Besides tree 20, which had the earliest leaf development (Figures 5, 6), it is worth mentioning tree 30, which is included in the long-term monitoring within IPG (Figures 5, 6, 7), and for which ARSO has long-term data on leaf unfolding (Figure 9). In this tree general leaf unfolding occurred on 14 April (DOY 105) (Figure 7).

The latest leaf unfolding was observed in trees 14 and 19 (Figure 3B, 5, 6, 8). As tree 14 grows in the group, it was difficult to follow its leaf development after the neighbouring trees unfolded their leaves. Therefore, we put special attention to the nearby tree 19 which is solitary and also showed late leaf unfolding, with a general leaf unfolding date of 22 April (DOY 113) (Figure 8). The upper part of the crown also developed numerous male flowers, which possibly affected late leaf flushing.

3.3 WEATHER SITUATION BEFORE AND DURING LEAF UNFOLDING
3.3 VREMENSKE RAZMERE PRED IN MED OLISTANJEM

Weather situation after the leaf fall of previous season was characterized by a warm winter 2019/2020 in Slovenia and Ljubljana with above average temperatures and smaller amount of precipitation compared to long-term data (Cegnar 2019; 2020a; b and Figure 9).

In winter 2019/2020 there were no days with maximum daily temperatures below 0°C. January and February 2020 were also very dry (Figure 9). The warm winter was followed by a warm early spring. The average March temperature in Ljubljana was 7.2°C, the average minimum daily temperature was 2.3°C, and the amount of precipitation

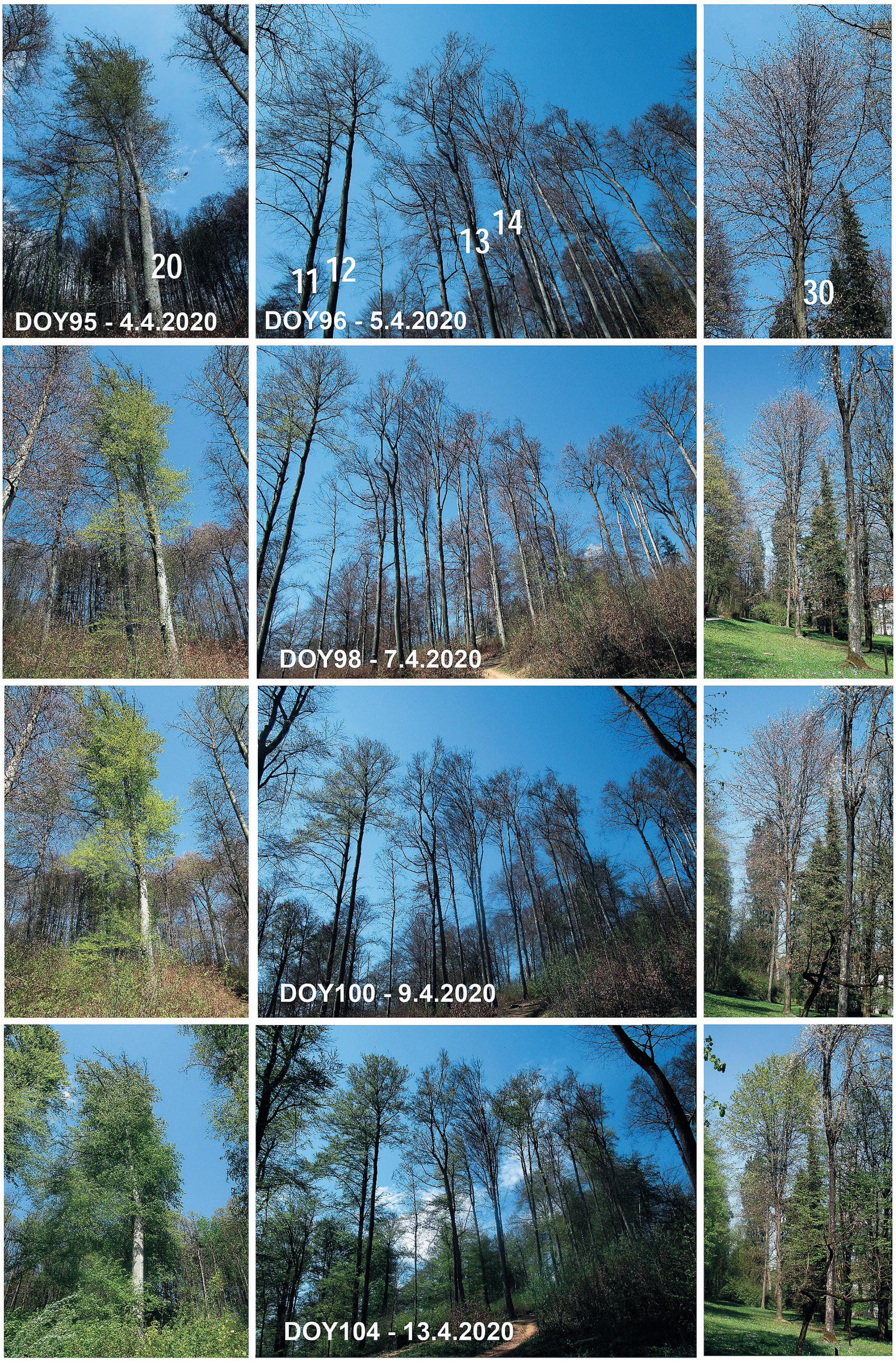

Figure 5. Phenology of leaf development of observed beech trees on chosen days of the year (DOY) - dates.
Slika 5. Fenologija razvoja listov opazovanih bukev na izbrane zaporedne dneve v letu (DOY) - datume.

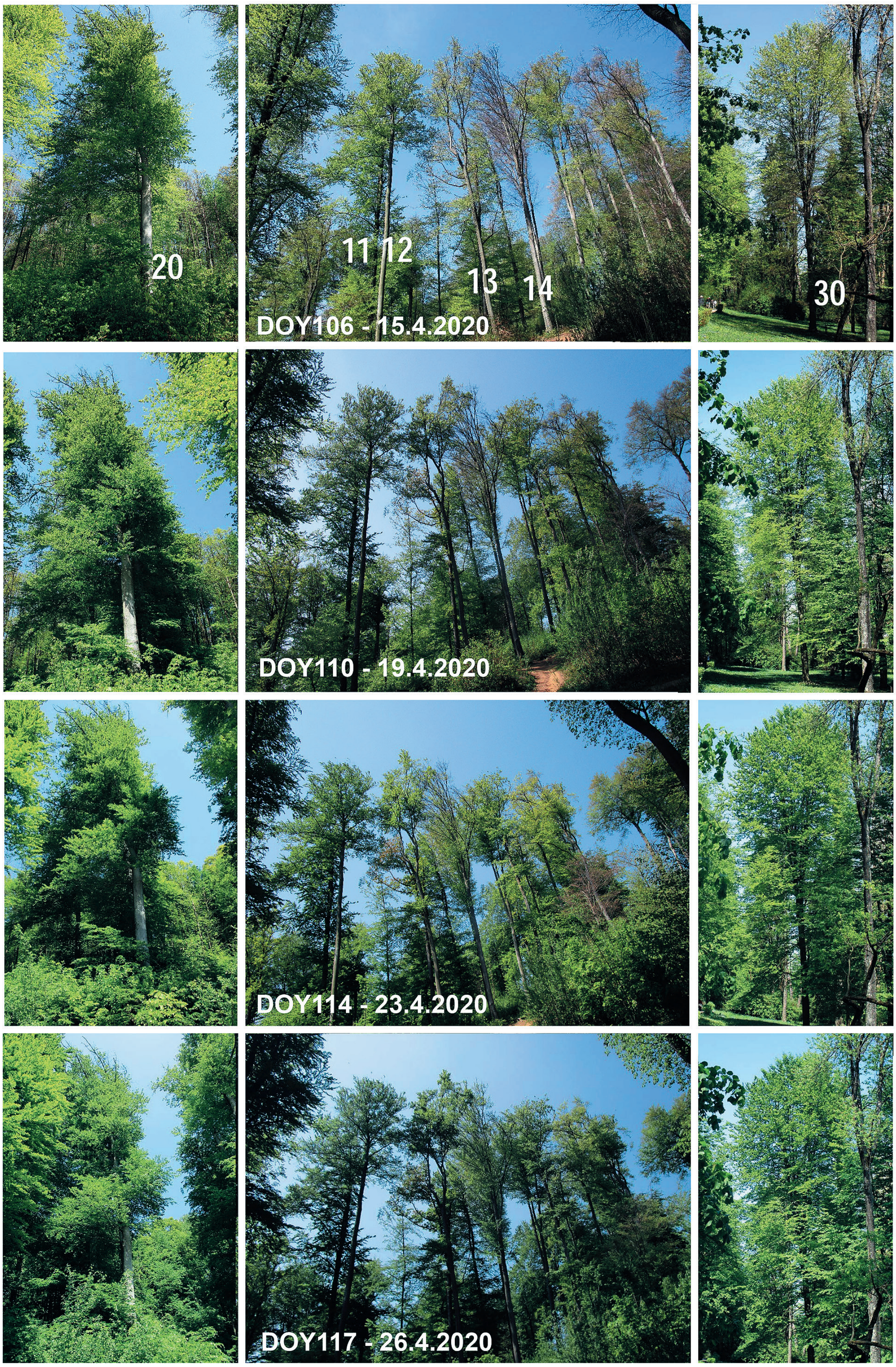

Figure 6. Phenology of leaf development of observed beech trees on chosen days of the year (DOY) - dates.
Slika 6. Fenologija razvoja listov opazovanih bukev na izbrane zaporedne dneve v letu (DOY) - datume.

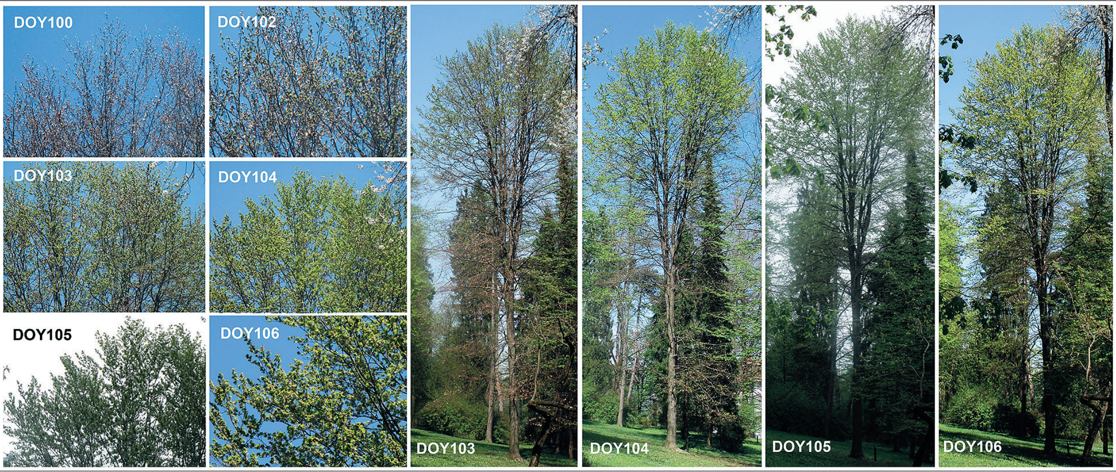

Figure 7. Tree 30, included in the International Phenological Gardens: leaf development between 9 April (DOY 100) and 15 April (DOY 106), with 14 April 2020 (DOY 105) considered as the day of general leaf unfolding (for detailed daily photos see Supplement https://repozitorij.uni-lj.si/IzpisGradiva.php?id=116807).
Slika 7. Drevo 30, vključeno v Mednarodne fenološke vrtove: razvoj listov med 9. aprilom (DOY 100) in 15. aprilom 2020 (DOY 106); 14. april 2020 (DOY 105) je dan splošnega olistanja za to drevo (za podrobne dnevne slike glej Dodatek https://repozitorij.uni-lj.si/IzpisGradiva.php?id=116807).

Figure 8. Tree 19 with late leaf unfolding: its position on the site, and detailed views of the crown on 19, 22 and 26 April 2020 (DOY 110, 113 and 117) (see Figure 4).
Slika 8. Drevo 19 s poznim olistanjem - položaj drevesa in podroben pogled na krošnjo 19., 22. in 26. aprila 2020 (DOY 110, 113 in 117) (glej sliko 4).

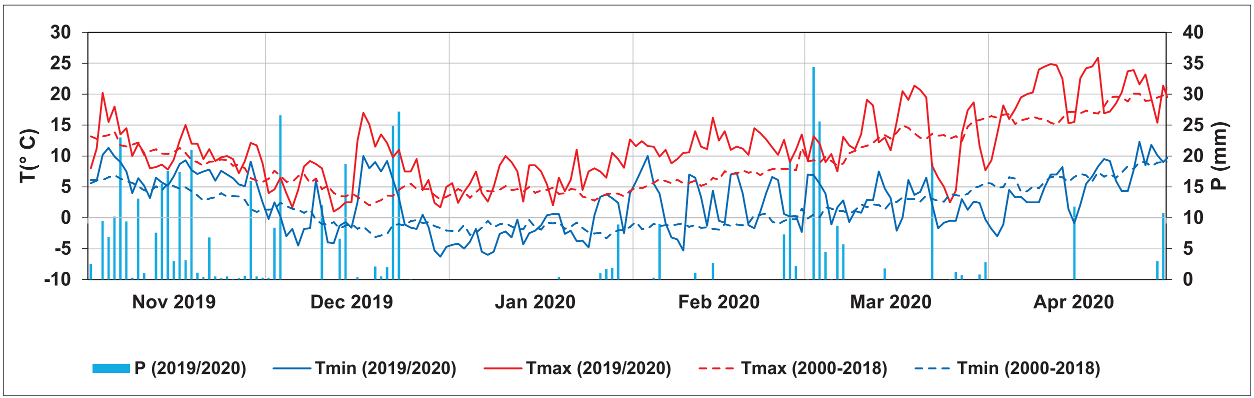

Figure 9. Minimum and maximum daily temperatures (T) and precipitation (P) in winter 2019/2020 and average minimum and maximum temperatures for the period 2000–2018.
Slika 9. Minimalne in maksimalne dnevne temperature (T) ter padavine (P) v zimi 2019/20 in povprečne minimalne ter maksimalne temperature za obdobje 2000–2018.

was 105 mm. Compared to the long-term average, March 2020 was generally warmer and had less precipitation, only in the period between 22 and 26 March was the weather cold and temperatures below the long-term average. In total, Ljubljana had eight frost days in March, when the minimum daily temperature was below 0°C. Agrometeorological conditions in March were characterised by premature flowering of early stone fruit trees, while the frost between 22 and 26 March caused damage to apricots and peaches throughout Slovenia. The lack of rainfall in winter and early spring caused drought conditions, which at the end of March affected the growth of plants in the area of Ljubljana (Žust, 2020).

April, when the leaf development was observed, was characterised by warm, sunny and dry weather. The average monthly temperature in Ljubljana in April was 12.9°C, and the minimum daily temperatures ranged between -3°C and 12.3°C. The maximum daily temperatures were between 9.3°C and 25.9°C. The amount of precipitation was only 25.6 mm, with just three rainy days (Figure 9).

Compared to the long-term average April 2020 was 2.1°C warmer and had only 26% of the long-term average amount of precipitation. April had four cold days and 292 hours (70% more than the long-term average) of sunshine. Agrometeorological conditions in April were characterised by a long drought period which had a negative impact on agriculture.

3.4 LEAF DEVELOPMENT PHENOLOGY IN THE LIGHT OF LONG-TERM OBSERVATIONS

3.4 FENOLOGIJA RAZVOJA LISTOV V LUČI DOLGOLETNIH OPAZOVANJ

As mentioned before, tree 30 (the number 30 is assigned to this tree only for the purpose of this study) is a clone (*Fagus sylvatica* Hardegsen) which is a reference tree for Ljubljana monitored in the framework of the Slovenian National Phenological Network included in the IPG and is one of a series of genetically identical trees that are planted all over Europe (The International…, 2020). Leaf unfolding in Ljubljana has varied over time, with the long-term (1951-2019) average day of leaf unfolding being DOY 109 (19 April when note a leap year). The earliest leaf unfolding was observed on DOY 95 (5 April 1990), and the latest on DOY 125 (5 May 1958) (Figure 10). In Ljubljana we can observe a trend towards an earlier general leaf unfolding date (Figure 10), which is however not statistically significant (Čufar et al., 2012). General leaf unfolding of tree 30 was observed on DOY 105 (14 April 2020), and this is thus four days earlier than the long-term average and can be ascribed to the generally warm winter.

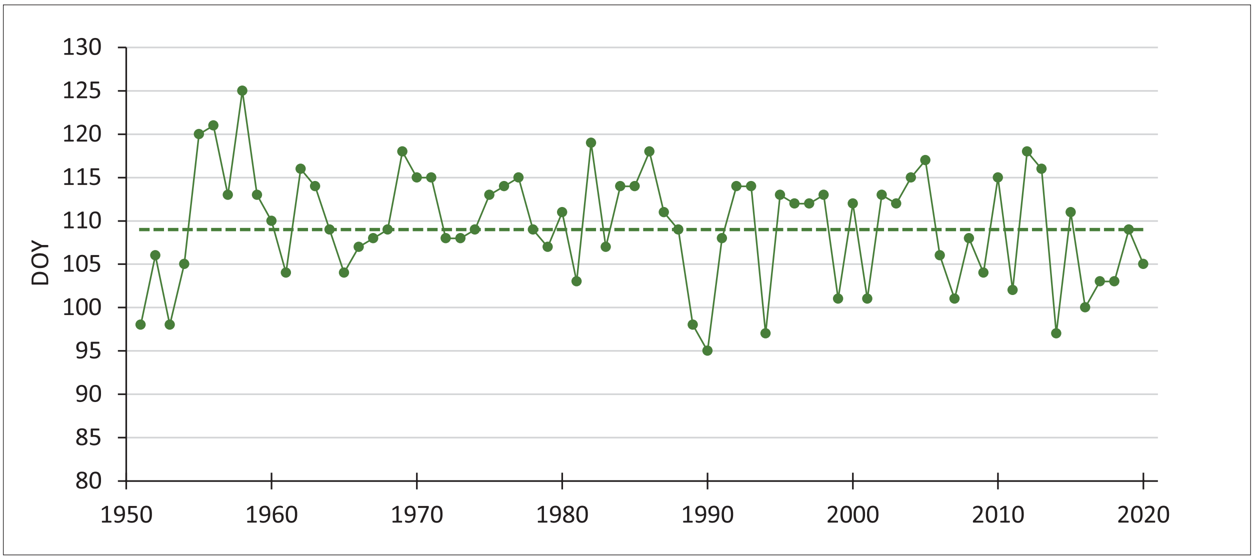

Figure 10. General leaf unfolding of beech in Ljubljana observed by ARSO in the period 1951-2020 and the corresponding average (dotted line). DOY - day of the year.
Slika 10. Dan olistanja bukve v Ljubljani, ki ga je spremljal ARSO v obdobju 1951-2020 in pripadajoče povprečje (črtkana črta). *DOY – zaporedni dan v letu.*

4 CONCLUSIONS
4 ZAKLJUČKI

Long-term phenological observations of beech carried out by ARSO throughout Slovenia provide a date for general leaf unfolding for an individual location. For beech in Ljubljana, the 70-year (1951-2020) set of leaf unfolding data shows that it occurs on average on DOY 109 (19 April when not a leap year), with a 30-day range between DOY 95 and DOY 125.

In this study, we investigated seven spring phenological phases of beech leaf development in one location in Ljubljana. We observed the trees with the earliest and latest leaf unfolding (on a 1.6 km long transect) and obtained information on the variability of the occurrence of individual phenological phases among the trees. The observed trees showed general leaf unfolding between 7 and 25 April 2020. There were large differences among the trees even if they grow very close to each other. In the reference beech, for which we have long-term data, general leaf unfolding occurred on DOY 105 (14 April). This is four days earlier than the long-term (1951-2020) average of the data collected by ARSO for the same tree/location. Earlier leaf unfolding of beech is in line with observations of ARSO in other plant species, which in sprig of 2020 generally showed up to one week earlier phenological phases than the long-term average, which is ascribed to the above-average warm winter and early spring (Cegnar, 2020c; Žust, 2020).

This study helped us to obtain basic information on phenological variability among the trees on the same microsite, which is, among other things, important to better understand tree physiology and cambial activity with wood and phloem formation.

5 SUMMARY
5 POVZETEK

Fenologija (iz grške besede φαινομαι, *phainomai* - pojaviti se) je veja ekologije, ki proučuje zakonitosti periodičnih pojavov v razvojnem ciklu rastlin in živali ter ugotavlja njihovo odvisnost od sezonskih in letnih nihanj podnebnih dejavnikov okolja. Primera tega sta čas razvoja listov in cvetov pri rastlinah ter prvega opaženega prihoda ptic selivk na določenem območju.

Pri gozdnih drevesih najpogosteje opazujemo fenologijo razvoja listov in iglic. Med najbolj raziskovanimi gozdnimi drevesi je navadna bukev (*Fagus sylvatica*). Posebej zanimiva je zgodnja (spomladanska) fenologija, ki proučuje faze razvoja listov od listnih brstov (popkov) v mirujočem stanju do nastanka zrelega, polno delujočega lista (slika 2, preglednica 2). Olistanje je med najbolj očitnimi zunanjimi znaki fiziološke aktivnosti drevesa po zimskem mirovanju. Povezano je tudi s procesi reaktivacije kambija ter nastajanja lesa in skorje, ki na zunaj niso vidni in jih lahko spremljamo samo, če iz drevesa odvzamemo tkiva in jih ustrezno pripravimo za proučevanje pod mikroskopom (Čufar et al., 2008; Prislan et al., 2013a; 2013b).

Navadna bukev je v Sloveniji najbolj zastopana drevesna vrsta in predstavlja tretjino (32,6 %) lesne zaloge (Poročilo Zavoda ..., 2018). Ob nedavni inventuri gozda so ugotovili, da v Sloveniji raste 208 milijonov bukovih dreves (Inventura gozda, 2018). Olistanje bukve naj bi označevalo začetek prave pomladi, cvetenje, ki je nekoliko kasnejše, pa glavno obdobje prave pomladi; dozoreli plodovi nato označujejo začetek prave jeseni (Žust, 2015).

Listno fenologijo bukve že od leta 1951 sistematično spremlja Agencija Republike Slovenije za okolje (ARSO). Na reprezentativnih drevesih po Sloveniji spremljajo naslednje faze: (1) olistanje (BBCH11), ki nastopi, ko se prvi listi izvijejo iz ovojne zaščitne luske, listna ploskev je odprta, značilne oblike, ni pa še prave velikosti, viden je listni pecelj. Mladi listi so porasli s številnimi dlačicami, ki kasneje odpadejo, (2) splošno rumenenje listja (BBCH94), ki nastopi, ko je več kot polovica listov jesensko porumenelih ter (3) odpadanje listov. ARSO je vključen tudi v aktivnosti mednarodne mreže fenoloških vrtov (The International .., 2020; Chmielewski et al., 2013; Žust, 2015) in v tem okviru spremlja fenologijo bukovih klonov, ki so nasajeni po botaničnih vrtovih Evrope, primer tega klona (*Fagus sylvatica* Hardegsen) raste tudi v Ljubljani na območju parka Tivoli (drevo 30 v naši raziskavi).

Dragoceni dolgoletni podatki listne fenologije bukve so med drugim tudi bogat vir informacij pri spremljanju odziva dreves na podnebne spremembe. Študija splošnega olistanja in rumenenja bukve na osnovi podatkov ARSO iz 47 krajev po vsej Sloveniji (nadmorske višine od 55 do 1.050 m), je za obdobje 1955–2007 pokazala, da olistanje nastopi od 13. aprila do 13. maja (Čufar et al., 2012) in se zakasni za 2,6 dni, če se nadmorska višina poveča za 100 m. Na olistanje vplivajo predvsem temperature v marcu (na nižjih nadmorskih višinah) in v aprilu (na višjih legah). V času 1955–2007 so temperature v marcu in aprilu naraščale, kar je vplivalo na vedno zgodnejše olistanje, to je za 1,52 dni na desetletje na 1000 m n. m. in za 0,67 dni na 500 m n. m. Slednje kaže, da podnebne spremembe vplivajo na fenološko vedenje bukve predvsem na višjih nadmorskih višinah. Splošno obarvanje listov je v istem obdobju nastopilo od 2. do 29. oktobra in se prej pojavi na višjih nadmorskih višinah (1,9 dni prej za vsakih 100 m). Rumenenje listov je pozitivno povezano s temperaturami v avgustu in septembru, vendar dolgoročni trendi in spreminjanje z nadmorsko višino tu niso statistično značilni (Čufar et al., 2012). Pokazalo se je tudi, da se čas olistanja približno ujema z začetkom delovanja kambija in nastajanja lesa, čeprav omenjene procese vodijo različne klimatske spremenljivke (Čufar et al., 2008). Fenologije listov na splošno niso mogli povezati z variiranjem širin branik (Čufar et al., 2015), prav tako se podaljšanje rastne sezone v splošnem ne odraža v širinah branik (Kolar et al., 2015).

Zaradi zahtevne organizacije fenoloških opazovanj se v zadnjem času razpravlja, kako bi jih lahko nadgradili z modeliranjem (Vilhar et al., 2018) ali s pomočjo satelitskih posnetkov (npr., Allevato et al., 2019; Lukasova et al., 2019). Nedavne raziskave bukve v Sloveniji, kjer so med leti 2001 in 2017 z analizo multispektralnih posnetkov satelitov MODIS in z izračunom vegetacijskega indeksa EVI spremljali spremembe zelene biomase v krošnjah dreves, so pokazale, da ločljivost satelitskih slik praviloma še ne omogoča spremljanja fenologije listov, zabeležiti pa je bilo mogoče poškodbe listov/krošenj zaradi izjemnih vremenski dogodkov in ujm, kot so vročinskih valovi, žledolomi in pozebe (Decuyper et al., 2020).

Na rezultate omenjenih raziskav vpliva velika variabilnost fenoloških faz istega drevesa, med drevesi in med rastišči, različne metode, kot so terensko opazovanje ali slikanje, pa na različne načine obvladujejo problem variabilnosti (Lukasova et al., 2019). Zato smo se odločili, da v času razvoja listov v aprilu 2020 vsakodnevno fotografsko spremljamo razvoj listov pri skupini dreves na območju Krajinskega parka Tivoli, Rožnik in Šišenski hrib v Ljubljani v Sloveniji (slika 1) ter predstavimo časovno variabilnost razvoja listov za posamezno drevo in med drevesi.

Ob 1,6 km dolgi poti ob vznožju hriba smo pregledali bukova drevesa in izbrali najzgodnejše drevo (drevo 20), skupino dreves z različno dinamiko olistanja (drevesa 11-19) in drevo 30 (klon *Fagus sylvatica* Hardegsen), ki ga ARSO spremlja v okviru mednarodne mreže fenoloških vrtov IPG ob podpori Mestne občine Ljubljana (Identifikacijska številka rastline: 221, leto sajenja: 1969, izvor: Nemčija) (sliki 1, 3). V času od 4. do 27. aprila 2020 smo dnevno fotografirali izbrana drevesa in popisali najbolj značilno fenološko fazo razvoja listov (slika 2). V maju 2020 smo drevesa obiskovali v tedenskih intervalih. Opazovanja so potekala po kriterijih, ki jih je izdala agrometeorološka komisija pri WMO (Guidelines …, 2009) (slika 2, preglednica 2).

Pridobljene podatke smo ovrednotili tudi z vidika dolgoletnih meteoroloških podatkov in fenoloških opazovanj bukve v Ljubljani.

Prvi dan opazovanja, 4. aprila 2020 (dan v letu=DOY 95) je drevo 20 že imelo liste v fazi razpiranja (faza E), medtem ko so bili brsti pri vseh drugih drevesih v mirujočem stanju ali v fazi nabrekanja (fazi A, B), listi pa še niso pogledali iz lusk (slike 3, 4, 5). Krošnja drevesa 30 je imela brste v mirujočem stanju, na vejah pa še veliko suhega listja iz prejšnjega leta.

Že 5. aprila 2020 (DOY 96) so se brsti na drevesu 12 začeli odpirati (faza C), medtem ko je bila faza C pri drevesu 30 opažena 7. aprila 2020 (DOY 98), pri drevesih 13, 19 in 14 pa po vrsti 10., 11. in 16. aprila (DOY 101, 102, 107). Fazi C je hitro sledil prvi razvoj listov (faza E) in olistanje (F), ko so bili listi popolnoma razprti. Splošno olistanje (F*) po definiciji Mednarodnih fenoloških vrtov, ko je olistane 50 % krošnje, smo najprej opazili pri drevesu 20 (7. aprila, DOY 98), nekoliko kasneje pri drevesu 12 (9. aprila, DOY 100), pri drevesu 30 pa 14. aprila (DOY 105). Pri drevesu 19 se je faza F* pojavila veliko kasneje, 22. aprila (DOY 113), pri drevesu 14 pa 25. aprila (DOY 116). Prve zrele temno zelene in čvrste liste, ki so značilni za fazo G, smo opazili 24. aprila (DOY 115) na drevesu 20. Na vseh drugih drevesih so listi ostali svetlo zeleni in mehki do 27. aprila 2020, ko smo zaključili vsakodnevno opazovanje. Ob naslednjem obhodu, 3. maja (DOY 124), pa je bila barva listov pri večini dreves temno zelena (slika 2A). Opisane faze so bile dokumentirane na fotografijah celotnih dreves, posnetih vsak dan (sliki 5, 6).

Poleg drevesa 20, ki je imelo najzgodnejši razvoj listov (sliki 5, 6), smo fotografsko predstavili tudi drevo 30, za katerega ima ARSO dolgoletne podatke (slike 5, 6, 7) in je v letu 2020 olistalo 14. aprila (DOY 105) (slika 7).

Nazadnje sta se olistali drevesi 14 in 19 (slike 3B, 5, 6, 8). Ker drevo 14 raste v skupini, je bilo po olistanju sosednjih dreves pri njem težko slediti razvoju listov, zato smo bolj podrobno predstavili olistanje drevesa 19, ki raste v neposredni bližini in ni utesnjeno. Drevo 19 je olistalo 22. aprila (DOY 113) (slika 8). Zgornji del krošnje je razvil številne moške cvetove, kar je morda dodatno vplivalo na pozno olistanje.

V prispevku diskutiramo tudi o vremenskih razmerah pred in med olistanjem (slika 9). Cikel razvoja listov se začne že v letu pred olistanjem, saj se tipični zašiljeni brsti oblikujejo že do zaključka predhodne sezone, za olistanje spomladi pa mora drevo skozi ustrezno dolgo obdobje mrzlega vremena, dovolj dolgo dolžino dneva in ustrezno toplo vreme pred olistanjem (Vitasse & Basler, 2013; Dantec et al., 2014; Wenden et al., 2020). Zima 2019/2020 je bila nadpovprečno topla, kar je veljalo tako za november in december 2019, ter januar in februar 2020 (Cegnar 2019; 2020a; 2020b). Razen novembra, ki je bil nadpovprečno moker, so bili ostali zimski meseci nadpovprečno suhi (Cegnar, 2019; 2020a; 2020b). Tudi marec je bil toplejši in bolj suh kot dolgoletno povprečje 1981–2010, v času od 22. do 26. marca pa se je močno ohladilo. V Ljubljani je bila povprečna marčevska temperatura 7,2 °C, povprečna najnižja dnevna temperatura pa je bila 2,3 °C, kar je 0,7 oz. 0,5 °C nad dolgoletnim povprečjem. V Ljubljani je bilo v marcu 8 hladnih dni, ko se najnižja dnevna temperatura spusti pod ledišče (Cegnar, 2020c). Fenološki razvoj pri večini rastlin je bil na začetku pomladi 2020 bolj zgoden kot običajno. V marcu je po Sloveniji predčasno zacvetelo koščičasto sadje, v hladnem obdobju med 22. in 26. marcem pa je prišlo do obsežne pozebe. Dve pozebi so po Sloveniji zabeležili tudi 8. in 15. aprila (ARSO, 2020). Temperature v Ljubljani so bile v obeh hladnih obdobjih v aprilu 2020 nekoliko višje kot po Sloveniji, zato učinkov obeh pozeb na bukev (v občutljivi fazi razvoja listov) v Ljubljani nismo zabeležili.

V tej študiji smo spremljali sedem faz razvoja listov pri bukvah na eni lokaciji, pri čemer smo skušali zajeti tudi drevesi z najzgodnejšim in najpoznejšim olistanjem in s tem pridobiti informacije o variabilnosti pojava posameznih faz med drevesi. Splošno olistanje je pri različnih drevesih nastopilo med 7. in 25. aprilom 2020, olistanje pri bukvi, za katero imamo dolgoletne podatke o datumu olistanja, pa je nastopilo 14. aprila (DOY 105), kar je 4 dni prej od dolgoletnega povprečja (DOY 109) (slika 10). Pri najzgodnejši bukvi na opazovanem transektu, za katero nimamo dolgoletnih podatkov, pa je olistanje nastopilo že 7. aprila (DOY 98). K zgodnjemu pojavu fenoloških faz pri bukvi je pripomogla nadpovprečno topla zima in zgodnja pomlad, kar je bilo opazno tudi pri drugih rastlinah, ki jih spremlja ARSO (Žust, 2020). V tej študiji smo pridobili informacije o variabilnosti listne fenologije, kar nam bo med drugim pomagalo bolje razumeti fiziologijo gozdnega drevja, vključno z delovanjem kambija ter nastajanjem lesa in skorje.

SUPPLEMENT
DODATEK

The supplement related to this article is available online in the Repository of the University of Ljubljana (RUL) and can be accessed through https://repozitorij.uni-lj.si/IzpisGradiva.php?id=116807, and cited as Škrk et al. (2020).

It contains daily photos (period 5 - 27 April and 2 May 2020) of leaf development in European beech (*Fagus sylvatica*) (tree 30 in this study) which is as a plant number 221 included in the long-term monitoring of the Slovenian National Phenological Network of the Environmental Agency of the Republic of Slovenia (ARSO) within the Ministry of the Environment and Spatial Planning as a part of the International Phenological Gardens of Europe.

Dodatek, povezan s tem člankom, je prosto dostopen na spletu v Repozitoriju Univerze v Ljubljani (RUL). Dostop do njega je možen preko povezave https://repozitorij.uni-lj.si/IzpisGradiva.php?id=116807 in se ga citira kot Škrk et al. (2020). Dodatek vsebuje dnevne fotografije (obdobje od 5. do 27. aprila in 2. maja 2020) razvoja listov pri navadni bukvi *Fagus sylvatica* (drevo številka 30 v tej študiji), ki je kot drevo z identifikacijsko številko 221 vključeno v dolgoletno spremljanje v okviru Slovenske nacionalne fenološke mreže Agencije Republike Slovenije za okolje (ARSO) Ministrstva za okolje in prostor Republike Slovenije, ki je vključen v aktivnosti Mednarodnih fenoloških vrtov Evrope.

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DENDROCLIMATIC STUDY OF A MIXED SPRUCE-FIR-BEECH FOREST IN THE CZECH REPUBLIC

DENDROKLIMATOLOŠKA ŠTUDIJA MEŠANEGA SMREKOVO-JELOVO-BUKOVEGA GOZDA V ČEŠKI REPUBLIKI

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Abstract / Izvleček

Abstract: *European forests are undergoing an important transition due to the current climate change, as monocultures are being gradually replaced by mixed forests. Understanding tree growth in mixed forests under a changing climate is challenging because of tree species' adaptation and long-term forest planning. In this study, we evaluate the long--term behaviour of Norway spruce (*Picea abies*), silver fir (*Abies alba*) and European beech (*Fagus sylvatica*) from a low montane range at the Czech-Austrian border. Species-specific tree-ring width chronologies have revealed significantly decreasing growth trends since the 2000s. Temporally unstable climate–growth relationships showed an increasing negative effect of current growing season drought on spruce growth and a positive effect of dormant season temperature on fir and beech growth. Our results suggest that though species' response to climate change differs in the mixed forest, growth reduction in the last years has been proved for all species, likely due to frequent climate extremes.*

Keywords: Abies alba*,* Fagus sylvatica*,* Picea abies*, tree-ring width chronology, climate change, growth trends, mixed forest, Gratzen Mountains*

Izvleček: *Evropski gozdovi doživljajo pomembne spremembe zaradi trenutnih podnebnih dogajanj, ko monokulture postopoma nadomeščajo mešani gozdovi. Razumevanje, kako rastejo drevesa v mešanih gozdovih v spreminjajočem se podnebju, je izziv zaradi njihovih prilagoditev in dolgoročnega gozdnogospodarskega načrtovanja. V tej raziskavi smo ovrednotili dolgoročno obnašanje navadne smreke (*Picea abies*), bele jelke (*Abies alba*) in navadne bukve (*Fagus sylvatica*) iz nizkega montanskega pasu na češko-avstrijski meji. Kronologije širin branik za posamezne drevesne vrste od leta 2000 izkazujejo negativne trende rasti. Časovno nestabilne odvisnosti rasti od klime so pokazale naraščajoč negativni vpliv suše med tekočo rastno sezono na rast smreke in pozitiven učinek temperatur v obdobju mirovanja na rast jelke in bukve. Naši rezultati kažejo, da čeprav se odzivnost na podnebne spremembe razlikuje med posameznimi vrstami v mešanem gozdu, je bilo v zadnjih letih dokazano zmanjšanje rasti za vse vrste, najverjetneje zaradi pogostih izjemnih vremenskih dogodkov.*

Ključne besede: Abies alba*,* Fagus sylvatica*,* Picea abies*, kronologije širin branik, podnebne spremembe, trendi rasti, mešani gozd, Novohradské hory*

1 INTRODUCTION
1 UVOD

Norway spruce (*Picea abies* L. Karst) and European beech (*Fagus sylvatica* L.) are among the most widespread tree species in continental Europe (Euforgen, 2009). Although Norway spruce was less represented in Central European forests until the 18th century (Jansen et al., 2017), planting of its monocultures far beyond the limits of its natural range in the last two centuries has made this species very important socio-economically (Caudullo et al., 2016). Because of the intensification of human interventions in forests, manifested especially by the enforcement of spruce monocultures since

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the 19th century, the distribution of silver fir (*Abies alba* Mill.) markedly decreased in the Czech Republic (Kozáková et al., 2011). Currently, extensive spruce forest dieback due to increased pathogen and insect outbreaks (Marini et al., 2016) has led to the gradual conversion of conifer monocultures into more stable mixed forests with an abundant proportion of deciduous trees, especially European beech (Pretzsch et al., 2014). The historical changes described in forest management strategies caused that mixed spruce-fir-beech forests, which are typical of natural or extensively managed submontane forests, are nowadays relatively scarce (FMI, 2007). At present in the Czech Republic about 50% of the forest cover is represented by Norway spruce, 9% by European beech and only 1% by silver fir (RPFD, 2020). Spruce and beech, as the most widespread coniferous and broadleaved species with a wide range of utilization, are very important for wood technology and wood economy in the country.

Climatic fluctuations have a substantial impact on forest ecosystems (Hartl-Meier et al., 2014). The current climate change manifested by a significant temperature increase (Štěpánek et al., 2016) together with the decreasing soil moisture content (Trnka et al., 2015) can lead to a reduction in tree vitality and higher vulnerability of forest stands (Kölling & Zimmermann, 2007). Tree responses to climate change have been frequently studied in Central Europe for spruce (e.g. Koprowski, 2013; Rybníček et al., 2012), fir (e.g. Koprowski, 2013; Latreille et al., 2017), and beech (e.g. Bošeľa et al., 2018; Kolář et al., 2016). Most of these studies have presented the general conclusion that altitude is the leading factor controlling growth in temperate forests (Bošeľa et al., 2014), i.e. the growth of forest trees at high altitudes and latitudes is mainly limited by temperature (Leonelli et al., 2016), and of those at low elevations by precipitation and/or drought (Dobrovolný et al., 2016). Additionally, pure stands, especially even-aged conifer monocultures, are vulnerable to disturbances caused by climate change (Felton et al., 2017). By contrast, uneven-aged mixed stands seem to have better resilience (Lafond et al., 2014). Given that tree responses to a changing climate can significantly differ between pure and mixed stands (Nothdurft & Engel, 2020), it is important to study both kinds of stands in detail to support forest adaptation and mitigation strategies (Conte et al., 2018) and wood production.

In this study we used tree-ring width (TRW) series to analyse the radial growth of Norway spruce, silver fir and European beech growing at the same mixed forest stand since the 1960s. The study aims to investigate 1) the growth trends of these species in the last few decades when climate has been getting significantly warmer and drier, and 2) temporal climate-induced changes in the growth variability. We hypothesized that growth of *Picea abies* with a shallow root system is significantly more sensitive to unprecedented temperature increases accompanied by drier conditions than *Abies alba* and *Fagus sylvatica*, which have larger ecological niches and more differentiated root system stratifications.

2 MATERIALS AND METHODS
2 MATERIAL IN METODE

2.1 MATERIAL
2.1 MATERIAL

The Gratzen low mountain range along the Czech-Austrian border is a part of south and south-eastern foothills of the Bohemian Massif. The highest peak is the Viehberg on the Austrian side, reaching 1,112 metres a.s.l. The region consists of several old-growth forests and peat bogs. About

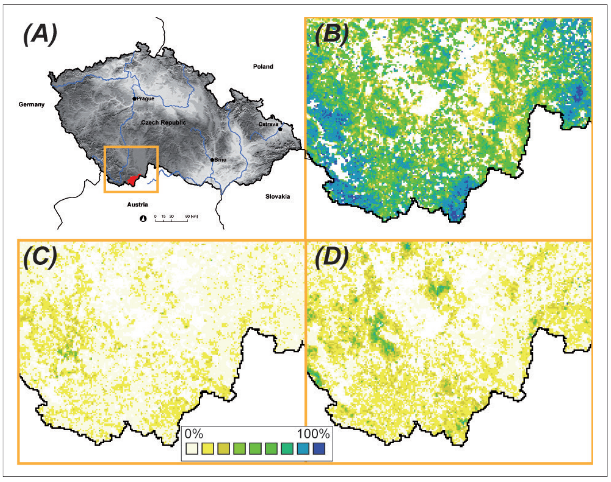

Figure 1. The Gratzen (Novohradské) Mountains at the Czech-Austrian border (A) and the current distribution of Picea abies *(B),* Abies alba *(C) and* Fagus sylvatica *(D) in the southwestern part of the Czech Republic.*
*Slika 1. Novohradské hory na češko-avstrijski meji (A) in trenutna razširjenost smreke (*Picea abies*) (B), bele jelke (*Abies alba*) (C) in navadne bukve (*Fagus sylvatica*) (D) na jugozahodnem delu Češke republike.*

three quarters of the region are covered by coniferous (approx. 90%) and deciduous forests, mostly represented by fir-beech and spruce-fir-beech forests. Currently, Norway spruce is the dominant species in the region (Fig. 1), cultivated mostly in monocultures, though originally European beech prevailed in the region (RPFD, 2020).

The study was performed in a spruce-fir-beech mixed forest stand (48.72481N, 14.73666E) located at 850 m a.s.l. in the north-eastern area of the Gratzen Mountains. During the focal period (1961–2017), the mean annual temperature was 6.2 °C. The lowest mean temperatures appear in January (-3.0 °C), the warmest months are June (15.2 °C) and August (14.9 °C). Annual precipitation totals vary from 660 to 1240 mm, with the highest totals in the summer months. During the April–August growing season the mean temperature ranged between 9.8 °C and 14.1 °C and precipitation totals between 340 and 700 mm. Increases in the annual mean temperature, evapotranspiration and precipitation totals were observed from 1961 to 2017. The relative soil water content (AWR) in the first 1.3 m of the soil profile slightly decreased in this period (Fig. 2).

2.2 TRW SAMPLING, CHRONOLOGY DEVELOPMENT AND VISUAL ASSESSMENT OF CROWN CONDITION

2.2 VZORČENJE LESA, SESTAVA KRONOLOGIJE IN VIZUALNA OCENA STANJA KROŠNJE

The sampling sites were selected in a mixed spruce-fir-beech forest. One core per tree was extracted (Kirdyanov et al., 2018) using a Pressler borer at breast height (1.3 m) along the contour line to avoid compression wood. Tree-ring width was measured on the cores using the VIAS TimeTable measuring system (©SCIEM, Austria) with 0.01-mm accuracy. The measuring and cross-dating of tree-ring width (TRW) series were performed using the PAST4 (©SCIEM, Austria) and COFECHA (Grissino-Mayer, 2001) programmes. The coherency among the individual TRW series was assessed using t-test Baillie and Pilcher (1973), t-test Hollstein (1980), Gleichläufigkeit (Eckstein & Bauch, 1969), and an optical comparison of the series. In order to remove non-climatic, age-related growth trends from the raw TRW series as well as other non-climatic factors (e.g. competition), cubic smoothing splines with a 50% frequency

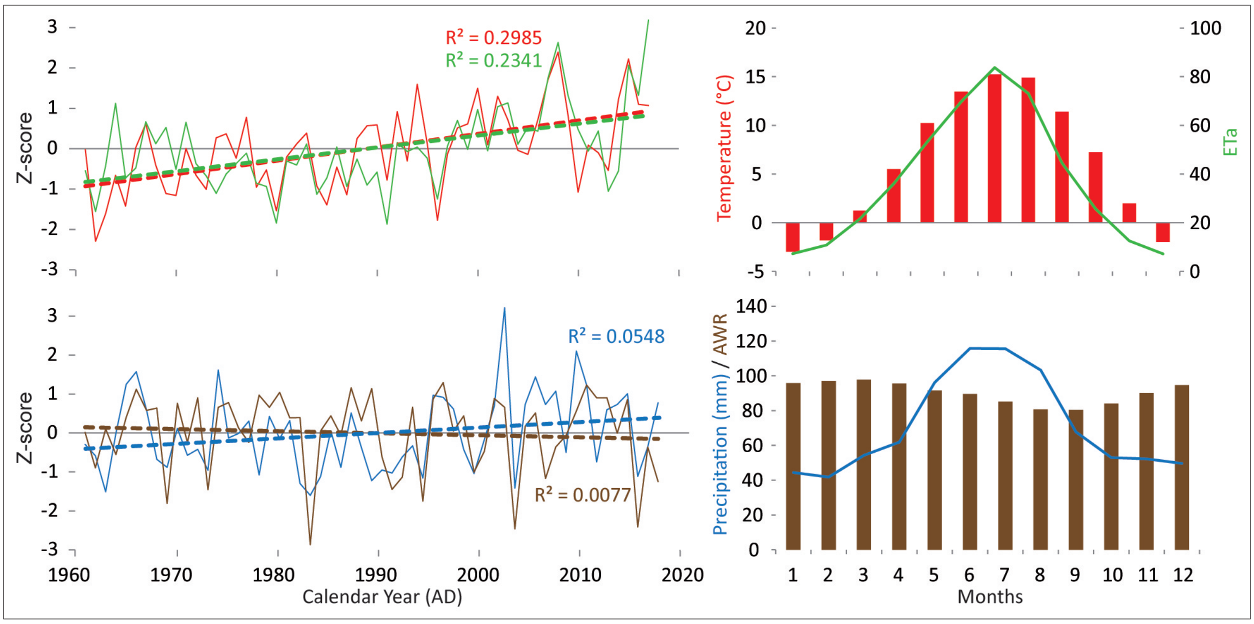

Figure 2. Annual standardized values with coefficients of determination (left) and climate diagram (right) of mean temperature, precipitation totals, evapotranspiration (Eta) and soil moisture content (AWR; depth 0–1.30 m) for the study site from 1961 to 2017.

Slika 2. Letne standardizirane vrednosti z determinacijskimi koeficienti (R^2) (levo) in klimograma (desno) za povprečne mesečne temperature, vsote padavin, evapotranspiracijo (Eta) in vsebnosti vlage v tleh (AWR; globina 0–1,30 m) za raziskovalno ploskev od leta 1961 do 2017.

cut-off at 100 years were applied (Cook & Peters, 1981) using the ARSTAN software (Cook & Krusic, 2005). This standardization method was chosen due to its flexibility, as each raw TRW chronology revealed a different growth trend (Fig. 3), and because of its ability to preserve inter-annual to multi-decadal growth variations. TRW indices (TRWi) were calculated as residuals after the appropriate power transformation of the raw data to minimize end-effect problems (Cook & Peters, 1997). Mean TRW species-specific chronologies were calculated using bi-weight robust means, and their signal strength was assessed using the inter-series correlation (Rbar) and the Expressed Population Signal (EPS) (Wigley et al., 1984).

Concurrently, we visually evaluated crown condition of the same trees using binoculars (Cudlín et al., 2001; Eichhorn et al., 2010). We assessed the following parameters in summer (July): total defoliation, proportion of secondary shoots (both in intervals of 5%), stem foliation, discolouration, i.e. yellowing and browning (unspecific damage symptoms), and fruiting, with the number of trees having these features being recorded. Defoliation was defined as needle/leaf loss in the assessable crown compared to a local reference tree (Eichhorn et al., 2010), and was observed regardless of the cause of lost foliage.

2.4 CLIMATE DATA
2.4 KLIMATSKI PODATKI

Climate data were derived from the 500-m-resolution gridded daily dataset for the location (48.72481N, 14.73666E, 850 m a. s.l.) based on the interpolation from a set of nearby weather stations by applying the local weighted regression and accounting for the effect of the altitude. The original station series were subjected to quality control and homogenization using ProClimDB (Štěpánek, 2007). All observations of the weather variables were tested for outliers and breaks using a detailed homogenization sequence, and the gaps of missing data were filled. All weather elements could be interpolated using the high-density network for the sampling site (Štěpánek et al., 2011). The database for the research area included daily data on the maximum and minimum temperatures, precipitation and global radiation totals and the daily mean wind speed and water vapour pressure. Using the AgriClim (Trnka et al., 2012) and SoilClim (Hlavinka et al., 2011) software packages, the daily soil moisture content (expressed as relative water availability – AWR; depth 0–1.3 m) was calculated. The AWR is estimated for a daily time step accounting not only for the balance among evapotranspiration, precipitation and the antecedent AWR, but also for the snow presence/absence, aspect and slope of the site, critical soil water holding properties, and the phenological stage of the canopy. This routine was based on the approach proposed by Allen et al. (1998) and described in detail by Hlavinka et al. (2011) and Trnka et al. (2015).

2.3 ANALYSIS OF GROWTH TRENDS AND GROWTH-CLIMATE RELATIONSHIPS
2.3 ANALIZA RASTNIH TRENDOV IN ZVEZE MED RASTJO IN KLIMO

Growth trends of the species-specific TRWi chronologies were explored during three delineated periods to find the species' response to the effects of environmental factors during the study period (1961–2017). The delineated periods were established based on the main and previously studied environmental changes. The first period (1961–1980) was characterized by increasing air pollution in Central Europe (Smith et al., 2011), the second (1980–2000) by gradual pollution control and concurrent temperature increase (Kolář et al., 2015), and the most recent period (2000–2017) by an unprecedented rise in temperature (Neukom et al., 2019). Simple linear regressions were calculated in the R package to show growth trends during the delineated periods.

The residual TRWi chronologies were used to calculate the correlation with the climatic variables in the treeclim R package (Zang & Biondi, 2015) for the period 1961–2017. Given that monthly correlations were generally low and mostly insignificant (not presented), correlation coefficients in 20-year moving windows for the previous growing season (previous April–previous August), dormant season (previous September–March) and growing season (April–August) of the year of tree-ring formation (referred to as the "current year") were calculated.

3 RESULTS AND DISCUSSION
3 REZULTATI IN RAZPRAVA

3.1 CHARACTERISTICS OF THE SPECIES-SPECIFIC CHRONOLOGIES
3.1 ZNAČILNOSTI KRONOLOGIJ POSAMEZNIH VRST

The species-specific TRW chronologies representing one mixed forest stand cover the common period of 1890–2017. These raw TRW chronologies, each replicated by seventeen trees, showed various growth characteristics (Tab. 1). The influence of juvenile wood on TRW was confirmed by the relationship between the mean segment lengths and the average growth rate, because the shortest beech series correspond to their widest TRW. Fir and beech showed a considerably higher growth variability (expressed by standard deviation) compared to spruce, especially in the most recent period (Fig. 3), even if the fir chronology was represented by very old trees. By contrast, the high growth variability of beech resulted from its highest age diversity. The high first-order autocorrelation of the fir raw TRW chronology indicates a greater temporal memory than in beech and spruce. These characteristics were also reflected in different growth trends of raw TRW chronologies. The increasing growth trend of fir mainly from 1980 to 2000 is in contradiction to the gradual growth decrease of spruce since the 1980s. However, beech showed an apparent decline of TRW in the first 60 cambial years followed by an unexpected rising growth trend, peaking in the 1930s, and a substantial growth reduction since the 1990s. The visual assessment of crown conditions showed the most damaged crowns in the case of spruce trees, where defoliation was more than double in comparison to fir and beech. The relatively high portion of secondary shoots in spruce and stem foliation in fir point to crown regeneration processes during the last ten years. However, while fir crown condition was improved thanks to the foliation, the current spruce crown condition is noticeably worse, which was indicated by marked defoliation or even the secondary shoots.

Table 1. Basic characteristics of the tree-ring width chronologies and tree habitus of Picea abies, Abies alba *and* Fagus sylvatica*.*

Preglednica 1. Osnovni podatki o kronologijah širin branik in habitusih dreves za vrste Picea abies, Abies alba *in* Fagus sylvatica*.*

Species / Vrsta	Tree number / Število dreves	Tree-ring width chronology / Kronologija širin branik									Tree habitus / Habitus drevesa				
		MSL / MSL	AGR / AGR	SD / SD	Rbar / Rbar	EPS / EPS	AC1 / AC1	Start / Začetek	End / Konec	Length / Dolžina	TD / TD	SS / SS	SF / SF	Dis / Dis	Fr / Fr
Picea	17	108	1.92	0.67	0.44	0.84	0.70	1890	2017	128	40.3	44.7	–	1	17
Abies	17	147	1.63	0.94	0.24	0.83	0.83	1831	2017	187	17.3	–	11	12	16
Fagus	17	80	2.61	1.09	0.33	0.87	0.76	1849	2017	169	18.2	–	0	2	11

MSL, mean segment length; AGR, average growth rate (mm); SD, standard deviation; Rbar, inter-series correlation; EPS, expressed population signal (minimum EPS in the studied period); AC1, first autocorrelation; TD, total defoliation (%); SS, secondary shoots (%); SF, stem foliation (no. of trees); Dis, Discoloration (no. of trees); Fr, Fruiting (no. of trees with beech masts / spruce and fir cones).

MSL, srednja dolžina segmenta; AGR, povprečna stopnja rasti (mm); SD, standardni odklon; Rbar, medsektorska korelacija; EPS, izražen populacijski signal (minimalni EPS v proučevanem obdobju); AC1, avtokorelacija prve stopnje; TD, skupna defoliacija (%); SS, sekundarni poganjki (%); SF, olistanost (št. dreves); Dis, diskoloracija (št. dreves); Fr, semenenje (št. dreves z bukovim žirom / smrekovimi in jelovimi storži).

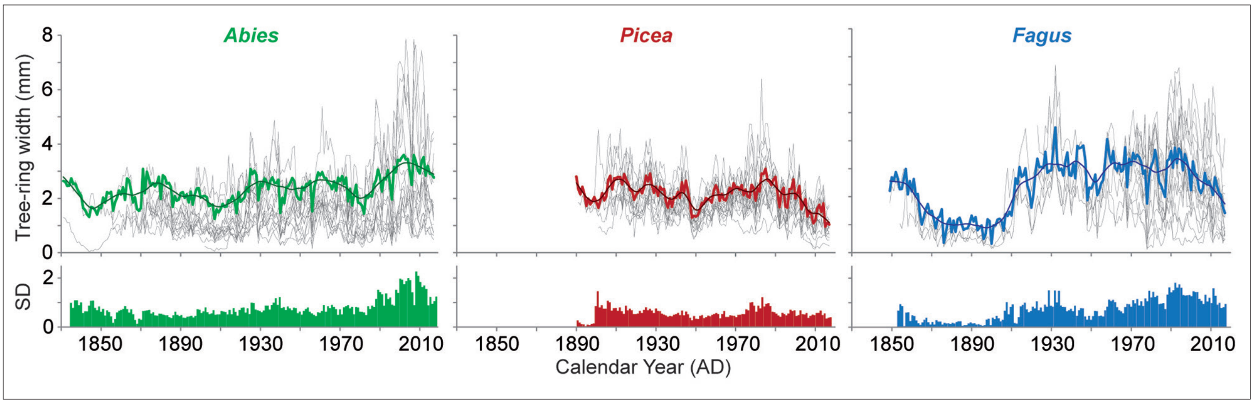

Figure 3. Tree-ring width chronologies (up) and standard deviation (down) of Abies alba*,* Picea abies *and* Fagus sylvatica *smoothed by the LOWESS (Locally Weighted Scatterplot Smoothing) curves. Individual TRW measurements are in grey.*

Slika 3. Kronologije širin branik (zgoraj) in standardni odklon (spodaj) za vrste Abies alba*,* Picea abies *in* Fagus sylvatica*, zglajene po metodi LOWESS. Posamezna zaporedja širin branik so prikazana v sivi barvi (zgoraj).*

3.2 ANALYSIS OF GROWTH TRENDS
3.2 ANALIZA RASTNIH TRENDOV

Growth trends of the standardized TRWi chronologies as evaluated by linear regression in the three delineated periods showed a wide variation of growth among species (Fig. 4). In the first period, beech and fir growth significantly declined, whereas spruce growth was stable. This period was characterized by a relatively stable climate (Fig. 2), but ended in the extremely cold and harsh winter of 1978/1979. An intensive cold front hit the Czech lands on 31 December 1978 and 1 January 1979. The meteorological stations recorded a sudden drop in temperature (approximately 25 °C in 24 h) from approximately +10 °C at the New Year's Eve night of 1978/1979 (Rein & Štekl, 1981). Beech and fir radial growth is very sensitive to climate changes and especially very cold winters (Koprowski, 2013; Šimůnek et al., 2019), which are more pronounced at higher altitudes. Short-term growth disturbances and growth depressions at the end of the 1970s were observed in tree ring series of beech trees growing on higher altitude sites in Central Europe, leading to the assumption that increased tropospheric ozone concentrations are involved in the process of changed beech sensitivity and resistance (Dittmar et al., 2003).

Additionally, air pollution could play an important role in the growth decline of silver fir because of its high vulnerability to emissions, as was recorded at the Czech–Polish–German border (Łuszczyńska et al., 2018), where extensive forest dieback occurred and hardly any fir stands in this region have been preserved until today. The SO_2 and NO_x emissions increased strongly after approximately 1950 (Smil, 1990), and peaked at the beginning of the 1980s (Kopáček & Veselý, 2005). Although our study site is quite far from the main foci of air pollution in the Black Triangle (Grübler, 2002), the whole territory of Czechoslovakia was markedly influenced and a significant effect on fir was also observed in Southern Germany (Elling et al., 2009). Therefore, air pollution together with the harsh winter of 1978/1979 most likely caused the substantial growth trend decline of silver fir, which is more susceptible to air pollution and sudden winter frosts than Norway spruce (Mikulenka et al., 2020).

From the early 1980s, radial growth of beech and fir suddenly started to improve (Fig. 4) together with growth variability among TRW series (Fig. 3) as a consequence of the previous apparent growth depression. Rapid growth recovery was probably caused by a complex of several factors, such as release after the harsh winter accompanied by a gradual temperature increase (Štěpánek et al., 2016), as well as pollution control, especially in the case of pollution-sensitive fir. Given that common growth variability can be interpreted as a similar response to climatic conditions, similarities among TRW series should increase under harsh climatic conditions when the same response of all trees is expected. Therefore, this sudden growth release and more favourable conditions (also evident from moving correlations getting near to zero; Figs. 5B and 5C) led to the high common inter-series growth variability of fir and beech. On the other hand, spruce growth, not impacted by the previous reduction, was slightly decreasing in this delineated period, which could be caused by the warming climate, in particular during the current growing season (see climate-growth relationship). Additionally, the still slightly decreasing spruce growth variability suggests that the warmer and drier climate has become more and more limiting to its growth.

At the beginning of the 21st century, the unprecedented growth improvement of conifers at higher elevations, mainly silver fir, was related to global warming (e.g. Büntgen et al., 2014; Bošeľa et al., 2018). However, all three species at the site in the Gratzen Mountains revealed statistically significant decreases (Fig. 4) despite, or likely due to, the continuing temperature increase. Although precipitation totals also increased slightly and available water in the soil moisture demonstrated no trend, evapotranspiration, owing to higher temperatures, showed a substantial increase (Fig. 2). Additionally, the period since 2000 is characterized by severe summer heat waves and drought spells, particularly in 2003 (Luterbacher et al., 2004) and 2015 (Ionita et al., 2017), with significant impacts on silviculture, agriculture, and viniculture (e.g. Možný et al., 2016; Brázdil et al., 2015; Štěpánek et al., 2016). Such phenomena can lead to the severe tree growth reduction of fir (Bošeľa et al., 2018), beech (Kolář et al., 2016), and especially spruce (Čermák et al., 2019), which is characterized by high transpiration demands and a shallow root system already threatened by short droughts. The drying of the upper soil could be intensified by a decreasing stand density (sanitary felling). These may also be the reasons why Norway spruce TRWi already decreased in the 1981–2000 period.

3.3 GROWTH–CLIMATE RELATIONSHIP
3.3 ZVEZA MED RASTJO IN KLIMO

The results of growth trends were reflected in the moving correlation coefficients between species-specific TRWi chronologies and climate parameters that have not been stable over time (Fig. 5). The radial growth of Norway spruce had been significantly negatively affected by evapotranspiration during the previous April–August, but the influence disappeared in the last twenty years. By contrast, an increasing positive effect of soil moisture content (to significant values) and precipitation together with a sharply increasing negative effect of temperature during current April–August emerged at the end of the study period (Fig. 5A). Water deficits during the growing season lead to the reduction of stomatal conductance, carbon uptake and tree growth (Lévesque et al., 2013). These relationships

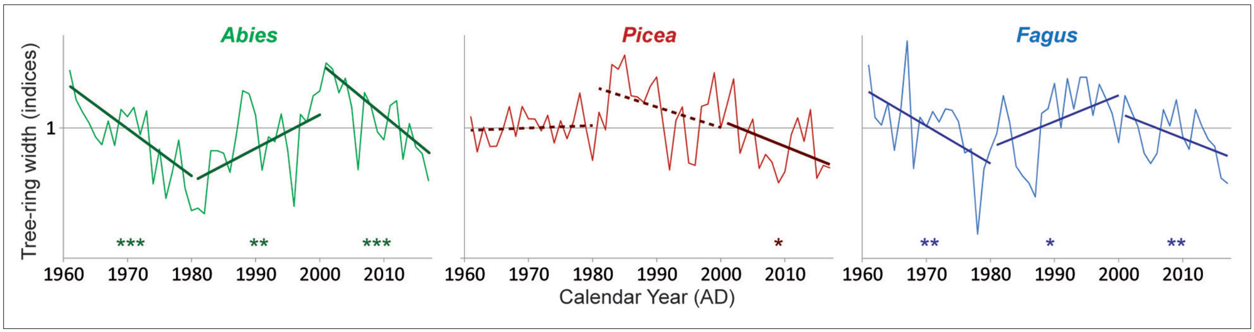

*Figure 4. Standardized TRW chronologies for the period (1961–2017) with linear regression fitted to standardized data in three intervals (1961–1980, 1981–2000 and 2001–present). Full lines show a significant regression trend, dashed lines non-significant trends. Stars indicate the significance level of regression at: *** - < 0.01, ** - < 0.05, and * - < 0.1.*

*Slika 4. Standardizirane kronologije širin branik za obdobje (1961–2017) z linearno regresijo, prilagojeno standardiziranim podatkom v treh intervalih (1961–1980, 1981–2000 in 2001-danes). Polne črte kažejo statistično značilen regresijski trend, črtkane črte pa neznačilnega. Zvezdice kažejo stopnjo statistične značilnosti regresije pri: *** - <0,01, ** - <0,05 in * - <0,1.*

indicate increasingly unfavourable climate conditions for Norway spruce growth, as previously reported for many areas of Central Europe, including its southern regions (e.g. Hartl-Meier et al., 2014; Lévesque et al., 2016; Kolář et al., 2017; Martinez del Castillo et al., 2018; Čermák et al., 2019).

All climate parameters of the previous growing season seem to be less important for silver fir growth than the winter dormant period and current growing season (Fig. 5B). While the significance of negative correlations with the current April–August precipitation totals and positive correlations with April–August evapotranspiration disappeared, the September–March temperature started to be statistically significant with values exceeding 0.6 (Fig. 5B). The strong positive impact of winter temperature has confirmed the high sensitivity of fir to extreme winter frosts (van der Maaten-Theunissen et al., 2013) as well as late winter/early spring temperature (Koprowski, 2013). The effect of late winter temperature is related to the relatively high temperature which is needed to start the photosynthetic activity (Guehl, 1985).

The results of beech growth-climate relationship showed a generally negative impact of drought during the previous growing season, which was recorded not only in Central Europe (e.g. Scharnweber et al. 2011) but mainly in the southern regions of the Mediterranean (e.g. Čufar et al., 2008; Tegel et al., 2014; Martinez del Castillo et al., 2018). By contrast, the dormant season temperature had a positive impact on TRW (Fig. 5) which is related to late frost sensitivity of European beech (e.g. Menzel et al., 2015; Kolář et al., 2016). The current growing season soil moisture content and precipitation totals reduced while tem-

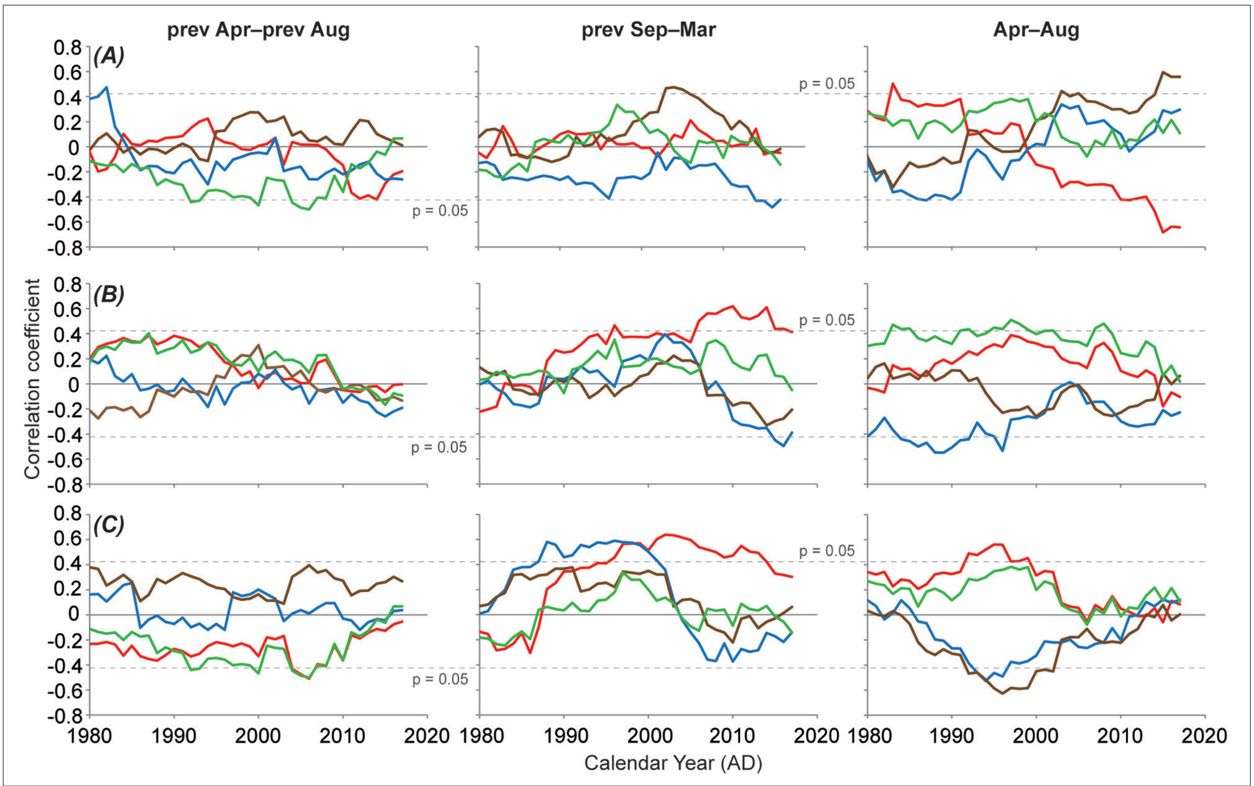

Figure 5. Twenty-year moving backward Pearson's correlation coefficients between residual TRW index chronologies of Norway spruce (A), silver fir (B) and European beech (C) and mean temperature (red), precipitation (blue), soil moisture content (brown) and evapotranspiration (green) for the previous growing season (left column), dormant season (middle column) and current growing season (right column).

Slika 5. Dvajsetletni Pearsonovi drseči korelacijski koeficienti med residualnimi kronologijami indeksov širin branik smreke (A), jelke (B) in bukve (C) ter povprečne temperature (rdeča), vsote padavin (modra), vsebnosti vlage v tleh (rjava) in evapotranspiracija (zelena) za predhodno rastno sezono (levi stolpec), obdobje mirovanja (srednji stolpec) in tekočo rastno sezono (desni stolpec).

perature enhanced beech radial growth (above all during the 1990s; Fig. 4, 5C), as already found for other areas, e.g. in the Western Carpathians and Southern Alps (Bošeľa et al., 2018). However, the correlation coefficients with all climate parameters in the current growing season have fallen near to zero since 2000.

The changes in fir and beech growth-climate relationships described above, especially for the current growing season, are probably connected to the growth decline after 2000 (Fig. 4). It seems that both species have stopped benefiting from the increasing temperature, which most likely initiated radial growth increases in the 1990s (Büntgen et al., 2014). It is assumed that the climatic extremes such as tropical days or a decreasing number of wet days during spring and summer (Štěpánek et al., 2016; Beranová & Kyselý, 2017) started to limit radial growth and disturb the relationships between monthly climate parameters and TRW.

4 CONCLUSIONS
4 ZAKLJUČKI

Our study showed that even if Norway spruce, silver fir and European beech grow in a mixed forest stand under the same conditions, each species displays different growth patterns and climate responses. While spruce has responded negatively to the recent warmer and drier climate, fir and beech have been proved to be more tolerant to drought and actually benefited from a temperature increase, especially during winter, due to the lower danger of extreme frosts. These patterns were reflected in growth trends as well as the visual assessment of the crown. Whereas fir and beech most likely profited from the significant rise in temperature of 1981–2000, spruce already exhibited a decreasing growth trend in that period. Although the growth trends of all species have significantly decreased since 2000, suggesting that more frequent climatic extremes limit the radial growth of all species, spruce seems to be the most vulnerable under such conditions, even in a mixed forest at quite a high elevation of 850 m a.s.l. This was also proved by the high total defoliation and the number of secondary shoots. Therefore, the projected scenarios of climate change, including recurrent climate extremes, should mainly be the cause of serious concern with regard to the spruce.

5 SUMMARY
5 POVZETEK

Evropski gozdni ekosistemi doživljajo pomembne spremembe zaradi trenutnih podnebnih sprememb, ko prej razširjene monokulture postopoma nadomeščajo mešani gozdovi. Razumevanje rasti dreves v mešanih gozdovih v spreminjajočem se podnebju je svojevrsten izziv zaradi prilagoditve drevesnih vrst in dolgoročnega gospodarjenja z gozdovi. V tej raziskavi smo proučili dolgoročno obnašanje navadne smreke (*Picea abies*), bele jelke (*Abies alba*) in navadne bukve (*Fagus sylvatica*) iz nizkega montanskega pasu v pogorju Novohradské hory na češko-avstrijski meji. Vzorce lesa za dendrokronološke raziskave smo pridobili iz odraslih dreves s pomočjo prirastoslovnega svedra. Sledila je priprava vzorcev, merjenje širin branik, sinhroniziranje, sestavljanje kronologij širin branik in analiza zveze med rastjo in klimo vzorcev rastnega in podnebnega odziva, pri čemer smo uporabili standardne dendrokronološke metode. Analize širin branik smreke, jelke in bukve, ki rastejo na 850 m n. m. v., so najprej omogočile sestavo treh kronologij širin branik, dolgih 128, 187 in 169 let, pri čemer je vsaka odražala prirastne značilnosti posamezne vrste. Raziskave so pokazale, da čeprav smreka, jelka in bukev rastejo v mešanem gozdu v enakih razmerah, vsaka vrsta kaže drugačen vzorec rasti in različen odziv na klimo. Medtem ko se je rast smreke negativno odzvala na nedavno toplejše in bolj suho podnebje, se je za jelko in bukev izkazalo, da bolje prenašata sušo in naraščanje temperatur, kar ima zlasti pozimi pozitiven vpliv predvsem zaradi manjše nevarnosti hudih zmrzali. Omenjeni vzorci so se odražali tudi v rastnih trendih in vizualnih ocenah krošenj. Medtem ko sta se jelka in bukev pozitivno odzvali na dvig temperatur v obdobju 1981–2000, je smreka že v tem obdobju kazala trend upada širin branik. Čeprav se trendi rasti vseh vrst znatno zmanjšujejo od leta 2000, kar kaže na to, da pogostejše vremenske skrajnosti omejujejo radialno rast vseh treh drevesnih vrst, se zdi, da je smreka v razmerah podnebnih sprememb najbolj ranljiva tudi v mešanem gozdu na precej visoki nadmorski višini 850 m. Slednje se je odražalo tudi v propadanju krošnje, ki ga spremlja izguba iglic in sekundarnih poganjkov. Glede na predstavljene ugotovitve bi morali biti napovedani scenariji podnebnih sprememb, vključno s ponavljajočimi se vremenskimi skrajnostmi, vzrok za resne skrbi predvsem za uspevanje in preživetje smreke.

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DENDROKRONOLOŠKE RAZISKAVE POSLIKANIH KMEČKIH SKRINJ IZ ZBIRKE GORENJSKEGA MUZEJA V KRANJU

DENDROCHRONOLOGICAL STUDY OF PAINTED CHESTS FROM THE COLLECTION OF THE GORENJSKA MUSEUM IN KRANJ

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Izvleček / Abstract

Izvleček: *Poslikane kmečke skrinje so pomemben del zbirk muzejskih predmetov ljudske umetnosti alpskega prostora. V Gorenjskem muzeju Kranj smo pregledali nad 30 in dendrokronološko raziskali 18 skrinj iz lesa iglavcev, pretežno navadne smreke (*Picea abies*). Na odsekih radialnih desk pokrovov in stranic skrinj smo posneli visoko ločljive fotografije za merjenje širin branik. Na osnovi dveh ali več zaporedij širin branik smo sestavili kronologijo za posamezno skrinjo ter uspešno datirali 9 skrinj (8 smrekovih in 1 jelovo) z datumi zadnje branike od 1742 do 1882. Raziskavo skrinje iz lesa jelke (*Abies alba*) smo podrobneje predstavili. Dendrokronološki datumi so praviloma za nekaj let odstopali od domnevnega leta izdelave posamezne skrinje. Med razlogi, da datiranje preostale polovice skrinj ni uspelo, je majhno število branik, velika variabilnost dendrokronološkega signala smreke v Sloveniji in pomanjkanje mreže ustreznih referenčnih kronologij. Rezultati kažejo, da lahko dendrokronologijo uporabimo za ugotavljanje starosti in pridobivanje informacij o skrinjah, ki jih ne moremo dobiti iz drugih virov.*

Ključne besede: *dendrokronologija, poslikano pohištvo, skrinje, navadna smreka=*Picea abies*, alpski prostor, ljudska umetnost, muzej, kulturna dediščina*

Abstract: *Painted chests are an important part of museum collections of folk art in the Alpine region. At the Gorenjska Museum in Kranj, we examined over 30 chests mostly made of Norway spruce (*Picea abies*) and selected 18 of them for dendrochronological analysis. We took high resolution images of the radial boards of the constructional parts of the chests for tree-ring analyses. We constructed tree-ring chronologies for each of the 18 chests. Nine of them were dendrochronologically dated (eight spruce chests and one silver fir) with the end dates ranging from 1742 to 1882. The study of the chest made of silver fir (*Abies alba*) is presented in detail. Half of the chests could not be dated, mainly due to the low number of tree-rings or large variability of tree-ring signal of spruce in Slovenia and consequently lack of adequate reference chronologies. The results show that dendrochronology can be used to determine age and obtain information about chests that cannot be obtained from other sources.*

Keywords: *dendrochronology, painted furniture, chests, Norway spruce (*Picea abies*), Alpine area, folk art, museum, cultural heritage*

1 UVOD
1 INTRODUCTION

Poslikano kmečko pohištvo predstavlja pomemben del zbirk muzejskih predmetov. Poslikava skrinj, zibelk, omar in drugega pohištva je bila značilna ljudska umetnost alpskega prostora, kamor sodi tudi severozahodna Slovenija z Gorenjsko, kjer je poslikava pohištva doživela vrhunec v 19. stoletju. Poslikano pohištvo odlikuje preprostost, funkcionalnost in uporaba lokalnih materialov (Dolžan Eržen et al., 2013). Omenjeno pohištvo je bilo tipično za kmečke domove. V drugi polovici 20. stoletja je zaradi spremembe načina življenja in miselnosti izgubilo pomen, zato so bili pri prenovi in posodabljanju domov zavrženi številni dragoceni predmeti. Pri njihovem ohranjanju so muzeji odigrali pomembno vlogo, saj so prepoznali pomen »kmečke dediščine« in jo sistematično reševali pred uničenjem. V Sloveniji največje zbirke kmečkega pohištva hranita Etnografski muzej v Ljubljani in Gorenjski muzej. V slednjem so med

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eksponati poslikanega pohištva najbolj številne poslikane skrinje.

Skrinje so preživele dolga obdobja razmeroma dobro ohranjene, drugi podatki o njih pa so skopi ali se sploh niso ohranili. V grobem vemo, kaj so v njih hranili in kako so jih uporabljali, manj pa vemo, kdo jih je naredil ter kdo jih je uporabljal. Skrinje so bile na mnogih domačijah skoraj edino hrambno pohištvo. V njih so shranjevali skoraj vse: obleko, prejo, blago, suho sadje, stročnice, žito in druga živila ter krmo za živali. Na skrinjah so sedeli, ležali in spali, uprabljali so jih tudi kot potovalne kovčke. O izvoru skrinj vemo malo tudi zato, ker predstavljajo »premično blago«. Izdelali so jih domači ali potujoči mojstri in so se pogosto selile z lastniki. Pri umeščanju v čas in kraj si pomagamo s proučevanjem posebnosti z vidika konstrukcij in poslikav (Dolžan Eržen et al., 2013).

Največ poslikanih skrinj je izdelanih iz lesa iglavcev. V splošnem predstavljajo zaboj na podstavkih s pokrovom. Pokrovi skrinj so navadno s kovinskimi tečaji pritrjeni na zunanjo stran hrbta skrinje in na notranjo stran pokrova. Skrinje imajo večinoma ključavnice in se zaklepajo s ključi. Notranjost skrinj je običajno z desko predeljena v večji prostor in manjši (okrog pol metra dolg) predal, ki je pokrit s pokrovom. Skrinje imajo lahko tudi več predalov, police in dvojno dno, v katerem je prostorček za shranjevanje dragocenosti.

Poleg funkcionalnosti je bil pri skrinjah pomemben tudi lep videz, ki so ga dosegli s poslikavo. Z vidika poslikave je bila najlepše okrašena prednja stran, stranici občasno, pokrov pa redko. Prednja stranica je bila izdelana iz plošče (praviloma iz dveh topo spojenih desk), ki so ji bile pogosto dodane deščice ali letvice in včasih izrezljani stebrički, pri čemer so nastala ločena polja za poslikavo. Za gorenjske skrinje je v splošnem značilna okrašena prednja stranica, členjena v tri, pet ali sedem različno oblikovanih polj kot na fasadi hiš (Dolžan Eržen et al. 2013). Motivi poslikav so cvetlični, razni simboli in ornamenti, redkeje figure svetnikov. Poslikavanje kmečkega pohištva je povezano s poslikanimi stropi podružničnih cerkvic, ki so se na Gorenjskem ohranili iz časa od 16. do 18. stoletja in so pogosto okrašeni v tehnikah in z motivi, ki jih najdemo tudi na skrinjah.

Skrinje v slovenskih muzejih po nam znanih podatkih doslej še niso bile raziskane z vidika lesa in dendrokronologije. Dendrokronologija kot znanost o branikah v lesu, temelji na postopku datiranja oz. ugotavljanja, v katerem koledarskem letu je nastala posamezna branika (Kaennel & Schweingruber, 1995). Branika je po definiciji prirastna plast lesa, ki je nastala v enem letu in jo lahko vidimo v prečnem ali radialnem prerezu, meje med branikami pa imenujemo letnice (Torelli, 1990). Dendrokronološka raziskava najpogosteje temelji na merjenju širin branik in jo uporabljamo za datiranje lesa oz. lesenih predmetov in je še posebej pomembna takrat, ko ne poznamo starosti in nimamo drugih podatkov o predmetu (Čufar, 2007; Haneca et al., 2009). Dendrokronologijo pri tem uporabimo za razbiranje informacij, zabeleženih v lesu, ki jih prevedemo v jezik drugih strok (Eckstein, 2007).

Za datiranje lesenih predmetov je pomembno, iz katerega lesa so narejeni in koliko branik vsebujejo, zato je prvi korak raziskave identifikacija lesa in ocena števila branik. Za datiranje potrebujemo ustrezne referenčne kronologije za preiskovano lesno vrsto, območje in obdobje. Na Oddelku za lesarstvo Biotehniške fakultete Univerze v Ljubljani se že več kot 20 let ukvarjajo s sestavljanjem referenčnih kronologij za različne potrebe v Sloveniji. Za različna obdobja, območja in predmete so ključne drevesne vrste hrast, jelka, macesen in smreka, kronologije teh vrst pa nenehno dopolnjujejo (Čufar & Levanič, 1998; Levanič et al., 2001; Čufar, 2010; Čufar et al., 2008, 2015). Dendrokronologijo zato tudi pri nas uspešno uporabljamo za ugotavljanje starosti in proučevanja informacij v lesu iz prazgodovine, npr. koliščarskih naselbin (Čufar & Velušček, 2012; Čufar et al., 2015), rimske dobe (Čufar et al., 2019) ter zgodovinskih objektov, kot so na primer lesene konstrukcije stavb (Čufar et al., 2014), leseni stropi (Čufar & Lozar Štamcar, 2004) in glasbeni inštrumenti (Čufar et al., 2010, 2018). Pri glasbenih inštrumentih je dendrokronologija postala nepogrešljiva za ugotavljanje starosti, originalnosti, geografskega porekla in izdelovalcev glasbenih inštrumentov.

Dendrokronologija je primerna tudi za datiranje pohištva, vendar so se le redke raziskave ukvarjale s kmečkim pohištvom, kot na primer v Avstriji (Klein et al., 2014), v Sloveniji pa po naših podatkih takih raziskav še ni bilo.

Cilj te študije je bil pregledati poslikane skrinje v muzejski zbirki, izbrati primerne za dendrokronološke raziskave ter proučiti, ali lahko dendrokronologijo uporabimo za ugotavljanje starosti, izvora in originalnosti skrinj. Poleg tega smo želeli ovrednotiti potencial dendrokronologije za raziskavo skrinj in podobnih predmetov iz muzejskih zbirk, da bi pridobili čim več informacij, zabeleženih v lesu, in predstavili, kako jih lahko uporabimo na področju drugih strok.

2 MATERIAL IN METODE
2 MATERIALS AND METHODS

V letu 2019 smo pregledali nad 30 skrinj iz zbirke Gorenjskega muzeja, ki so razstavljene v Mestni hiši v Kranju. Muzejska dokumentacija vsebuje tudi podatek, kje so bile skrinje pridobljene; večinoma izvirajo iz okolice Kranja in Zgornjesavske doline (slika 1, preglednica 1). Za natančen pregled smo izbrali 19 skrinj iz lesa iglavcev, določili lesno vrsto in nato podrobneje pregledali 18 skrinj.

Pregledali smo pokrove, stranice, notranje predale in dna skrinj z vidika orientiranosti desk ter števila branik. Za analize smo izbrali 18 skrinj, ki so bile izdelane iz pretežno radialnih desk (slika 7) s čim večjim številom branik. V naslednjem koraku smo določili mesta za dendrokronološke analize, kjer so bile branike najbolj vidne in so domnevno vsebovale les zunanjega dela debla. Nato smo izbrana mesta označili in opremili z merilom ter jih pripravili za fotografiranje (slika 2). Posnetke radialnih površin lesa visoke ločljivosti smo uporabili za merjenje širin branik.

Slika 1. Območje Gorenjske, od koder izvirajo raziskane skrinje in lokalne različice poslikanih skrinj in pohištva ter zemljevid Slovenije, kjer piki nakazujeta Domžale na jugovzhodu in Rateče na severozahodu območja ob tromeji z Italijo in Avstrijo (risba iz Dolžan Eržen et al., 2013).

Figure 1. The map of Gorenjska region - the origin of the investigated chests, and local variants of painted chests and furniture. On the small map of Slovenia (left), the dots indicate Domžale in the southeast and Rateče in the northwest of the area, near the border with Italy and Austria (drawing from Dolžan Eržen et al., 2013).

Slika 2. Delo v muzeju: (A) pregled skrinje in označevanje dela deske pokrova za merjenje širin branik ter (B) fotografiranje.
Figure 2. Work in the museum: (A) inspection of the chest and marking of the part of the board for measuring tree-ring width, and (B) photographing a chest.

Delo smo nadaljevali v laboratoriju na Oddelku za lesarstvo, kjer smo posnetke uredili in po potrebi obdelali. Nato smo s pomočjo programa CooRecorder na izbranih mestih izmerili širine branik in v programu CDendro shranili zaporedja širin branik (grafe širin branik v odvisnosti od časa). Na večini skrinj smo meritve lahko opravili na več mestih, ki so vključevala različne deske. Dobljena zaporedja širin branik smo medsebojno sinhronizirali in za vsako skrinjo izračunali povprečje oz. kronologijo širin branik. Sledila je primerjava kronologije posamezne skrinje z razpoložljivimi referenčnimi kronologijami smreke in jelke ter nato datiranje, podprto s statističnimi kazalniki, kot so: Gleichläufigkeit - koeficient skladnosti (istosmernosti) GLK(%), t-vrednost Baillie Pilcher TVBP, t-vrednost Hollstein TVH in prekrivanje OVL. Datiranje je potrjeno (statistično značilno), če so vrednosti kazalnikov GLK > 65 % in TVBP ali TVH ≥ 4.

3 REZULTATI
3 RESULTS

Od 19 raziskanih skrinj jih je bilo 17 narejenih iz lesa smreke (*Picea abies*), po ena pa je bila iz lesa jelke (*Abies alba* Mill.) in bora - najverjetneje rdečega bora (*Pinus sylvestris*) (preglednica 1). V nadaljevanju najprej predstavljamo raziskavo skrinje iz lesa jelke, nato rezultate raziskav skrinj iz lesa smreke. Skrinje iz lesa bora (E4320=SK19) pa nismo dendrokronološko raziskali, ker za to lesno vrsto v Sloveniji nimamo ustreznih referenčnih kronologij za datiranje.

3.1 SKRINJA IZ LESA JELKE Z NASLIKANO LETNICO 1793
3.1 CHEST MADE OF SILVER FIR WOOD WITH THE YEAR 1793 PAINTED ON IT

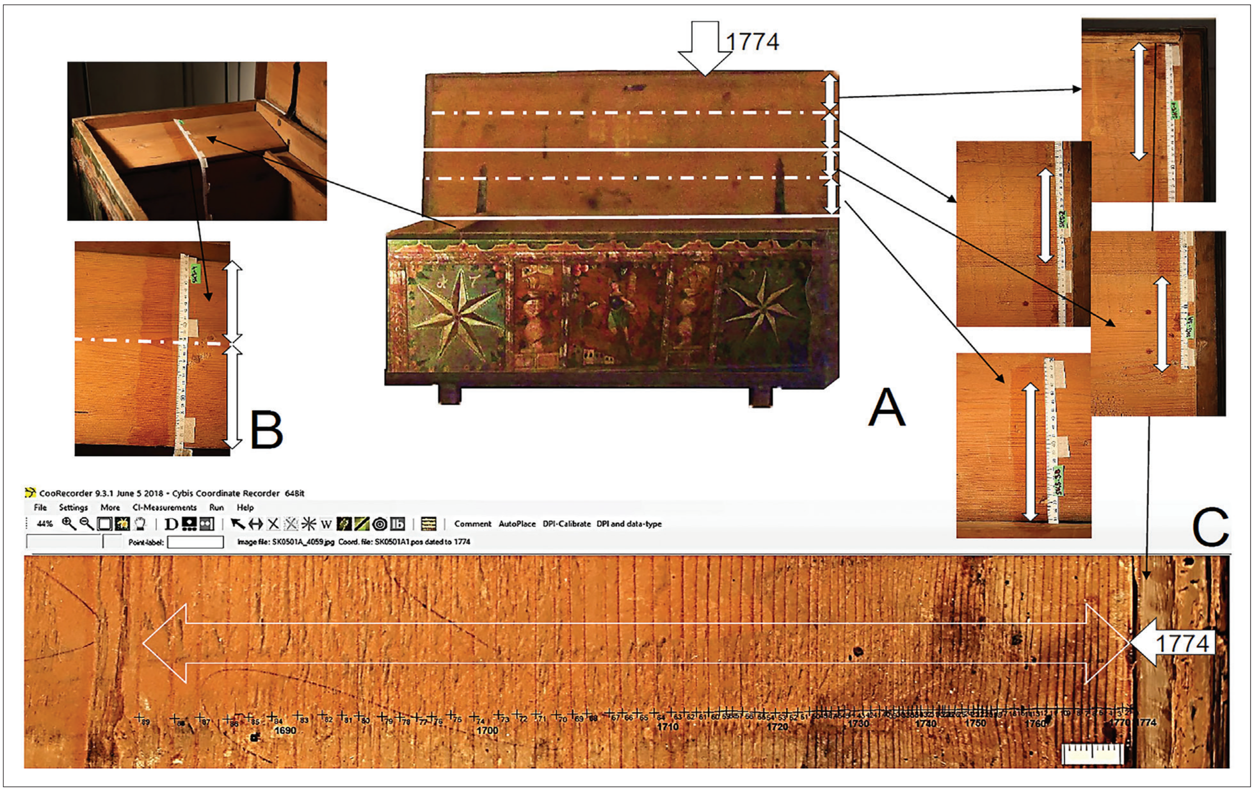
Skrinja z inventarno številko Gorenjskega muzeja E1118, in dendrokronološko šifro SK05 (preglednica 1), je v knjigi Dolžan Erženove (2013) predstavljena kot skrinja z letnico 1793, ki je zelo kakovostno in samosvoje poslikana (slika 3). Skrinja je po navedbi istega vira izdelek Layerjeve delavnice iz časa vodenja Marka Layerja. Bila je restavrirana, kraj pridobitve skrinje je Srednja vas pri Šenčurju.

Skrinja ima dimenzije: dolžina 154 cm, širina 67 cm in višina 64 cm. Za izdelavo prednje in zadnje strani, stranic, dna in pokrova so uporabili po dve topo spojeni deski. Za izdelavo skrinje so uporabili tudi številne deščice in podstavke (slika 3). Ocenjena neto količina lesa v skrinji je približno 0,2 m^3.

Za merjenje širin branik sta bili primerni dve jelovi deski pokrova, ki sta imeli dovolj branik za merjenje levo in desno od sredine drevesa (slika 4). Izmerili smo tudi širine branik na pokrovu notranjega predala.

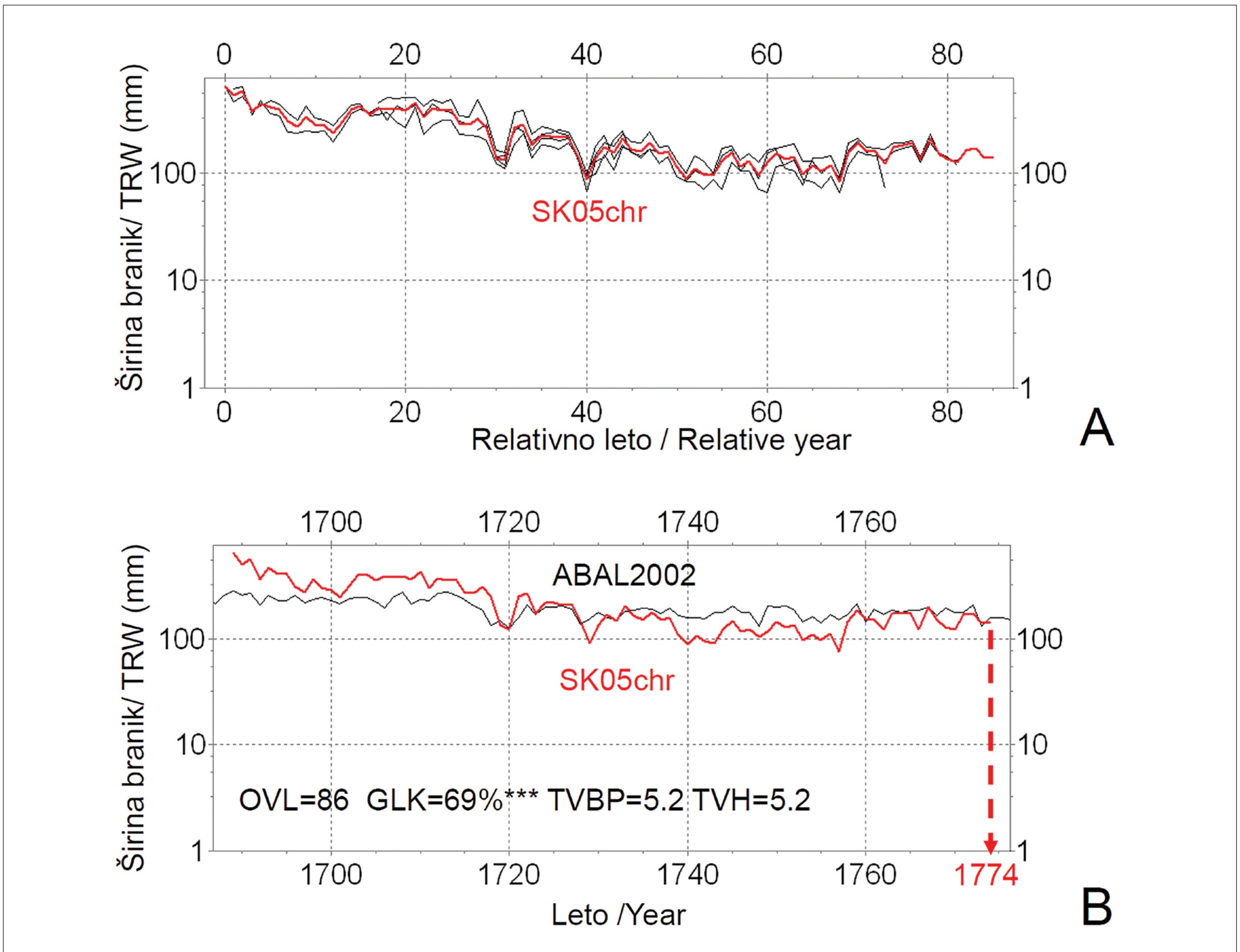
Meritve smo opravili na 2 deskah pokrova in na pokrovu predala v skrinji in pridobili 6 zaporedij širin branik. Zaporedja širin branik pokrova skrinje smo uspešno sinhronizirali in sestavili kronologijo, dolgo 86 let – SK05chr (slika 5). Zaporedji širin branik pokrova predala nismo mogli vključiti v kronologijo, ker se dendrokronološko nista ujemali z zaporedji širin branik pokrova.

Slika 3. Skrinja z letnico 1793, s poslikano prednjo stranjo, členjeno v pet polj z različnimi motivi: na sredini je figura sv. Florjana, ob straneh se v ožjih poljih nahajata baročno ovita stebra, v širših stranskih poljih pa vetrovnica in letnica 17-93. Večja tri polja so zgoraj okrašena s kepastimi cvetovi, skrinja je od pokrova navzdol baročno ornamentirana. Na obeh bočnih stranicah sta v okroglih poljih naslikana obraza.
Figure 3. The chest with the year 1793 painted on the front, divided into five fields with different motifs: in the middle is the figure of St. Florian with the baroque columns in the narrower fields, whereas the wider lateral fields contain a windmill and the year 1793. The larger three boxes are decorated with spiky flowers on the upper part, and the chest has baroque ornamentation from the lid downwards. On both sides, faces are painted in round fields.



Slika 4. Skrinja E 1118 = SK05: (A) mesta merjenja širin branik na pokrovu skrinje, ki je sestavljen iz dveh desk, na katerih smo izmerili širine branik vzdolž dveh radijev in (B) na zgornjem delu predala. (C) Slika za merjenje širin branik na pokrovu skrinje z mestom branike, nastale v letu 1774, ki je ključna za datiranje.
Figure 4. Chest E 1118 = SK05: (A) locations of tree-ring width measurements on the chest cover consisting of two boards with two radii and (B) the cover of the drawer. (C) Image of the chest cover in the Coo Recorder showing the ring formed in 1774, which is crucial for dating.

Kronologijo skrinje (SK05chr) smo datirali z regionalno kronologijo jelke iz Slovenije ABAL2002 (slika 5). Leto nastanka zadnje (najmlajše) izmerjene branike na skrinji je 1774. Kazalniki ujemanja kronologije skrinje (SK05chr) in referenčne kronologije ABAL2002 so visoki in statistično značilni: prekrivanje OVL=86 let, Gleichläufigkeit -koeficient ujemanja GLK=69 %***, t-vrednost Baillie Pilcher TVBP=5,2 in t-vrednost Hollstein TVH=5,2. Datacijo smo preverili in potrdili tudi s kronologijami jelke različnih objektov kulturne dediščine iz Slovenije (npr. Čufar & Lozar Štamcar, 2004; Čufar & Zupančič, 2009) in z regionalno jelovo kronologijo laboratorija Hohenheim iz Nemčije, ki temelji na lesu jelke iz več držav Evrope (Becker & Giertz-Siebenlist, 1970).



Slika 5. Skrinja E 1118 = SK05: (A) zaporedja širin branik, izmerjena na različnih delih skrinje (črne krivulje) in povprečje oz. kronologija skrinje (rdeča krivulja SK05chr), po sinhroniziranju v relativnem času, (B) kronologija skrinje po datiranju s pomočjo referenčne kronologije ABAL2002 (črna krivulja). Leto nastanka zadnje (najmlajše) izmerjene branike na skrinji je 1774 s kazalniki datiranja: prekrivanje OVL, koeficient skladnosti GLK(%), t-vrednost TVBP in TVH; (C) merjeni del pokrova in mesto branike, nastale v letu 1774.
Figure 5. Chest E 1118 = SK05: (A) tree-ring width (TRW) series measured on different parts of the chest (black curves) and average - the chronology of the chest (red curve SK05chr), after cross-dating in relative time, (B) the chronology of the chest after dating with the reference chronology ABAL2002 (black curve). The end date, i.e. year of the last (youngest) measured tree-ring on the chest, is 1774 within the statistical parameters of the dating. (C) The measured part of the lid and the outermost tree-ring formed in 1774. The cross-dating parameters are: OVL overlap, Gleichläufigkeit - GLK coefficient of coincidence (%), t-value after Baillie Pilcher TVBP and t-value Hollstein TVH.

Dobro dendrokronološko ujemanje s kronologijami jelke je v tem primeru pripomoglo k potrditvi lesne vrste, saj pri popolnoma nedestruktivnem pregledu lesa brez vidnih prečnih prerezov (kjer lahko opazujemo smolne kanale), lesne vrste na posameznih delih skrinj na terenu nismo mogli natančno identificirati. Pokrov predala v skrinji je iz lesa smreke (*Picea abies*), kar smo potrdili na osnovi smolnega žepa (slika 7), ki je poleg drugih makroskopskih znakov (neobarvane jedrovine in postopnega prehoda iz ranega v kasni les) potrdil, da gre za les smreke, ki ga nismo mogli datirati z jelovimi kronologijami. Lesa pokrova žal nismo mogli datirati niti z razpoložljivimi kronologijami smreke.

Ugotovljeno leto zadnje branike 1774 (sliki 4 in 5) se ne ujema popolnoma z letnico, naslikano na sprednji stranici skrinje, ki je 1793 (slika 3). Neujemanje letnic je lahko posledica obdelave lesa za pokrov. Če bi bil les posekan 1793, bi leto zadnje zunanje branike 1774 lahko pomenilo, da so pri izdelavi pokrova odstranili 19 branik, kar bi predstavljalo približno 2,5 cm lesa iz zunanjega dela debla. Potrebno je upoštevati tudi čas sušenja in hrambe lesa, med posekom in nadaljnjo obdelavo, ki je lahko od nekaj mesecev do nekaj let.

3.2 RAZISKAVE SKRINJ IZ LESA SMREKE
3.2 INVESTIGATIONS OF CHESTS MADE OF NORWAY SPRUCE WOOD

Za raziskavo preostalih 17 skrinj iz lesa smreke (*Picea abies*) (slika 6), smo na vsaki (na 2–4 mestih) izmerili širine branik in sestavili kronologijo. Kronologijo vsake skrinje smo nato skušali datirati s kronologijami jelke, vendar to v nobenem primeru ni bilo uspešno. Nato smo vsako kronologijo skrinje primerjali z več kot 20 referenčnimi kronologijami smreke iz različnih rastišč in datiranih objektov v Sloveniji. Za primerjavo smo uporabili še kronologije smreke iz Avstrije, Nemčije in Italije, ki jih med drugim uporabljamo tudi pri datiranju violin (Bernabei et al., 2017; Čufar et al., 2010, 2017, 2018).

*Preglednica 1. Rezultati raziskav skrinj iz lesa smreke (*Picea abies*), jelke (*Abies alba*) in bora (*Pinus sylvestris*). Dendro datum – dendrokronološko ugotovljeni datum zadnje (najmlajše) branike na skrinji, Δt – razlika med letnico na skrinji in dendrokronološkim datumom.*

*Table 1. Results of analyses of chests made of Norway spruce (*Picea abies*), silver fir (*Abies alba*), and Scots pine (*Pinus sylvestris*). Dendro date - the dendrochronologically obtained end date, i.e. the year of formation of the last tree-ring, Δt - the difference between the year on the chest and the dendrochronological date.*

Šifra	Kraj izvora	Naslikana letnica	Število branik	Dendro datum	Δt	Lesna vrsta
Code	*Place of Origin*	*Painted Year*	*Tree Ring No.*	*Dendro Date*	*Δt*	*Wood Species*
SK01 E 4303	Cerklje	1881	78	1882	-1	*Picea abies*
SK02 E 1487	Šmartno pri Cerkljah	1835	76	1832	3	*Picea abies*
SK03 E 1055	Šenčur	1832	57	1836	-4	*Picea abies*
SK04 E 1137	Voklo	1862	70			*Picea abies*
SK05 E 1118	Srednja vas pri Šenčurju	1793	86	1774	19	*Abies alba*
SK06 E 1054	Gameljne	1836	72			*Picea abies*
SK07 E 2565	Kranj	1819	72			*Picea abies*
SK08 E 4324	Podbrezje		51			*Picea abies*
SK09 E 4309	Olševek	1838	66			*Picea abies*
SK10 E 1136	Okolica Kranja	1860	67	1847	13	*Picea abies*
SK11 E 1056	Kranjska Gora	1839	47			*Picea abies*
SK12 E 1122	Ravne v Bohinju	1793	127	1785	8	*Picea abies*
SK13 E 1124	Rodine	1716	55			*Picea abies*
SK14 E 1126	Dovje	1748	55	1742	6	*Picea abies*
SK15 E 1128	Rateče	1788	52	1788		*Picea abies*
SK16 E 5922	Bohinjska Bistrica	1776	71			*Picea abies*
SK17 E 8289 (F8890)	Gornjesavska dolina	1841	93	1838	3	*Picea abies*
SK18 E 8541	Podkoren	1888	76			*Picea abies*
SK19 E 4320	Prebačevo	1874				*Pinus sylvestris*

*Slika 6. Skrinje iz lesa smreke (*Picea abies*) SK01 do SK18, jelke (*Abies alba*) SK05 in bora (*Pinus sylvestris*) SK19. Šifre SK* smo skrinjam dodelili v dendrokronološkem laboratoriju, šifre E* pa so evidenčne številke Gorenjskega muzeja (prim. preglednica 1).*

*Figure 6. Chests made of Norway spruce (*Picea abies*) wood SK01 - SK18, silver fir (Abies alba) SK05, and Scots pine (*Pinus sylvestris*) SK19. SK* are the codes of the dendrochronological laboratory, and the E * are the codes of the Gorenjska Museum (cf. Table 1).*

Število branik pri skrinjah je bilo od 47 do 127, od tega je 8 kronologij skrinj imelo manj kot 70 branik (preglednica 1), kar je z vidika dendrokronologije neugodno. Število je bilo še dodatno zmanjšano, ker so bile skrinje večinoma narejene iz radialno tangencialnih desk (slika 7) in za merjenje niso bile primerne vse branike na deski. Prečni prerezi, ki so najbolj primerni za merjenje širin branik, pa niso bili vidni. Kljub temu smo uspešno datirali 8 skrinj iz lesa smreke, ugotovljeni so bili datumi zadnje branike v razponu od 1742 do 1882 (preglednica 1). Datiranje smo opravili z različnimi kronologijami smreke iz različnih rastišč in objektov predvsem z območja Gorenjske s kazalniki TVBP ≥ 4, GLK > 65 % in z dobrim vizualnim ujemanjem kronologij. Pri skrinjah SK02, SK03 in SK10 iz okolice Kranja in naslikanimi letnicami 1835, 1832 in 1860 (slika 6, preglednica 1), smo ugotovili tudi medsebojno podobnost kronologij skrinj, s čemer smo datiranje lahko dodatno potrdili. Ostale kronologije niso izkazovale podobnosti, saj je variabilnost rasti smreke iz različnih rastišč Gorenjske zelo pogosta, raziskava pa je tudi vključevala skrinje iz različnih obdobij.

Izračun vrednosti Δt (razlike med domnevnim letom izdelave skrinje in dendrokronološkim datumom zadnje branike) kaže, da se je v enem primeru letnica, napisana na skrinji, ujemala z dendrokronološko datacijo, v enem je bila razlika 1 leto, pri petih skrinjah pa je bila dendrokronološka datacija za 3-13 let pred letom, napisanim na skrinjah. Slednje predstavlja razpon, ki ga redno opažamo pri številnih izdelkih, tudi violinah in je posledica časa, potrebnega za sušenje lesa, ter »izguba« branik iz zunanjega dela debla zaradi obdelave lesa (Čufar et al., 2017, 2018). Ta rezultat se ujema tudi z opažanji raziskave v Avstriji, kjer so ugotovili, da je les za kmečko pohištvo vseboval branike iz zunanjega dela debla. To nakazuje, da je bil les skrbno uporabljen, pri čemer so skušali material čim bolje izkoristiti in ga čim manj odstraniti zaradi obdelave (Klein et al., 2014). Pri eni skrinji je bil nastanek zadnje branike eno, pri eni pa 4 leta kasnejši kot letnica, napisana na skrinji.

4 RAZPRAVA IN SKLEPI
4 DISCUSSION AND CONCLUSIONS

Dendrokronologijo so za raziskave lesenih predmetov kulturne dediščine najprej uvedli za določanje starosti, vendar poleg datacije običajno nudi veliko dodatnih informacij o uporabljeni lesni vrsti, izvoru in rabi lesa. To se je potrdilo tudi pri raziskavi poslikanih skrinj.

Dendrokronološka raziskava se začne z identifikacijo lesa**.** Pri pregledu skrinj smo se morali omejiti na makroskopske znake v lesu, ki jih vidimo predvsem na radialni in tangencialni površini, ker prečni prerezi navadno niso bili vidni. Večina skrinj je bila narejenih iz lesa smreke, ena iz lesa jelke in ena iz lesa bora. Smreka in jelka sta vrsti brez obarvane jedrovine z razločnimi branikami ter postopnim prehodom iz ranega v kasni les: smreka ima aksialne in radialne smolne kanale, jelka pa jih nima. Identifikacijo lesa smo dodatno podprli z uporabo dendrokronologije, kjer smo na primer les jelke potrdili z zelo dobrim ujemanjem s kronologijami jelke, smreke pa z njimi nismo mogli datirati.

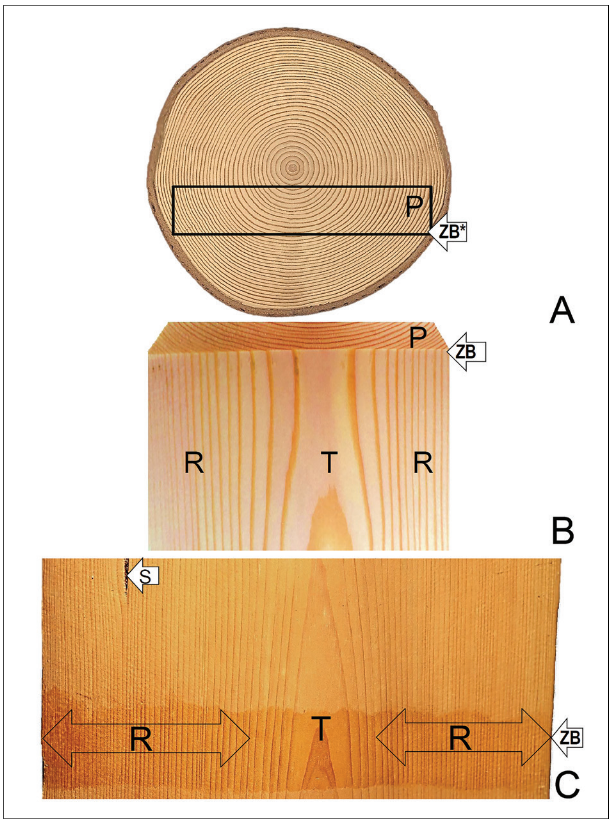
Les smreke in jelke ima tudi podobne lastnosti, zato ju pogosto uporabljajo za istovrstne izdelke. Pogosto celo v istem izdelku uporabijo les obeh vrst. Slednje smo opazili pri skrinji SK05, ki je imela stranice in pokrov iz lesa jelke, pokrov notranjega predala pa iz lesa smreke. Uporabo lesa jelke ali smreke včasih posredno nakazuje tudi starost in izvor lesa. Do sredine 19. stoletja je bila v večjem delu Slovenije uporaba jelovine bolj pogosta kot uporaba smrekovine (npr. Čufar et al., 2013, 2014). Raba smrekovine je bila vezana predvsem na območje Alp oz. naraven areal razširjenosti smreke (Brus, 2012). Smrekovino so v 19. stoletju na območju Slovenije začeli pospešeno razširjati tudi na rastišča izven njenega naravnega areala in na rastišča na nižjih nadmorskih višinah (Brus, 2012). Glede na posebnosti lesa preiskanih skrinj sklepamo, da je les za večino skrinj najverjetneje izviral iz rastišč na nižjih nadmorskih višinah, kjer smreke dobro priraščajo. Posledično so bile branike dokaj široke (večinoma 2-3 mm), njihovo število pa je bilo relativno majhno.

Pri skrinji, izdelani iz lesa bora, moramo poudariti, da uporaba lesa rdečega bora pri nas ni pogosta, je pa zelo razširjena na severu Evrope (npr. v baltskih in skandinavskih področjih), kjer borovino uporabljajo za širok nabor izdelkov, podobno kot mi uporabljamo smrekovino.

Dendrokronološka datacija je na leto natančna, a ima poleg prednosti tudi omejitve. Pove namreč leto nastanka posamezne branike in ne leta izdelave predmeta. V kolikor leseni predmet vsebuje zadnjo braniko pod skorjo in to braniko datiramo, ugotovimo, kdaj je bilo drevo, iz katerega izvira les, še živo oz. kdaj je bilo posekano (Haneca et al., 2009). Ker večina skrinj ne vsebuje skorje, moramo leto najmlajše branike na predmetu obravnavati kot *terminus post quem*, to je mejnik oz. leto, po katerem je bila skrinja narejena. Za oceno starosti bi morali vedeti, koliko časa je preteklo med posekom drevesa in izdelavo predmeta. Razliko med letom izdelave in letom nastanka najmlajše branike označuje interval »Δt« (Bernabei & Čufar, 2018; Čufar et al., 2018). Izračun Δt je smiseln, če se lahko zanesemo na podatek o starosti, ki ga predstavlja letnica, naslikana na skrinji. Δt pove, koliko let je preteklo od poseka drevesa do uporabe lesa in tudi kako dolgo so les sušili ter koliko branik je bilo odstranjenih zaradi obdelave lesa. Slednje vključuje tudi obžagovanje, skobljanje oz. odstranjevanje lesa za pridobitev ravnih površin za lepljenje in spajanje plošč. Na interval Δt vpliva tudi čas sušenja lesa, ki je bil po naši oceni na primeru iglavcev najmanj eno leto.

Pri skrinjah smo zabeležili en primer, ko dendrokronološki datum kaže na leto po domnevni izdelavi predmeta. Tudi za to je več možnih vzrokov, ki so znani iz raziskav violin. Pri violinah dendrokronološka datacija pogosto pokaže, da je bil les posekan po domnevnem letu izdelave ali celo po smrti domnevnega mojstra. To navadno nakazuje, da je inštrument ponaredek, nalepka v inštrumentu s podatki o letu izdelave in mojstru pa je ponarejena (Čufar et al., 2010). Tudi pri lesenih stavbah se vrezana letnica na objektu pogosto ne ujema z dendrokronološko datacijo, kar je pogosto posledica popravil in menjav lesenih delov, ali pa vrezana letnica enostavno ne sporoča leta, ko je bil izdelek narejen (Čufar & Strgar, 2011). V primeru skrinj bi bilo verjetno, da letnica ne sporoča leta, ko je bil izdelek narejen. Skrinje so zanesljivo tudi popravljali in predelovali, pri čemer je bilo najlažje zamenjati pokrov, ki je bil v večini raziskanih skrinj najprimernejši in najbolj dostopen element za dendrokronološke raziskave.

Za merjenje širin branik je najprimernejši prečni prerez, uporaben pa je tudi radialni prerez. Na radialno tangencialnih deskah, ki prevladujejo v skrinjah, je za merjenje uporaben samo radialno orientirani del deske (slika 7). Pri izdelavi plošč za stranice, dno in pokrov so navadno spojili po dve deski, od tega je vsaj ena na vsaj enem mestu veči-



Slika 7. Les smreke ali jelke, brez barvnih razlik med beljavo in jedrovino: (A) prečni prerez (P) z nakazano lego tangencialno radialne deske (okvir), (B) tangencialno radialna deska z vidnim prečnim prerezom in (C) tangencialno radialna deska kot jo vidimo na skrinji, kjer je les v sredini usmerjen tangencialno (T), proti robovom pa radialno (R), mesti označeni s puščico sta uporabni za merjenje širin branik. ZB - mesto zadnje branike, ZB - zadnja branika pod skorjo, S – smolni žep.*

Figure 7. Wood of Norway spruce or silver fir without coloured heartwood: (A) cross-section (P) with the indicated position (frame) of the tangential - radial board, (B) tangential - radial board with visible cross section, and (C) tangential - radial board as seen on the chest, with the tangentially (T) oriented part in the centre and radially (R) oriented one towards the edges (arrows) which are useful for tree ring measurement. ZB - outermost ring, ZB - waney edge, and S - resin pocket.*

noma segala skoraj do skorje. Les so uporabili tako, da so dosegli čim večjo dimenzijsko stabilnost, oz. čim manjše krčenje in nabrekanje lesa zaradi sprememb vlažnosti, preprečiti so morali tudi zvijanje lesa. Take lastnosti so dosegli tako, da so uporabili čim bolj radialno usmerjen les in se izognili lesu v notranjem delu debla (ob strženu), zato so deske v skrinjah večinoma radialno tangencialne (slika 7).

Les smreke predstavlja izziv za datiranje, saj je dendrokronološki signal smreke v Sloveniji močno odvisen od mikrolokacije, posebno od nadmorske višine rastišč (Ferlin, 1991; Levanič et al., 1995). Posledično potrebujemo več kronologij za datiranje. V tem se smreka razlikuje od jelke, kjer les običajno lahko datiramo s pomočjo ene same regionalne kronologije iz Slovenije, datum pa pogosto lahko preverimo in potrdimo tudi z evropsko kronologijo jelke iz laboratorija Hohenheim (Becker & Giertz-Siebenlist, 1970). Uspeh datiranja smreke je zato večji, če imamo ustrezno mrežo referenčnih kronologij. Za zgodovinske predmete morajo kronologije pokrivati obdobje, iz katerega izhaja predmet, zato jih sestavimo iz lesa oz. kronologij dreves in različnih zgodovinskih predmetov (Čufar et al., 2008). Kronologije so zato plod interdisciplinarnih raziskav, kamor je vključenih več strok, kot v primeru te študije. Izzive za dendrokronološko datiranje predstavlja tudi majhno število branik in orientacija lesa, saj je samo del desk za skrinje radialno orientiran in uporaben za učinkovito merjenje širin branik.

V ugodnem primeru je tudi mogoče ugotoviti izvor lesa (kar smo že nakazali) in mojstra, ki je predmet naredil, saj ima les iz istega območja (in časa) podoben dendrokronološki signal, mojstri pa so pogosto predelovali les iz določenega območja. Les enega debla je bil predelan v več izdelkov, za skrinje pa so uporabili les iz enega ali dveh debel.

Predstavljene raziskave so pokazale, da je dendrokronološka analiza skrinj mogoča. V našem primeru je bila v približno polovici primerov tudi uspešna, računamo pa, da bomo nekatere skrinje lahko datirali, ko bomo izboljšali referenčne kronologije za raziskano območje. Rezultati nakazujejo, da bi dendrokronološka analiza lahko bila v pomoč pri ugotavljanju izvora skrinj in mojstra, ki jih je izdelal. Predvsem pri podrobneje predstavljeni skrinji iz lesa jelke smo tudi pokazali, da dendrokronološka analiza predstavlja dodatni vir podatkov o predmetu (skrinji) in da bi bila posebej pomembna tam, kjer prave starosti in izvora skrinje ne poznamo. Hkrati je ugotavljanje starosti pomembno tudi pri skrinjah, ki imajo napisane letnice, a dendrokronološka datacija ne potrjuje, da predstavljajo leto domnevne izdelave predmeta. Neujemanje datumov nas lahko pripelje do povsem novih spoznanj o predmetu, ki bi jih praviloma lahko pojasnili le z dodatnimi obširnejšimi raziskavami.

5 POVZETEK

5 SUMMARY

Painted furniture is an important part of the museum collections of Alpine folk art. The Gorenjska Museum keeps a collection of chests, cradles, cupboards and wardrobes, bed frames with head and foot boards, the housings of clocks, and interior doors. Painted chests in the collection of furniture predominate, with over 120 items (Dolžan Eržen et al., 2013). Most of them originate from Gorenjska, more precisely from the region along the upper course of the Sava river, extending from the outskirts of Ljubljana to the border between Slovenia, Austria and Italy, bounded by the Julian and Karavanke Alps (Figure 1). The art of painting rural furniture in Gorenjska was most popular from the beginning of the 17th till the late 19th centuries, with the peak in the first two-thirds of the 19th. The painted chests have been intensively studied, although mainly from the ethnological and art-historical point of view (Dolžan Eržen et al., 2013).

The objective of this study was to investigate the wood of the chests by means of dendrochronology to obtain the dating and additional information on these valuable objects.

We inspected more than 30 chests exhibited in the Gorenjska Museum in Kranj. They originated from various locations in Gorenjska (Figure 1, Table 1). We selected 19 chests made of softwoods with mostly radially oriented panels and a larger number of tree-rings for further investigation. In the next step we inspected the orientation, number and visibility of tree-rings on the covers (lids) and front or side panels of the chests, and performed macroscopic wood identification. As one of the chests was made of Scots pine (*Pinus sylvestris*), only 18 were used for dendrochronology.

As the construction of the chests did not allow us to observe the cross-sections of the panels

(which are covered with wooden ledges), tree-rings were only accessible for ring width measurements on radial sections of the boards. In every chest we identified two to six optimal locations for tree-ring width measurement, and took high-resolution images showing tree-rings from the centre (near the pith) to the periphery of the selected boards. Tree-ring width measurements were performed on different radii and boards of every chest and were used to construct a chronology of the object. These chronologies were then cross-dated with the available reference chronologies of Norway spruce and silver fir from Slovenia and checked with the ones from the neighbouring countries obtained from ITRDB (International Tree Ring Data Base) or by exchange with tree-ring laboratories of the University of Natural Resources and Life Sciences, Institute of Wood Technology and Renewable Materials, Vienna, Austria (Dr. Michael Grabner) and at the National Research Council of Italy, Trees and Timber Institute, Trento, Italy (Dr. Mauro Bernabei).

Tree-ring width measurements were performed on images with the help of the CooRecorder and CDendro, whereas the cross-dating was performed with the TSAP Win program in accordance with standard procedures.

Seventeen chests were made of Norway spruce (*Picea abies*) and one of silver fir (*Abies alba*). For each of them we obtained two to six tree-ring series (of different radii and boards), and chronologies of the chests spanning 47 to 127 years were constructed. The chronologies were then cross-dated with the available reference chronologies of Norway spruce and silver fir from Slovenia and other countries. Half of the chronologies were successfully dated with the obtained end dates between 1742 and 1882. The dendrochronological end dates slightly deviated from the presumable years of the production indicated by the painted year on the chests or estimated by the museum based on other historical sources.

The investigation of the chest made of silver is presented in detail. This is an interestingly painted chest with the year 1793 painted on it (Figure 3), while the dendrochronologically defined end date was 1774 (Figure 4, 5). Although the bottom, walls and the lid were made of silver fir, the lid of the inner drawer was made of spruce.

Half of the chests made of Norway spruce and the one made of pine could not be dated by means of dendrochronology. The obstacles for successful dating were the small number of tree-rings, radial-tangential orientation of the boards, which additionally reduced the number of tree-rings suitable for ring width measurement (Figure 7), and great likelihood that the object contained wood of only one tree. Dendrochronological dating is better if the chronology (to be dated) is based on several trees (e.g., samples originating from seven to 15 trees are recommended when investigating constructions) and if the number of tree-rings is large (e.g., over 100 tree-rings). In Slovenia, wide tree-rings are usual for Norway spruce from the lowlands where the tree-ring signal is also greatly affected by local factors hampering dendrochronological cross-dating (Bernabei et al., 2017). The large variability of the dendrochronological signal of the spruce in Slovenia is probably the main reason that we would need a dense network of local chronologies of spruce covering all potential sources of wood origin.

Nevertheless, this study shows that dendrochronology can be successfully used for investigation of chests and that it could serve as a source of independent information about chests, especially when their age and origin are unknown. The findings of this study also apply for the use of dendrochronology to investigate other objects in museum collections.

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EFFICIENCY EVALUATION OF NEEM (*AZADIRACHTA INDICA*) OIL AND COPPER-ETHANOLAMINE IN THE PROTECTION OF WOOD AGAINST A SUBTERRANEAN TERMITE ATTACK

OCENA UČINKOVITOSTI NIMOVEGA OLJA (*AZADIRACHTA INDICA*) TER BAKER-ETANOLAMINSKIH PRIPRAVKOV PRI ZAŠČITI LESA PRED NAPADOM PODZEMNEGA TERMITA

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Abstract / Izvleček

Abstract: *The demand for environmentally safe preservatives for wood is increasing all around the world. This study is focused on the evaluation of the ability of Neem (*Azadirachta indica*) seed oil and copper-ethanolamine to protect Sydney blue gum (*Eucalyptus saligna*) and Ayous (*Triplochiton scleroxylon*) against termites. Wood blocks were impregnated with solutions of Neem oil in acetone and/or an aqueous solution of copper-ethanolamine. Impregnated woods with a retention rate of up to 108.3 kg/m^3 were obtained. A leaching experiment was used to determine the fixation of preservatives in wood. The termicidial effect of the preservatives was studied through exposure in a termitarium. Neem oil was less efficient for Sydney blue gum but showed significant protection for Ayous at a higher retention rate. At the concentration investigated, the treatment of both wood species with copper-ethanolamine solution was not suitable. However, a combination of copper-ethanolamine and Neem oil showed an improvement in the protection of Sydney blue gum wood. Nevertheless, the impregnated woods still suffered an increased termite attack after leaching.*

Keywords: *Neem oil, copper, ethanolamine, wood, preservation, leaching, termite*

Izvleček: *Povpraševanje po za okolje varnih zaščitnih sredstvih za les narašča po vsem svetu. Ta študija je osredotočena na oceno sposobnosti olja semen nima (*Azadirachta indica*) in baker-etanolaminskega pripravka za zaščito lesa evkalipta (*Eucalyptus saligna*) in sambe (*Triplochiton scleroxylon*) pred termiti. Lesene preizkušance smo impregnirali z raztopinami nimovega olja v acetonu in / ali baker-etanolaminski vodni raztopini. Količina navzema v impregniranem lesu je znašala 108,3 kg/m^3. Vezavo zaščitnih sredstev v les smo določili z izpiranjem. Termiticidni učinek zaščitnih sredstev je bil raziskan z izpostavitvijo v termitariju. Nimovo olje je bilo manj učinkovito za zaščito lesa* Evkaliptus saligna*, pomembno zaščitno učinkovitost pa je pokazalo za les* Triplochiton scleroxylon *pri višjem navzemu. Pri uporabljeni koncentraciji baker etanolaminskega pripravka za zaščito obeh preučevanih lesnih vrst ni bila zadostna. Vendar je kombinacija baker-etanolaminskega pripravka in nimovega olja pokazala pomembno izboljšanje zaščite lesa evkalipta. Kljub temu je bil impregnirani les po izpiranju zopet bolj dovzeten za napad termitov.*

Ključne besede: *nimovo olje, baker, etanolamin, les, zaščita, izpiranje, termiti*

1 INTRODUCTION

1 UVOD

Inorganic as well as organic-based preservative formulations have long been used to protect wood against fungi, termites, and bacteria. The efficacy of copper compounds to control the growth of a wide range of microorganisms has been successfully exploited, and copper-based products formulated with the addition of other metal compounds such as chromium to help in the fixation of copper in wood, and arsenate or boron to extend bioactivity to copper-resistant agents of biodegradation (Freeman & Mcintyre, 2008; Hingston et al., 2001). Organic-based formulations containing creosote,

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pentachlorophenol or naphtenates were once also widely used for preservation of wood. However, these products are now subjected to increasing restrictions or even banned in many countries around the world due to their potential health hazards and adverse environmental effects (the liberation of toxic carcinogen metals such as chromium and arsenate, emissions of organic non-biodegradable pollutant as creosote) (Hingston et al., 2001; McMahon & Chen, 2001; Tobia et al., 1994). To address these issues, copper alternatives with reduced environmental impact have been developed using nitrogen-based organic mediators such as azole or ethanolamine to facilitate the fixation of copper in wood and thus prevent leaching (Freeman & Mcintyre, 2008; Humar et al., 2006; Thaler et al., 2013; Zhang & Kamdem, 2000). Owing to the increasing demand for more and more environmentally friendly, sustainable alternative products all over the world, natural organic products such as plant-extracts from wood or barks, vegetable oils, and essential oils have been investigated as alternative solutions (Adedeji et al., 2018, Dev & Nautiyal, 2004; Gilmara et al., 2013; González et al., 2015; Hyvönen et al., 2005; Muktarul et al., 2009, Saheb & Mouhouche, 2016; Singh & Singh, 2012; Syofuna et al., 2012). Fatima and Morell (2015) studied the ability of various plant oils (Neem, Eucalyptus, jatropha and linseed oils) to inhibit damp wood termite (*Zootermopsis angusticollis*) growth, and concluded that most of these affect protozoa in the hindgut of termite workers and that protozoa loss was closely followed by termite mortality.

Neem (*Azadirachta indica*) is a tree species of the Meliaceae family growing in the tropical and semi-tropical regions of the world (Girish et al., 2008). This species originated from the Indian subcontinent but is now widespread in Africa and Australia, being classified as an invasive species in the latter. One special feature of this tree is that almost all its parts (leaves, fruits, seed, bark) exhibit bioactivity against insects and fungi (Pankaj et al., 2011) and are used for medicinal applications (Subipriya & Nagini, 2005). About 195 insect species have been found to show high sensitivity to Neem extracts, including insects that have become resistant to synthetic pesticides (Menn, 1990). Applications of Neem extracts for wood preservation are thus under investigation. For example, the bioactivity of extractives from Neem leaves was tested against wood destroying fungi and termites by Dhyani et al. (2004), Machado et al. (2013) and Venmalar and Nagaveni (2005). Moreover, Subbaraman and Brucker (2001) examined formulations containing Azadirachtin extracted from Neem tree with a lignin or tannin compound added as a binding agent and usable as wood preservatives against termites.

This work reports the ability of Neem oil, copper-ethanolamine or a combination of both in the protection of wood against termites. For this purpose, two wood species from Cameroon were tested: Sydney blue gum (*Eucalyptus saligna*) and Ayous (*Triplochiton scleroxylon)*. Sydney blue gum was the main targeted wood because of its use for electricity poles for the distribution of power in Cameroon and neighbouring countries. Untreated wooden poles are rapidly eaten by termites, leading to a short service life (5-10 years). Previous research (Adebawo et al., 2015; Fatima & Morell, 2015; Himmi et al., 2013; Machado et al., 2013; Sotannde et al., 2011; Syofuna et al., 2012) on the application of Neem oil as a wood preservative against termites were performed at lower retention rates and showed the ability of the oil to cause the mortality of termites, although with an undesirable weight loss of wood. In this work, the impregnation parameters were set to attain a higher oil retention rate.

2 MATERIALS AND METHODS
2 MATERIALI IN METODE
2.1 MATERIALS
2.1 MATERIALI

Blue gum wood was collected from a local timber market in Bamenda in the North-West region of Cameroon while Ayous was obtained in a local timber market in Yaounde in the Central region. Sydney blue gum (*Eucalyptus saligna)* is an exotic wood species mainly cultivated in the high mountains of West and North-West Cameroon, while Ayous (*Triplochiton scleroxylon*) comes from the natural forests located in the Center, South and East regions. Heartwood was used for both species. Neem oil was extracted from Neem seeds by a cold mechanical process. The copper chloride, ethanolamine and acetone were reagent grade and used without further purification.

2.2 WOOD SPECIMENS
2.2 VZORCI LESA

Wood blocks with the dimensions of (6 x 2 x 2) cm^3 were cut from each wood species and dried in the laboratory till constant mass was obtained (after about one month). The moisture content of the wood was determined by drying some dedicated samples in an oven at 103 °C till constant mass was achieved. The moisture content was 11.9(±0.3)% and 11.1(±0.6)% for Sydney blue gum and Ayous, respectively.

2.3 IMPREGNATION OF WOOD WITH PRESERVATIVE SOLUTIONS
2.3 IMPREGNACIJA LESA Z RAZTOPINAMI ZAŠČITNIH SREDSTEV

Homogeneous preservative solutions were prepared and used for impregnation of wood blocks under reduced pressure. Neem oil was diluted with acetone. The mass ratio of Neem oil (NO)/acetone of different solutions was 10:90 (NO 10%), 30:70 (NO 30%), 50:50 (NO 50%) and 70:30 (NO 70%). Copper-ethanolamine solution (Cu-EA) was prepared using distilled water as a solvent. The mass concentrations of copper and ethanolamine in the solution were 0.5% copper chloride and 1.4% ethanolamine. A combining treatment was carried out by impregnation of wood with Cu-EA, drying the wood for 24h, and finally a second impregnation with NO 50%. Xylamon® (Syl), a commercial product still sold in Cameroon for wood protection, was used as a reference. Xylamon is a mixture of permethrin or cypermethrin, tebuconazole and benzalkonium chloride according to the former certification CTP-P+ 2002 of CTBA (today FCBA) (CTBA, 2002). Impregnation process was carried out under reduced pressure in a 5 L round bottom flask. Care was taken to keep all wood blocks completely immersed in the impregnation solution. Twelve wood blocks were used for each impregnation, and the impregnation was performed for 30 min using a tap water pressure reduction system. Afterwards, any excess solution on the surface of the impregnated wood samples was mopped up and the mass of the sample determined. The retention rate (%) was calculated using Equation 1 (Sen et al., 2009):

$$\mathrm{R}(\%) = \frac{(m_1 - m_0) \times \mathrm{C}}{\mathrm{V}} x10\ (kg/m^3) \qquad (1)$$

Where (m_1-m_o) is the amount of impregnation solution retained by the wood in g, C the mass concentration of the solution in (%) and V the volume of wood block in cm^3. m_1 and m_0 are the wood masses after and before impregnation, respectively.

The impregnated wood blocks were air dried in the laboratory till constant mass was obtained (after two weeks).

2.4 LABORATORY LEACHING EXPERIMENTS
2.4 LABORATORIJSKI POSKUSI IZPIRANJA

The impregnated wood blocks were divided into two groups: the first consisted of six blocks that were used for the leaching experiment, while the second six blocks were kept as the non-leached samples. The leaching experiment was performed according to the standard NF X41-565 with a slight modification. Wood blocks were introduced in glass containers with 5 to 10 times their equivalent volume in distilled water. The glass containers were placed on a mixing mechanical table (Edmund Bühler GmbH SM-30) and kept under agitation for four cycles of leaching (1h, 2h, 4h and 8 h). The leaching water was changed after each time period. The leached wood blocks were air dried till constant mass was achieved (after two weeks) and then weighed. The percentage weight loss (PWLL) due to leaching was determined by Equation 2:

$$PWLL = \frac{m_1 - m_2}{m_1 - m_0} x100 \qquad (2)$$

Where m_1 and m_0 are the formal masses of wood after and before impregnation respectively, and m_2 the mass of wood after leaching.

2.5 ACTIVITY OF TERMITES – FIELD TESTS
2.5 DEJAVNOST TERMITOV – TERENSKI POSKUS

Termites are highly destructive wood agents in many tropical regions, particularly in sub-Saharan Africa. The efficiency of preservative products against a subterranean termite was assessed by a field test. Non-impregnated, impregnated and leached wood samples were placed in a termitarum located on the university campus. Wood samples were covered with a black polyethylene sheet to be in the dark. The test was performed for 16 weeks (see Figure 1).

Figure 1. Wood blocks in a termitarium (Isoptera: Termitidae)
Slika 1. Leseni preskušanci v termitarju (Isoptera: Termitidae)

After the defined time, wood (or residual wood) was collected, cleaned and dried in an oven for 72h at 103 °C. Percentage weight losses (PWLT) due to termite attack were determined according to the equation 3.

$$PWLT(\%) = \frac{m_0 - m_3}{m_0} x100 \quad (3)$$

m_0 and m_3 are the masses of the wood block before and after exposure to termites.

3 RESULTS AND DISCUSSION
3 REZULTATI IN RAZPRAVA

3.1 RETENTION RATE
3.1 NAVZEM

The retention rates of the different solutions are presented in Figure 2. The retention rate gives the amount of active preservative substance introduced in a wood block. As expected, Ayous showed a greater retention capacity than Sydney blue gum. This difference in behaviour is attributed to the difference in density, as the Sydney blue gum and Ayous apparent densities were 0.79(±0.06) g/cm^3 and 0.36(±0.04) g/cm^3, respectively. Blue gum is thus less porous, and it is more difficult for the solution to ingress towards the depths of the wood. The results showed that rising concentration of Neem oil in the Neem oil-acetone mixtures significantly increased the retention rate even though the solutions were slightly more viscous at higher Neem oil concentrations. Retention of Neem oil varied from 11.0 kg/m^3 to up to 108.3 kg/m^3 under the conditions investigated, and these results are consistent with those in the literature (Can & Sivrikaya, 2016; Naveri et al., 2017). It is well recognized that retention depends on the concentration of active substances in the solution, as well as other parameters such as impregnation process and time. An increase in the concentration of preservative generally increases the retention (Naveri et al., 2017). Can and Sivrikaya (2016) reported that, for impregnation of wood with tall-oil in similar experimental conditions, the retention rate followed the same order. A combination of copper-ethanolamine and NO 50% showed a retention rate (67.0 kg/m^3 for Sydney blue gum and 90.7% for Ayous) closer to that of the solution NO 50% (69.5 kg/m^3 for Sydney blue gum and

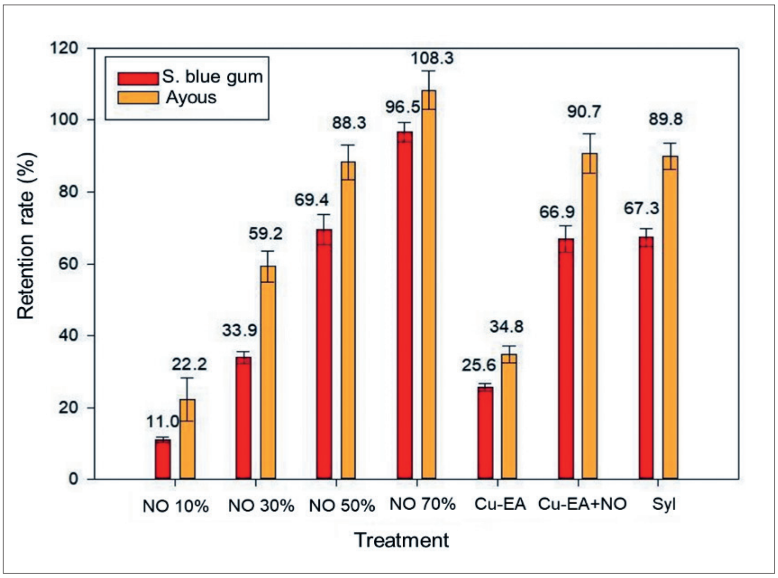

Figure 2. Retention of preservatives in wood from the different impregnation solutions. Abbreviations: NO X%: Neem Oil-Acetone with X% of Neem oil; Cu-EA: copper-ethanolamine formulation, Cu-EA + NO: double treatments with Cu-EA and NO 50%; Syl: pure Sylamon® formulation.

Slika 2. Navzem zaščitnih sredstev v lesu evkalipta in sambe iz različnih impregnacijskih raztopin. Okrajšave: NO X %: Mešanica nimovega olja in acetona z X % nimovega olja; Cu-EA: formulacija bakra in etanolamnina, Cu-EA + NO: dvojna obdelava s Cu-EA in NO 50 %; Syl: čista formulacija Sylamon®.

88.3% for Ayous). For comparison, the retention rates for CCA preservative are around 4kg/m^3 for surface applications and around 40 kg/m^3 for underground applications or those in salt water (American Wood-Preservers Association, 1997). For Alkaline-Copper-Quaternary (ACQ), retention is around 2.4 kg/m^3 for above-ground treatments and 6.4 kg/m^3 for underground wood (American Wood-Preservers Association, 2006). It can be noticed that the retention rates obtained in this study were significantly higher compared to the traditional preservative requirements for underground applications of wood.

3.2 LEACHING

3.2 IZPIRANJE

The percentage weight losses caused by leaching (PWLL) of wood impregnated with Neem oil or copper-ethanolamine are shown in Figure 3.

Leaching can extract non-fixed preservatives, but also some extractives naturally present in wood. The extractive contents (ethanol-toluene and hot water) obtained from those wood species were 3.4% for Ayous (non-published research work) and 5.0% for Sydney blue gum (Chokouadeu Youmssi et al., 2017). The PWLL obtained for almost all the treatments was higher than the extractive content

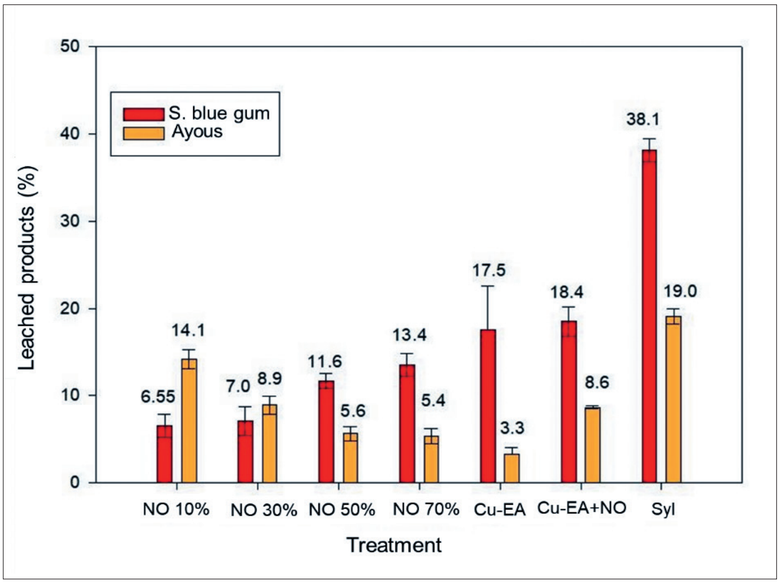

Figure 3. Leaching of wood impregnated with different preservative solutions.

Slika 3. Izpiranje iz lesa, impregniranega z različnimi raztopinami zaščitnih sredstev.

of the woods and showed that Neem oil as well as copper-ethanolamine were both leached. The PWLLs were generally lower with Ayous than with Sydney blue gum. This result can be explained by the depth of penetration and amount of oil in the wood. Sydney blue gum, being denser, had less in-depth impregnation and underwent more leaching. The higher oil content in Ayous could also confer to this wood a certain hydrophobicity limiting the ingress of leaching water. Wood impregnated with oil exhibited reduced water absorption, as reported in the literature (Can & Sivrikaya, 2016). The PWLL decreased for Ayous as retention increased. Copper-ethanolamine was significantly leached from the woods. Thaler and Humar (2014) also reported a mass reduction of the copper content of around 3-5% for wood impregnated with copper-ethanolamine, based on laboratory leaching tests. Sylamon® was the most leached product for both wood species.

3.5 EVALUATION OF TERMITE ACTIVITY
3.5 OCENA AKTIVNOSTI TERMITOV

The percentage weight losses caused by termite activity (PWLT) after exposure of wood blocks to field termites are shown in Figure 4.

Some degraded wood blocks at the experimental site are shown in Figures 5 and 6.

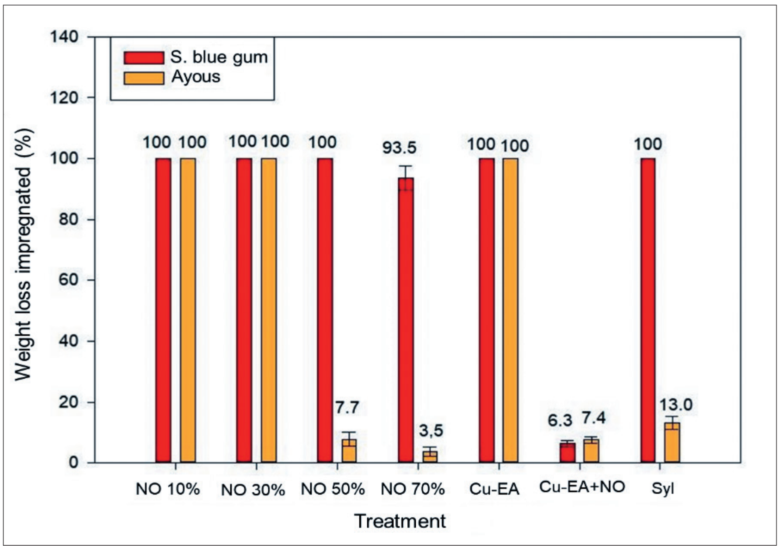

*Figure 4. Percentage weight losses due to termite (PWLT) attack for Sydney blue gum (*Eucalyptus saligna*) and Ayous (*Triplochiton scleroxylon*) impregnated with different preservative solutions.*

*Slika 4. Izguba mase (%) zaradi napada termitov (PWLT) lesa vrst evkalipta (*Eucalyptus saligna*) in sambe (*Triplochiton scleroxylon*), impregniranega z različnimi raztopinami zaščitnih sredstev.*

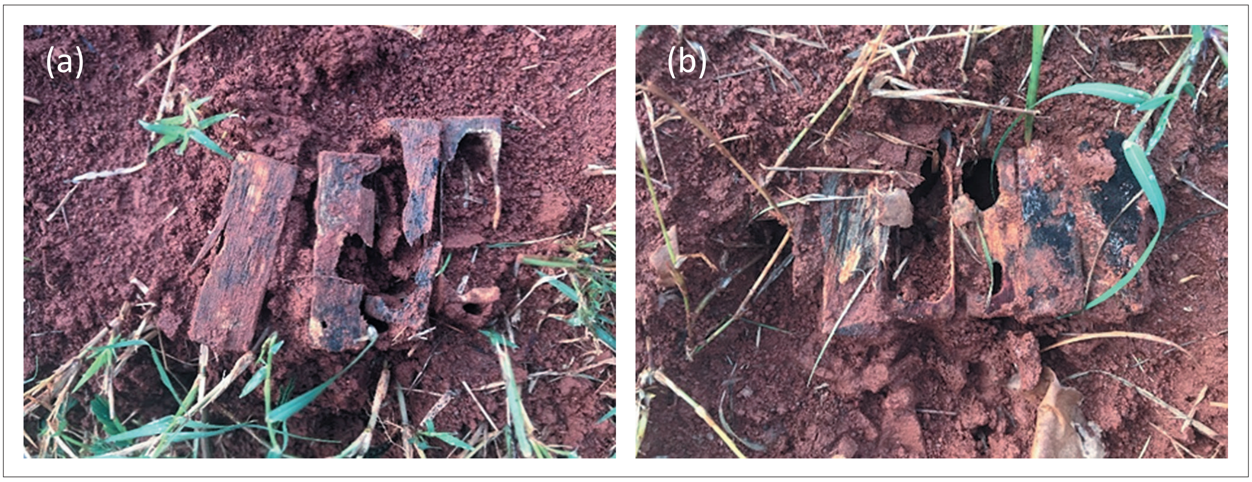

*Figure 5. Ayous (*Triplochiton scleroxylon*) wood impregnated with NO 10% (a) and NO 30% (b) after 16 weeks in a termitarum.*

*Slika 5. Les sambe (*Triplochiton scleroxylon*), impregniran z NO 10 % (a) in NO 30 % (b), po 16 tednih v termitarju.*

*Figure 6. Sydney blue gum (*Eucalyptus saligna*) wood impregnated with Cu-EA and NO 50% (a) and NO 10% (b) after 16 weeks in a termitarum.*

*Slika 6. Les evkalipta (*Eucalyptus saligna*), impregniran s Cu-EA in NO 50 % (a) in NO 10 % (b), po 16 tednih v termitarju.*

Non-treated wood was completely consumed by termites, and thus the PWLTs were 100% for both wood species. Neem oil was globally less efficient in the preservation of wood against the investigated termites. For Sydney blue gum approximately 100% of wood was degraded at retentions lower than 69.5 kg/m^3, but a significant reduction in PWLT was noticed at the retention of 96.6 kg/m^3. Ayous with a retention value of 108.3 kg/m^3 showed the most significant resistance to termites. Many research reports have been published on the efficiency of Neem oil for the preservation of wood with different experimental conditions and retention rates. It is shown that Neem oil and other vegetable oils (linseed oil, jatropha) are toxic to termites and can cause 100% death in laboratory tests, but with a certain loss of wood weight (degradation) (Ahmed et al., 2020; Fatima & Morell, 2015; Himmi et al., 2013; Machado et al., 2013). Tests performed in field conditions (a graveyard) also revealed that wood treated with Neem oil was susceptible to termite attack, but the level of resistance was better than that seen with untreated wood (Adebawo et al., 2015; Sotannde et al., 2011). Given the higher retention rates tested compared to the values generally used with traditional commercial products for efficient preservation, it can be concluded that Neem oil could not be applied alone for the protection of wood against termites.

At the concentration investigated, the treatment of the wood blocks with copper-ethanolamine solution was not suitable. Copper is mostly a fungicide and has insufficient termiticide or insecticide activity. The addition of co-biocides (e.g. boron) to copper amine could improve the efficacy against termites, as reported by Kalawate (2013), who found no damage after 24 months and less than 5% average weight loss after 30 months for wood impregnated with copper-ethanolamine-boron formulations and exposed to a subterranean termite attack in a field test/graveyard test. Xylamon showed significant activity with Ayous but much less with Sydney blue gum. Sydney blue gum was surprisingly (according to general perceptions) more sensitive to termites than Ayous. A combination of copper–ethanolamine and Neem oil was also tested in this study. The resistance of Sydney blue gum was significantly improved by the mixed preservatives. Further studies are under consideration to understand the synergetic effects and explain the results.

The percentage weight losses due to termite infestation of leached impregnated woods are presented in Figure 7. The samples of leached Sydney blue gum for all the treatments were almost completely decomposed by termites. The effect of leaching with Ayous was mitigated, probably because of the lower leaching rate in some samples. Ayous blocks impregnated with copper-etha-

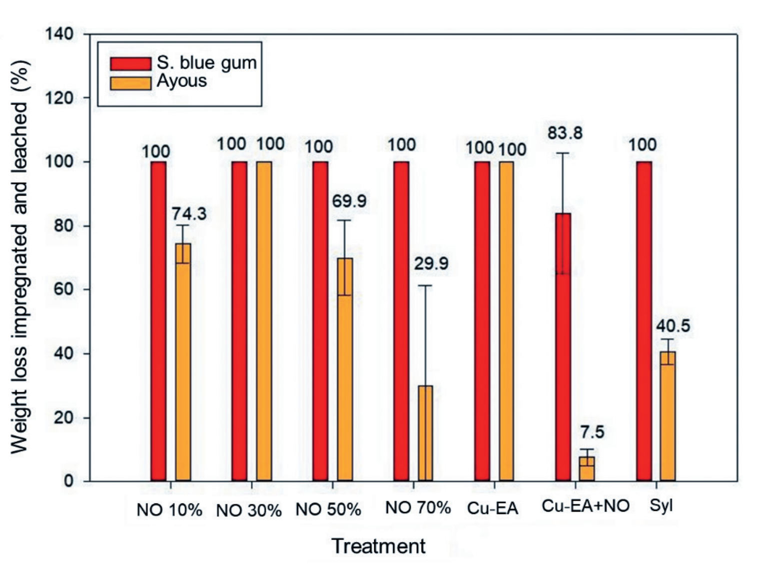

*Figure 7. Percentage weight losses due to termite activity (PWLT) for Sydney blue gum (*Eucalyptus saligna*) and Ayous (*Triplochiton scleroxylon*) impregnated with different preservative solutions and after leaching.*

*Slika 7. Izguba mase (%) zaradi aktivnosti termitov (PWLT) pri lesu vrst evkalipta (*Eucalyptus saligna*) in sambe (*Triplochiyton scleroxylon*), impregniranega z različnimi raztopinami zaščitnih sredstev in po izpiranju.*

nolamine followed by Neem oil showed the highest resistance to termites after leaching. Leaching generally removes part of active preservatives introduced in wood and increases wood biodegradation. The significant difference between non-leached and leached Sydney blue gum treated with the combined solutions suggested the loss of synergy between both preservatives.

4 CONCLUSIONS
4 ZAKLJUČKI

Neem oil applied as a natural preservative showed a low efficiency in the protection of wood against termites in the field test. An increase in the retention increased the resistance to termite attack. Copper-ethanolamine used alone was also less suitable in the protection of wood at the experimental conditions investigated. A combination of Neem oil and copper-ethanolamine showed a promising improvement in the protection of wood. A reduction of the percentage weight loss due to termite activity from 100% (Sydney blue gum impregnated with copper-ethanolamine or with Neem oil) to 7.4% (Sydney blue gum impregnated with combined copper-ethanolamine and with Neem oil) was observed. Nevertheless, the impregnated wood samples were more exposed to termite attack after leaching. Further research efforts are under consideration to understand the synergetic effects between these two products, increase the fixation of preservatives into wood and modulate their leaching.

5 SUMMARY
5 POVZETEK

Anorganska in organska zaščitna sredstva so že dolgo v uporabi za zaščito lesa pred biološko razgradnjo, ki jo povzročajo glive, termiti in drugi insekti ter morski lesni škodljivci. Tradicionalna zaščitna sredstva na osnovi spojin bakra, ki vsebujejo strupene spojine kroma in arzena ali organski sredstvi kreozot in pentaklorofenol (PCP), so podvržena vse večjim omejitvam in so v mnogih državah po svetu celo prepovedana. V iskanju okolju prijaznejših izdelkov kot zanimive alternative preučujejo baker-aminske pripravke in različne naravne organske proizvode, kot so na primer rastlinski izvlečki iz lesa ali skorje dreves in grmov, rastlinska olja in eterična olja. Ta študija je osredotočena na oceno možnosti uporabe olja nima (*Azadirachta indica*) in baker-etanolaminskega sredstva za zaščito lesa evkalipta (*Eucalyptus saligna*) in sambe (*Triplochiton scleroxylon*) pred napadom zemeljskega termita. Omenjeni evkalipt je pomembna lesna vrsta, ki se uporablja za električne drogove v Kamerunu in sosednjih državah. Nim (*Azadirachta indica*) je drevesna vrsta družine Meliaceae - melijevke, ki raste v tropskih in subtropskih območjih. Vrsta izvira z indijske podceline, danes pa je razširjena v Afriki in Avstraliji. Ta vrsta je znana že vsaj dva tisoč let, ker imajo izvlečki iz njenih listov, skorje in semen fungicidne, protibakterijske in insekticidne lastnosti in se uporabljajo za zdravila. Predhodne raziskave o uporabi nimovega olja za zaščito lesa proti termitom so bile izvedene z manjšimi navzemi in so pokazale, da olje lahko povzroči smrtnost termitov ob sicer neželeni izgubi mase lesa. V tej študiji smo prilagodili parametre impregnacije, da bi dosegli višje navzeme olja. Preučen je bil tudi baker-etanolaminski pripravek, ki se je izkazal kot učinkovit pri zaščiti lesa pred glivami in insekti v drugih regijah. Pripravili smo vzorce lesa dimenzij (6 x 2 x 2) cm^3 iz jedrovine obeh lesnih vrst in jih posušili v laboratoriju do konstantne mase. Uporabili smo štiri načine impregnacije in za vsakega uporabili po dvanajst vzorcev. V ta namen smo pripravili nimovo olje, razredčeno z acetonom pri masnih razmerjih nimovo olje / aceton: 10:90, 30:70, 50:50 in 70:30. Baker-etanolaminski pripravek smo pripravili z mešanjem bakrovega klorida in etanolamina v destilirani vodi, tako da smo dosegli koncentracijo bakra in etanolamina 0,5 % oziroma 1,4 %. Za referenco je bil uporabljen xylamon, komercialno zaščitno sredstvo. Impregnirane vzorce lesa (šest vzorcev na poizkus) smo izpirali po standardu NF X41-565, ki smo ga nekoliko prilagodili. Lesni vzorci so bili šestnajst tednov izpostavljeni termitom v poljskem termitarju (Isoptera: Termiditae). Z nimovim oljem smo dosegli navzem do 108,3 kg/m^3. Navzemi so bili v splošnem višji pri impregnaciji sambe, kar pripisujemo manjši gostoti lesa (ki je skoraj za polovico nižja od gostote lesa proučenega evkalipta). Nimovo olje je bilo manj učinkovito za zaščito lesa evkalipta, a je pokazalo pomembno zaščito lesa sambe pri višjem navzemu. Za evkalipt smo izmerili skoraj 100-odstotno izgubo mase pri navzemu 69,4 kg/m^3 in 93,5 % izgubo mase pri 96,5 kg/m^3, medtem ko smo pri sambi zabeležili 7,7 % in 3,5 % izgube mase pri navzemih 88,3 kg/m^3 in 108,3 kg/m^3. Pri raziskanih koncentracijah obdelava obeh lesnih vrst z raztopino baker-etanolamina ni bila primerna. Rezultati kažejo, da uporabljenih zaščitnih sredstev samih ni mogoče uporabiti za učinkovito zaščito lesa pred termiti. Vendar je kombinacija baker-etanolamina in nimovega olja pomembno izboljšala zaščito lesa evkalipta. V tem primeru so bili vzorci lesa impregnirani z baker-etanolaminsko raztopino, 24 ur sušeni na zraku in ponovno impregnirani z nimovim oljem in acetonom v razmerju 50:50. Kljub temu so bili impregnirani vzorci po izpiranju izpostavljeni povečanim napadom termita. Predvidene so nadaljnje študije, da bi bolje spoznali sinergijo obeh zaščitnih sredstev, izboljšali fiksacijo spojin v lesu, zmanjšali izpiranje in povečali učinkovitost s kombiniranjem z različnimi drugimi anorganskimi sredstvi in pripravki naravnega izvora.

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PHOTOSTABILIZATION OF RUBBERWOOD USING CERIUM OXIDE NANOPARTICLES PART 1: CHARACTERIZATION AND COLOUR CHANGES

FOTOSTABILIZACIJA LESA KAVČUKOVCA Z NANODELCI CERIJEVEGA DIOKSIDA 1. DEL: KARAKTERIZACIJA IN SPREMEMBE BARVE

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Abstract / Izvleček

Abstract: *Light induced darkening and deterioration of wood used outdoors is undesirable. Photoprotection of wood could be achieved by using additives that reflect or absorb harmful radiation responsible for degradation. Nano metal oxides have strong absorption in the UV range of solar radiation and good transparency in the visible region. They offer unique benefits in protecting coatings and coated substrates from being degraded by UV radiation. However, to exploit the properties of nanoparticles, homogenous dispersion without agglomeration is necessary. In the present work, the photostabilization of rubberwood surfaces coated with cerium oxide (CeO_2) was studied. The nanoparticles were surface functionalized with an organic alkoxy silane (3-glycidyloxypropyltrimethoxy silane) to improve the homogenous distribution in coatings, and the modified nanoparticles were dispersed in isopropanol and polyurethane (PU) coating. Rubberwood surfaces coated with dispersed nanoparticles (concentration 0.5 % to 6 % w/v) were exposed to a fluorescent UVA light source (λ=340 nm) at 60* °C in an accelerated weathering tester for *500 h and 1000 h. Colour changes due to UV light exposure were monitored using a spectrocolourimeter. Dispersion of CeO_2 nanoparticles in PU coatings (concentration >2 %) restricted the photoyellowing of wood polymers.*

Keywords: *Rubberwood, PU coating, Nanoparticles, Cerium oxide, Photostability, Colour stability*

Izvleček: *Degradacija in potemnitev lesa, ki je v uporabi na prostem, je nezaželena. Les je pred učinki svetlobe možno zaščititi z dodatki, ki odbijajo ali absorbirajo škodljivo sevanje, ki povzroča njegovo razgradnjo. Nano kovinski oksidi izkazujejo močno absorpcijo svetlobe v UV območju sončnega sevanja in dobro transparentnost v vidnem območju. Zato ponujajo edinstvene prednosti pri zaščiti premazov in površinsko obdelanih substratov, ki so občutljivi na UV sevanje. Vendar pa je za izkoriščanje zaščitnih lastnosti nanodelcev potrebna njihova homogena disperzija, tako da se ne tvorijo aglomerati. V tem prispevku poročamo o raziskavah fotostabilizacije površin lesa kavčukovca z nanodelci cerijevega dioksida (CeO_2). Nanodelci so bili površinsko funkcionalizirani z organskim alkoksi silanom (3-glicidiloksi propiltrimetoksi silan) za izboljšanje homogene porazdelitve v premazih. Modificirane nanodelce smo dispergirali v izopropanolu in v poliuretanskem (PU) premazu. Površine lesa kavčukovca, na katere smo nanesli dispergirane nanodelce (koncentracija od 0,5 % do 6 % m/v), smo v napravi za umetno pospešeno staranje za 500 ur in 1000 ur in pri 60 °C izpostavili UVA svetlobi (λ = 340 nm). Barvne spremembe zaradi izpostavitve UV svetlobi smo spremljali s kolorimetrom. Disperzija nanodelcev CeO_2 v PU premazih (koncentracija >2 %) je zmanjšala foto-rumenenje lesnih polimerov.*

Ključne besede: *kavčukovec, PU premaz, nanodelci, cerijev dioksid, fotostabilnost, stabilnost barve*

1 INTRODUCTION
1 UVOD

Wood is a versatile raw material that is widely used for indoor and outdoor applications. Consumption of wood and wood products has increased due to concern about the environment (Rowell, 2005; Hill, 2006). Wood has gained lot of attention because of its low embodied energy, which also acts as carbon sink and contributes to climate change mitigation. Being a biological material, unprotected wood is susceptible to degradation due to a combination of environmental factors (sunlight, moisture, heat, atmospheric pollution, chemicals and biological agents) (Feist & Hon, 1984; Williams, 2005; Evans, 2013). Some of the limitations associated when wood is used

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outdoors are the low durability of many species, dimensional instability with change in moisture content, low resistance against fungi and insect attack and photodegradation of wood (Rowell, 2005).

The colour stability of natural wood against light exposure is an important issue from aesthetic point of view. Reducing or eliminating the damaging effects of solar and artificial UV radiation is a major challenge for material scientists. One of the most widely used methods of UV protection is the dispersion of UV-absorbing molecules into a material (George et al., 2005). Photoprotection of wood can be achieved by additives that reflect or harmlessly absorb the light responsible for photodegradation or terminate the free radicals that degrade wood constituents. Inorganic particles can block light from reaching wood substrates and protect wood from photodegradation. Small particles below a certain size are thus able to scatter UV light while having little effect on the visible component of the spectrum. These properties of nanoparticles and their ability to absorb UV light underpins the use of metal oxides (titanium dioxide, iron and zinc oxides) as transparent photoprotective agents for coatings applied onto wood.

Recently, many studies have focused on improving the UV absorption characteristics of wood coatings by incorporation of nanoparticles (Aloui et al., 2007; Clausen et al., 2010; Auclair et al., 2011; Nikolic et al., 2015). Moreover, some studies use nanoparticles along with or in contrast to organic UV absorbers to protect wood from photodegradation (Forsthuber et al., 2013). But the majority of such studies report the use of zinc oxide or titanium dioxide as the nano additives in coatings for UV protection (Allen et al., 2002; Cristea et al., 2010; Fufa et al., 2012; Wang et al., 2014; Miklečić et al., 2015), and very few use cerium oxide as a UV stabilizer (Liu et al., 2010; Blanchard & Blanchet, 2011; Schaller et al., 2011; Saha et al., 2013).

The photostability of yellow cedar veneers pre-treated with micronized iron oxide and cerium oxide nanoparticles was examined by Liu et al. (2010). The results revealed that, in comparison to iron oxide, the cerium oxide nanoparticles were not as effective at restricting the weight loss, tensile strength losses, and preventing the photodiscolouration of exposed veneers. Blanchard and Blanchet (2011) studied the colour stability of ZnO and CeO_2 nanoparticles in comparison with UV absorbers dispersed in a waterborne UV curable polyurethane / polyacrylate resin. The inorganic absorbers performed better in comparison with the organic UV absorbers, while zinc and cerium oxides efficiently reduced yellowing. A similar comparison study was carried out by Schaller et al. (2011) for a longer exposure time. The poor performance of CeO_2 nanoparticles that was found was attributed to the presence of aggregates and lower concentration. The acrylic polyurethane coatings modified with CeO_2 nanoparticles alone or in combination with lignin stabilizer and/or bark extracts showed better protection of thermally treated jack pine compared to coatings containing organic UV absorbers (Saha et al., 2013).

In the present study, the photostability of rubberwood coated with different concentrations of CeO_2 nanoparticles exposed to UV-A light under accelerated weathering conditions is discussed. Colour changes occurring due to UV light irradiation were regularly monitored and analysed. Rubberwood (*Hevea brasiliensis*) is a low durable, light yellowish-brown plantation grown, easy to work, hard wood species. It finds applications in furniture, toys, kitchen accessories, pulp and paper products, and fibreboards.

2 MATERIALS AND METHODS
2 MATERIALI IN METODE

2.1 MATERIALS
2.1 MATERIALI

Specimens of rubberwood (*Hevea brasiliensis*) of size (150 mm × 75 mm × 5 mm) (length × width × thickness) were prepared from defect-free wood for the evaluation of photostability. Wood specimens were air dried followed by drying in a hot air oven at 65 °C and stored at room temperature. Cerium oxide nanoparticles (~25 nm) were purchased from Sigma Aldrich, 3-glycidyloxypropyltrimethoxy silane (GPTMS) from Gelest Inc., and polyurethane (PU) coating material (without any additives) was procured from Asian Paints, Mumbai. Other chemicals used in the study were of AR grade.

2.2 SURFACE MODIFICATION AND DISPERSION OF NANOPARTICLES
2.2 POVRŠINSKA MODIFIKACIJA IN DISPERGIRANJE NANODELCEV

In order to obtain a homogenous distribution of nanoparticles in solution, alkoxy silane 3-glycidyloxypropyltrimethoxy silane (GPTMS) was used as a surface modifier. The process used for dispersion of CeO_2 nanoparticles was carried out as per the procedure discussed elsewhere in detail (Srinivas & Pandey, 2017).

2.3 CHARACTERIZATION OF SILANE MODIFIED NANOPARTICLES
2.3 KARAKTERIZACIJA NANODELCEV, MODIFICIRANIH S SILANOM

Surface modified nanoparticles were characterized using UV-visible absorption spectroscopy, X-ray diffraction (XRD) and the dispersion of nanoparticles by Dynamic Light Scattering (DLS) and Scanning Electron Microscopy (SEM).

The UV-Vis spectra of surface modified nanoparticles in powder form were measured using an Ocean Optics HR 4000 UV-Vis spectrophotometer (UV-Vis-NIR light source, DT-MINI-2-GS, Jaz detector) at Kuvempu University, Shimoga, Karnataka. The baseline of UV spectra was set by using standard $BaSO_4$. The dried nanoparticle samples were packed tightly in a circular opening (diameter 0.4 cm) with a thickness of 0.5 mm on a glass plate. The UV spectra of samples were recorded using the optical fibre held exactly at 90° to the sample. XRD analysis was carried out to know the phase and size of surface modified nanoparticles. XRD patterns were recorded from 10° to 90° with a PANalytical X'pert pro diffractometer using Cu Kα (λ=1.5418 Å) with a nickel filter. Data were collected from modified nanopowder with a counting rate of 5° per min.

Dynamic light scattering was used to determine the size distribution profile of particles in PU suspension using BIC Zeta PALS. DLS analysis was done at concentration levels of 0.01 % of nanoparticles in liquid suspension (PU base material). PU alone was also analysed to assess any interference in DLS analysis when nanoparticles are used, and the findings showed that it did not have any significant monomer/oligomeric structure which could interfere in the results.

The distribution of nanoparticles in polyurethane was also examined using a high resolution scanning electron microscope (Gemini Ultra 55, with ESB detector at 5.0 kV). Thin films of nanoparticle dispersed in PU were prepared by pouring dispersed solution on a clean plastic sheet. After drying at room temperature, the thin films were pulled from the plastic sheets and kept in a vacuum desiccator for 72 hours before analysis. A thin layer of gold (9 nm) was sputtered onto the thin films mounted on a metal grid using carbon tape to make the sample conductive. XRD, DLS and SEM analysis were carried out at CeNSE, Indian Institute of Science, Bengaluru.

2.4 COATING OF WOOD WITH NANOPARTICLES DISPERSED IN ISOPROPANOL/PU
2.4 POVRŠINSKA OBDELAVA LESA Z NANODELCI, DISPERGIRANIMI V IZOPROPANOLU/PU

In order to know the effects of nanoparticles alone, one set of wood samples were coated with modified nanoparticles dispersed in isopropanol and another set with nanoparticles dispersed in PU coating. Different concentrations (0.5 %, 1.0 %, 2.0 %, 4.0 % and 6.0 %) of silane modified CeO_2 nanoparticles were added to isopropanol or PU, subjected to homogenisation in a homogeniser (IKA T25 digital ULTRA-TURRAX) for 20 minutes at 10 krpm. Wood surfaces were coated with two coats of homogenized solution of nanoparticles using sprayer with an intermittent drying time of one hour and dried overnight at room temperature. A coating thickness of ~50 µm was achieved. All the measurements made on wood samples coated with nanoparticles dispersed in isopropanol were done carefully to avoid loss of the nanoparticle layer from the wood surface.

2.5 PHOTOSTABILITY OF WOOD SURFACES COATED WITH CEO_2 NANOPARTICLE DISPERSED IN ISOPROPANOL/PU
2.5 FOTOSTABILNOST POVRŠIN LESA, OBDELANIH Z NANODELCI, DISPERGIRANIMI V IZOPROPANOLU/PU

The photostability of wood was assessed using a weatherometer (Qlab QUV accelerated weathering tester, UVA-340 lamp) at an irradiance of 0.68 W/m^2, chamber temperature of 60 °C. Initially samples coated with different concentrations of nanoparticle were exposed to UV light. Four replicas of wood samples per treatment were used in the study. Forty-eight samples were kept in a single run of 500 h. The samples were removed from the weathering tester after exposure of 50 h, 100 h, 150 h, 200 h, 250 h, and 500 h and were analysed for colour changes. Based on the results, only wood samples coated with higher nanoparticle concentrations (2 %, 4 % and 6 %) were exposed to UV light for another 500 h along with control wood samples.

2.6 COLOUR CHANGES
2.6 SPREMEMBE BARVE

Changes in the colour of wood surfaces due to irradiation were measured using a Hunter lab - Lab scan XE model spectrocolourimeter (10° standard observer, D65 standard illuminant, xenon flash lamp source and CIELAB system). The CIELAB system is characterized by three parameters L^*, a^*, b^*. L^* axis represents the lightness, a^* and b^* are the chromaticity coordinates, a^* varies from red (+) to green (-) and b^* varies from yellow (+) to blue (-). Coordinates L^*, a^* and b^* were measured on each sample before and after accelerated weathering exposure. Measurements were taken at six different locations for each sample; the mean value and standard deviation were calculated. Changes in colour coordinates after UV exposure were measured and changes in colour due to exposure were calculated as the ΔL^*, Δa^* and Δb^* values. These values were used to calculate the total colour change ΔE^* as a function of the weathering time, according to the following equation 1 (CIE 1986),

$$\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2} \quad (1)$$

The ΔL^*, Δa^* and Δb^* values given in eqn. 1, are the changes in L^*, a^* and b^* parameters due to irradiation with respect to unirradiated and irradiated wood specimens.

3 RESULTS AND DISCUSSION
3 REZULTATI IN RAZPRAVA

3.1 SURFACE FUNCTIONALIZATION OF CeO_2 NANOPARTICLE
3.1 POVRŠINSKA FUNKCIONALIZACIJA NANODELCEV CeO_2

Most of the widely used organosilanes ($R\text{-}(CH_2)_n\text{-}Si\text{-}X_3$) have one organic substituent (R) and three hydrolyzable substituents (X). In most surface treatment applications, the alkoxy groups of the trialkoxy silanes are hydrolyzed to form silanol-containing species. The reaction of silane with nanoparticles involves hydrolysis of the three labile groups followed by their condensation to oligomers, the formation of hydrogen bond by oligomers with -OH groups of the substrate and finally a covalent linkage is formed with the substrate with loss of water during drying or curing. The R group (glycidyloxypropyl) remains available for covalent reaction or physical interaction with other phases (PU coating). Among alkoxy silanes, only methoxy silanes are effective without catalysis. In order to minimize agglomeration, nanoparticles were chemically modified with 3-glycidyloxypropyltrimethoxy silane (GPTMS) using ultrasonication. The chemical structure of GPTMS is shown in Fig. 1, as given by the provider. The basic principle of using ultrasonication for dispersion is the cavitation in liquids created by ultrasonication, which accelerates chemical reactions by facilitating the mixing of reactants. It also enables the uniform dispersion of micron-size or nano-size materials (Suslick & Price, 1999).

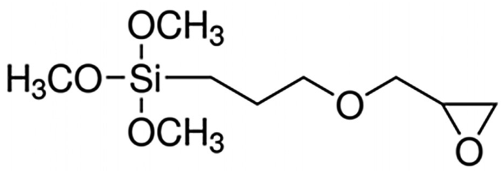

Figure 1. Chemical structure of 3-glycidyloxypropyltrimethoxy silane (GPTMS).
Slika 1. Kemijska struktura spojine 3-glicidiloksipropiltrimetoksi silan (GPTMS).

3.1.1 Ultraviolet- Visible Absorption spectra
3.1.1 UV-vidni absorpcijski spektri

Nanoparticles modified with GPTMS were characterized using UV visible absorption spectroscopy. The spectra of unmodified and modified nanoparticles are as shown in Fig. 2A. Absorption spectra showed a broad absorption in the region between (200-350) nm, which exhibit the strong tendency of nanoparticles to absorb UV radiation (Arul et al., 2011). The spectra also suggest that surface modification with silane has not altered or posed any interference in the UV absorption region of the nanoparticles, but was also observed to increase absorption in the visible region which affected the transparency of the coating.

3.1.2 X-ray diffraction (XRD) analysis of nanoparticles
3.1.2 Rentgenska praškovna difrakcija (XRD) nanodelcev

X-ray powder diffraction is a rapid analytical technique primarily used for phase identification of a crystalline material, and it can provide information on unit cell dimensions. X-ray diffraction is based on constructive interference of monochromatic X-rays and a crystalline sample**.** Various factors affect the broadening of diffraction peaks, such as crystalline size, domain size distribution, crystalline facets (external defects) and micro-strain (deformation of the lattice). As the size of the nanocrystals decreases, the line width is broadened. The XRD pattern for CeO_2 nanoparticles is shown in Fig. 2B. The 'hkl' values were compared with the standard JCPDS file (PCPDF 34-0394)20 (Arul et al., 2011). The exhibited XRD peaks correspond to the (111), (200), (220), (311), (222), (400), (331) and (420) of the cubic fluorite structure of CeO_2. There is no spurious diffraction peak found in the above samples. This confirmed that all the compounds were single phase. Further, the intensity of the XRD peaks of the sample reflects that the nanoparticles are crystalline and the broad diffraction peaks indicate very small size crystallites. The average crystallite size was estimated from the full width at half maximum (FWHM) of the diffraction peak of the powder samples, using Scherrer's formula the average crystallite size of CeO_2, and was found to be 84.08 nm.

3.1.3 Dynamic light scattering (DLS) of nanoparticle dispersions
3.1.3 Dinamično sipanje svetlobe (DLS) disperzij nanodelcev

Silane modified nanoparticles were dispersed in PU using ultrasonication and a homogenizer. The correlation functions of the intensity fluctuations were converted into intensity size distributions and are plotted in Fig. 3. A high proportion of the particle sizes were found between (105-120) nm having a poly dispersity index of 0.144.

3.1.4 Scanning Electron Microscopy of nanoparticles dispersed in PU
3.1.4 Vrstična elektronska mikroskopija nanodelcev, dispergiranih v PU

A scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals derived from electron-sample interactions reveal information about the sample including the external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample. In order to know the homogenous distribution of surface modified CeO_2 nanoparticles incorporated in PU coating, scanning

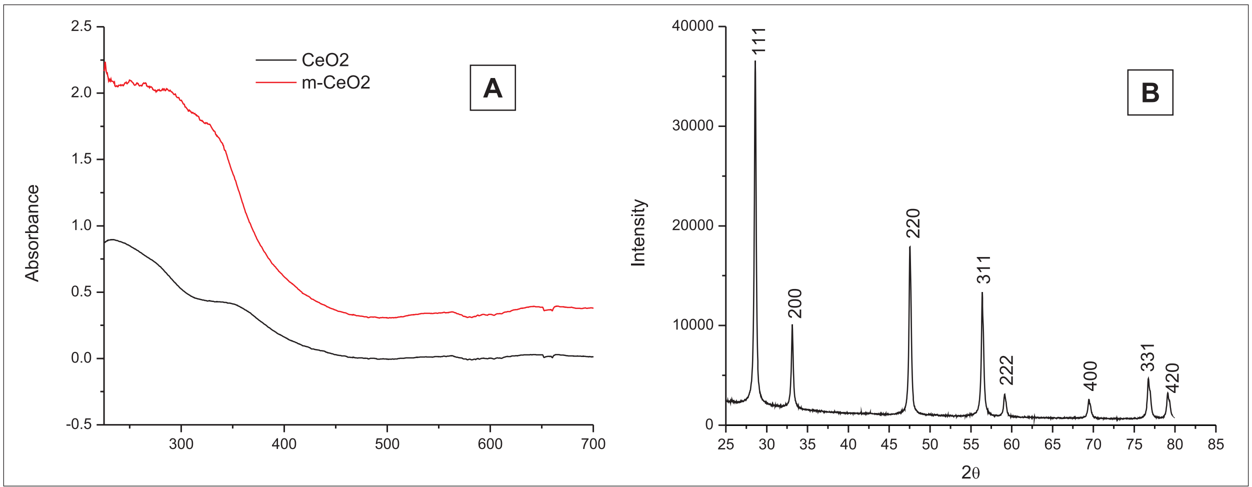

Figure 2. A) UV visible absorption spectra (m-CeO_2 means functionalized CeO_2) and B) XRD pattern of GPTMS modified CeO_2 nanoparticles.
Slika 2. A) UV-vis absorpcijska spektra (m-CeO_2 pomeni funkcionaliziran CeO_2) in B) rentgenski praškovni difraktogram z GPTMS modificiranih nanodelcev CeO_2.

electron micrographs (SEM) were recorded. SEM images of unmodified CeO_2 nanoparticles are shown in Fig. 4A. Severe agglomeration was observed in the case of unmodified CeO_2 particles with an average particle size >500 nm. The surface modified CeO_2 nanoparticles showed a size distribution of around 100-150 nm and a uniform dispersion (Fig. 4B). SEM analysis showed that the surface modification with GPTMS silane has a significant effect in minimizing the formation of agglomerates. All the characterization techniques show that the average size of the nanoparticles in the dispersing medium varies from

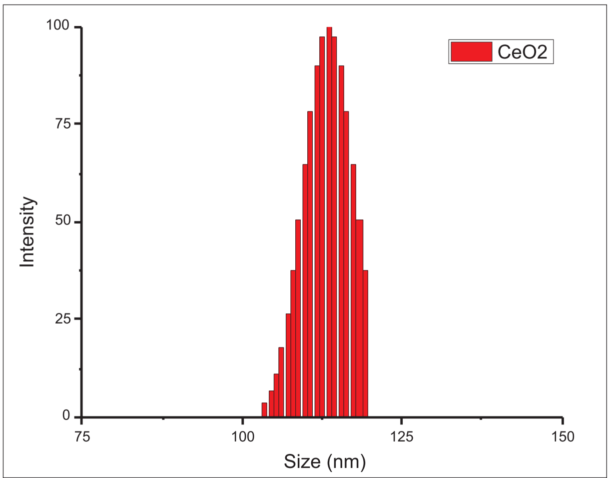

Figure 3. DLS analysis of the particle size distribution of modified CeO_2 nanoparticles in PU coating
Slika 3. Analiza DLS za določitev porazdelitve velikosti modificiranih nanodelcev CeO_2 v PU premazu

(90-130) nm. But the performance of nanoparticles mainly depends on the particle size, morphology and uniform size distribution. Though the surface modification with silane helped in avoiding the formation of agglomerates and encouraged an even distribution of nanoparticles in the PU coating, it was not effective to maintaining the particle size below 50 nm. Freeman and McIntyre (2008) reported that nanoparticles having a size smaller than wood pores (100 μm) and intercellular pores ((400-600) nm) could penetrate the porous structure of wood and thereby influence wood protection against damaging agents. Hence the size specific properties of nanoparticles can be efficiently utilized in the coating formulations reported in this study.

3.2 PHOTOSTABILITY OF WOOD COATED WITH NANOPARTICLES
3.2 FOTOSTABILNOST LESA, POVRŠINSKO OBDELANEGA Z NANODELCI

Wood specimens coated with modified nanoparticles dispersed in isopropanol and another set with dispersed nanoparticles in PU coating were exposed to accelerated weathering. Analysis of wood coated with nanoparticles dispersed in isopropanol revealed the effects of nanoparticles alone on the wood surfaces, since isopropanol evaporated at room temperature. In contrast, the analysis of nanoparticles dispersed in PU coating revealed the effects of light on PU coating containing the inorganic absorbers as well as the wood surface.

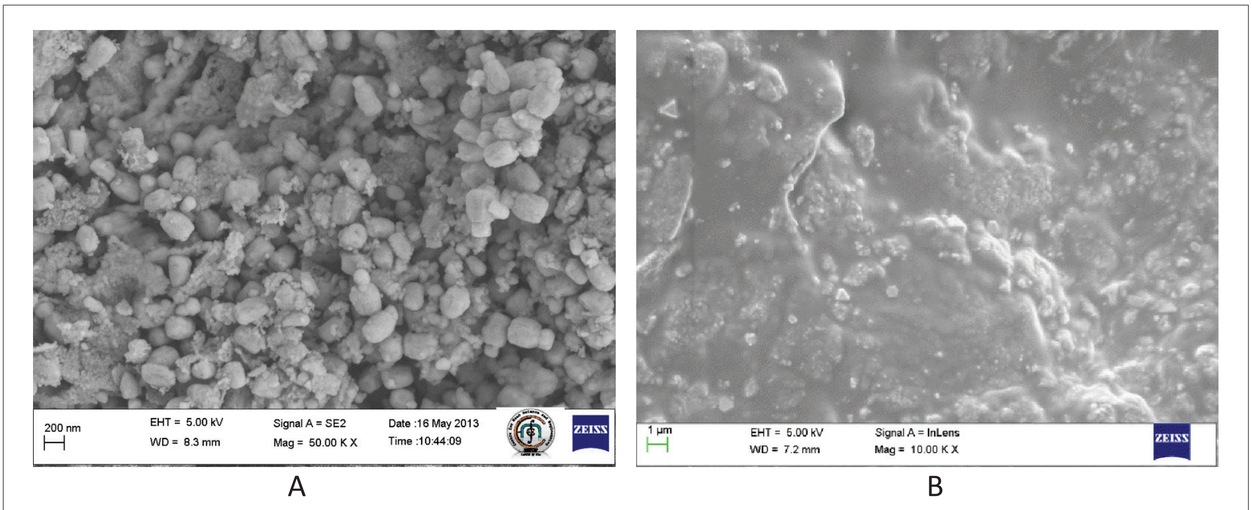

Figure 4. SEM images of A) unmodified and B) GPTMS modified CeO_2 nanoparticles dispersed in PU coating.
Slika 4. SEM mikrografi A) nemodificiranih in B) nanodelcev CeO_2, dispergiranih v PU premazu.

3.2.1 Effects of UV irradiation on colour parameters (*L**, *a** and *b**) of nano CeO_2 coated wood

3.2.1 Vpliv UV obsevanja na parametre barve (*L**, *a** and *b**) lesa, površinsko obdelanega z nanodelci CeO_2

Wood when exposed to light initially changes colour, showing the degradation of wood components by light absorption. By measuring the colour change of the clear coated wood with inorganic absorbers during artificial weathering, it is possible to obtain information on the performance of photostabilization. Changes in colour parameters of wood surfaces coated with nanoparticles of CeO_2 and exposed to UV radiation are shown in Fig. 5. Uncoated wood changes its colour within a few hours of irradiation due to photodegradation of chemical components mainly lignin present in wood (Tolvaj & Faix, 2009; Rosu et al., 2010; Müller et al., 2013). The control wood becomes darker and yellower with an

a b c d

Figure 5. Colour *changes after 1000 h of UV exposure of (a) uncoated, and coated with (b) 2 %, (c) 4 % and (d) 6 %* CeO_2 *(Top: without PU; Bottom: in PU coating).*

Slika 5. Spremembe barve po 1000 urah izpostavitve UV svetlobi (a) površinsko neobdelanega lesa in lesa, obdelanega z (b) 2 %, (c) 4 % in (d) 6 % CeO_2 *(zgoraj: brez PU; spodaj v PU premazu).*

increase in the irradiation time. Wood coated with a lower concentration of CeO_2 nanoparticles also showed colour changes with time. Wood coated with concentrations of (2 %, 4 % and 6 %) of nanoparticle loadings showed very less colour change when compared to that seen with lower loadings.

Similarly, wood samples coated with different concentrations of nanoparticles dispersed in PU were subjected to UV light irradiation in a QUV tester. The performance of the nanoparticles dispersed in PU coating on wood surfaces was compared with that of PU coating without nanoparticle. Wood coated with PU alone (without nanoparticles) exhibited severe colour changes, which increased with irradiation time. This indicates that PU coating without any UV stabilizer gets degraded rapidly upon UV light irradiation. Incorporation of nanoparticles in PU limited the colour changes. Figure 5 illustrates the colour changes in wood coated with different concentrations of CeO_2 nanoparticles embedded in PU coatings after 1000 h of UV irradiation. Colour changes in wood coated with CeO_2 dispersed PU were significantly reduced. The presence of CeO_2 gave a lighter colour to the coating, which was retained even after 1000 h of UV exposure. These visual observations were supported with spectroscopic analysis. Coating of wood surfaces with CeO_2 nanoparticles makes wood surfaces lighter in colour, which is indicated by the successive increase in *L** values and decrease in the values of *a** and *b**. Higher concentrations of nanoparticles dispersions showed stability against photoyellowing.

The variations in colour coordinates of uncoated and CeO_2 dispersed coatings before UV exposure are given in Table 1. It is seen that the *L** value increases while the *a** and *b** values decrease with an increase in the nanoparticle concentration, which is due to the increase in opacity of the coating. It was also observed that coating of wood with PU has effects on the colour parameters. Wood samples coated with PU had a darker appearance. *L** values were observed to be decreased and *a** and *b** increased in the PU coated wood compared to the corresponding coatings with isopropanol. This may be attributed to the coating material, as it was obtained without any additives. Upon light exposure, colour changes in the uncoated wood surface is indicated by a decrease in the value of lightness (*L**) and increase in the yellowness *b** (Fig. 6). The decrease in the *L** parameter indicates severe darkening of the control wood sample. The *b** values of uncoated wood increased. The increase in value can be attributed to the formation of a quinone-like structure from lignin degradation (Feist & Hon 1984). The lightness index (*L**) of uncoated wood decreased with an increase in irradiation time from 74.23 ± 1.68 (0h) to 69.18 ± 1.13 (500 h) and in wood coated with 0.5 % and 1% CeO_2 the *L** values were 72.96 ± 1.98 and 73.73 ± 0.50 after 500 h of exposure. In the case of wood treated with 2 % CeO_2 nanoparticles the *L** value varied from 78.33 ± 1.87 to 77.06 ± 1.60, similarly for wood treated with 4 % and 6 % of CeO_2 the values varied from 78.12 ± 1.86 to 76.37 ± 0.58 and 79.70 ± 0.59 to 79.63 ± 0.43, respectively, after 500 h of UV exposure. This shows there was no appreciable decrease in *L** values in comparison with uncoated wood and wood coated with lower nanoparticle concentrations. This indicates that the wood coated with a concentration of 2 % and more nano CeO_2 reduces the darkening of the wood surface due to light irradiation.

The chromaticity coordinates *a** and *b** in the case of uncoated wood increased with an increase in exposure time. This can be attributed to the photoyellowing of the wood surfaces upon light irradiation. The *a** value of uncoated wood increased from 6.63 ± 0.66 to 10.65 ± 0.30 after 500 h of UV exposure, in the case of wood coated with lower concentrations of CeO_2., 0.5 % and 1.0 %, the *a** values increased as in the control wood. However, in wood samples coated with 2 %, 4 %, and 6 % nanoparticles, the *a** value varied from 5.39 ± 1.21 to 5.25 ± 0.70, 4.64 ± 0.85 to 6.63 ± 0.55 and, 4.15 ± 0.66 to 5.25 ± 0.69 for the respective nanoparticle concentrations after 500 h of UV exposure. Yellowness induced in wood due to UV light exposure can be evaluated from *b** values. The chromaticity coordinate *b** values in the case of uncoated wood increased along with the exposure time. Uncoated wood became darker and yellower as the exposure time increased. In uncoated wood, the *b** values increased from 21.31 ± 0.99 to 29.38 ± 1.52 after 500 h of UV exposure. Even in wood coated with 0.5 % and 1.0 % CeO_2, *b** values increased with the time of exposure, but in the case of wood coated with 2 % and 4 % CeO_2, the increase in *b** values was much lower in comparison to those seen with the control wood. In wood coated with 6.0 % CeO_2, *b** values were found to decrease initially from

Table 1. Colour *parameters of wood coated with nanoparticles dispersed in isopropanol and PU coating before UV exposure.*

Preglednica 1. Barvni parametri lesa, obdelanega z disperzijo nanodelcev v izopropanolu in s PU premazom z nanodelci pred izpostavljenostjo UV.

Coating	CeO_2 in Isopropanol			CeO_2 in PU		
	L*	a*	b*	L*	a*	b*
Control	74.23 ± 1.68	7.63 ± 0.66	21.31 ± 0.99	63.26 ± 0.60	14.10 ± 0.08	33.25 ± 1.37
0.5 % CeO_2	75.92 ± 2.36	6.35 ± 1.54	20.45 ± 0.87	66.47 ± 0.68	10.53 ± 0.56	31.38 ± 1.30
1 % CeO_2	77.00 ± 1.06	6.02 ± 0.56	20.01 ± 0.69	67.01 ± 0.18	10.26 ± 0.90	30.96 ± 1.31
2 % CeO_2	78.33 ± 1.87	5.39 ± 1.21	17.30 ± 0.89	67.08 ± 0.41	10.03 ± 0.20	28.30 ± 1.74
4 % CeO_2	78.12 ± 1.86	4.64 ± 0.84	16.26 ± 0.67	69.15 ± 1.87	9.58 ± 0.59	23.46 ± 0.79
6 % CeO_2	79.70 ± 0.59	4.15 ± 0.65	14.15 ± 0.44	70.76 ± 1.73	9.17 ± 0.22	21.41 ± 0.15

14.15 ± 0.44 to 11.93 ± 1.39 (50 h) but increased to 13.51 ± 1.34 after 500 h of exposure.

Similarly, for wood coated with PU coatings, the lightness index *L** of wood coated with PU alone was found to darken with time, and the *L** values decreased from 63.26 ± 0.60 to 55.23 ± 1.60 after 500 h of UV exposure. The yellowness index *b** was observed to increase from 33.25 ± 1.37 to 49.13 ± 1.62 after 500 h of exposure. In the case of wood coated with nano CeO_2 in PU, the *L** values varied from 67.08 ± 0.41, 69.15 ± 1.87 and 70.76 ± 1.73 to 62.79 ± 0.28, 66.10 ± 1.15 and 67.77 ± 0.31 for 2 %, 4 % and 6 % nanoparticle loadings respectively after 500 h of exposure. The *a** values in PU control and wood coated with <1 % nanoparticle loadings showed an increase with time, whereas wood coated with >2 % loadings, *a** values slightly decreased or remained constant. The yellowness index *b** also increased with irradiation time in samples coated with (0.5 - 1.0) % CeO_2 and PU alone (33.25 ± 1.38 to 49.13 ± 1.62 after 500 h). The samples coated with 2 % nano CeO_2 showed an increase in *b** value (40.44 ± 1.23), and in wood coated with 4 % (30.94 ± 1.53) and 6 % CeO_2 (25.89 ± 2.03) samples the *b** values showed minor increase after 500 h of light exposure. Similar colour change results were observed for wood protected by depositing CeO_2 coating on surface (Lu et al., 2013; Nair et al. 2018). The changes in lightness (ΔL^*) and yellowness (Δb^*) for uncoated and nano coated wood are shown in Fig. 6. Δa^* values are not discussed, and only the lightness and yellowness indexes are discussed to explain the UV stabilization of wood. The maximum changes were observed in the case of uncoated control wood, which increased with the length of exposure. The negative ΔL^* values indicated the darkening of wood due to degradation from UV light. The ΔL^* values were negligible in wood coated with 6 % of CeO_2 even after 500h of UV exposure. The control wood showed an increase in Δb^* values with time. In contrast, negative Δb^* values were observed in wood coated with 4 % and 6 % CeO_2. This shows the effectiveness of CeO_2 nanoparticles at concentrations >2 % to stabilize wood surfaces against UV light induced photo-yellowing.

The ΔL^* and Δb^* values of PU coating with / without CeO_2 nanoparticles after 500 h of UV exposure are presented in Fig. 6. It was observed that changes in ΔL^* values were negative for wood coated with PU alone. ΔL^* values in wood coated with 2 %, 4 % and 6 % CeO_2 in PU remained constant. The Δb^* values in control wood increased with exposure time, and wood coated with 4 % and 6 % CeO_2 showed significantly less changes in yellowness (Blanchard & Blanchet, 2011; Saha et al., 2013). These results indicate that the UV resistance of wood coatings increases with the increase in concentration of nanoparticles.

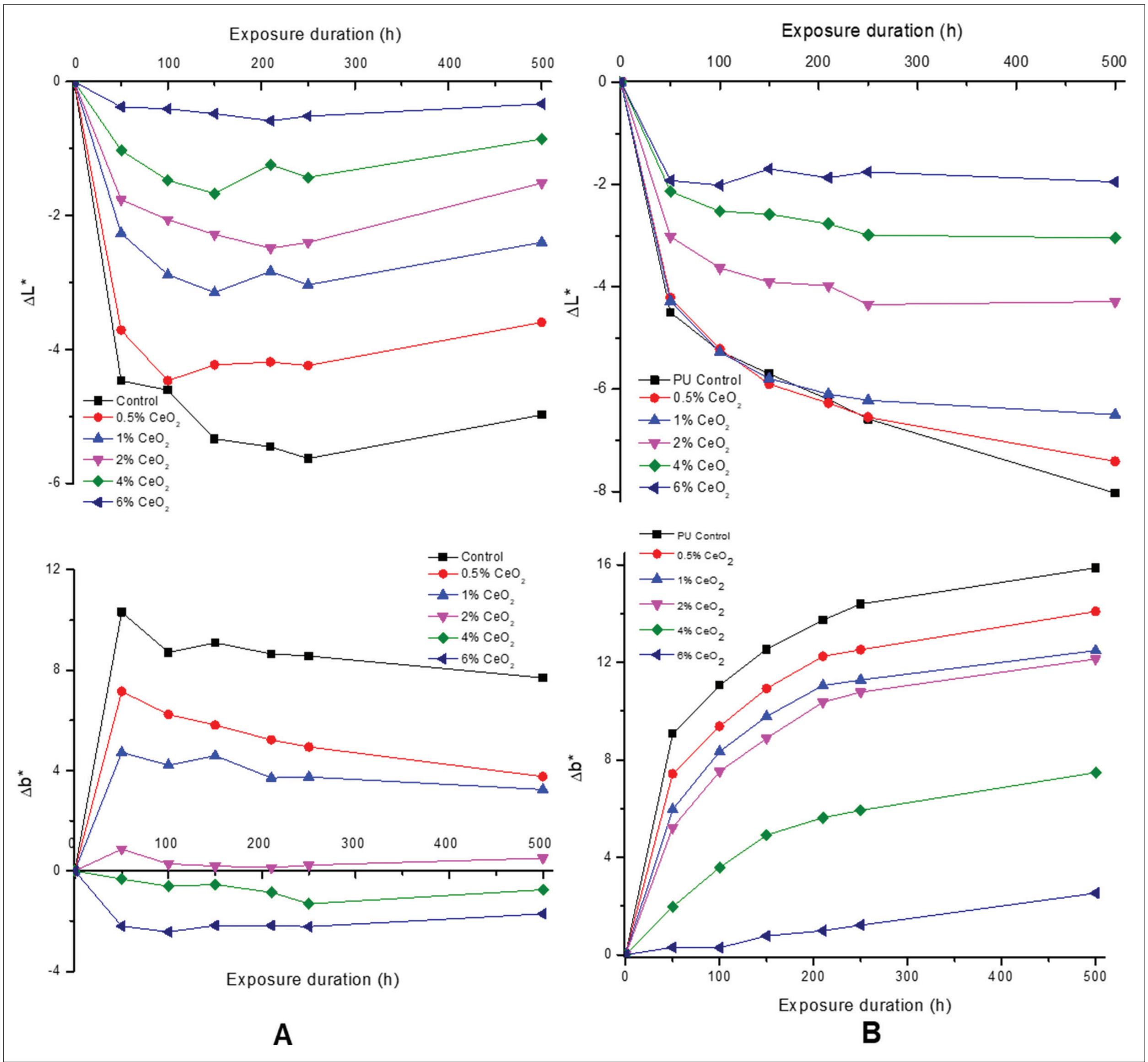

Figure 6. Changes in the **Δ***L* and Δb* values of control and wood surfaces coated with* CeO_2 *plotted against time of UV exposure. A) Without PU coating, B) with PU coating.*

Slika 6. Vrednosti **Δ***L* in Δb* kontrolnih vzorcev in površin lesa z nanodelci* CeO_2*, ki so bili izpostavljeni UV svetlobi.*

In order to verify the stability of these nano coatings, wood samples which showed good UV resistance were exposed to another 500 h along with control samples. The changes in colour parameters after 1000 h of UV exposure are shown in Fig. 7. With an increase in concentration, nanoparticles may form aggregates and thereby decrease the photostabilization efficacy of coatings (Blanchard & Blanchet, 2011). However, the results revealed that the photostability of wood coated with more nanoparticles was not altered even after longer exposure durations. It was observed that the changes in colour parameters after 1000 h exposure remained constant or only a slight variation was seen compared to the corresponding values after 500 h of exposure. It can be concluded that colour changes are more drastic in the initial hours and after a certain time they become less pronounced.

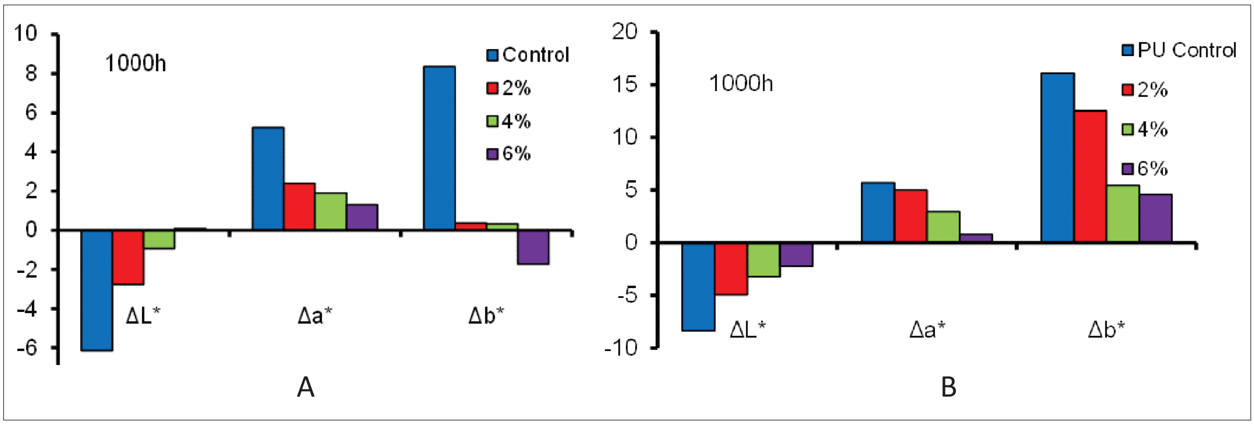

Figure 7. Changes in the **Δ***L*and Δb* values of control and wood surfaces coated with* CeO_2 *after 1000 h of UV exposure. A) Without PU coating, B) with PU coating.*

Slika 7. Vrednosti **Δ***L*in Δb* kontrolnih vzorcev in površin lesa z nanodelci* CeO_2*, po 1000 urah izpostavitve UV svetlobi.*

The total colour change (Δ*E**) of control and nano coated wood at different time intervals is shown in Fig. 8. The Δ*E** in the uncoated control wood and wood with 0.5 % CeO_2 increased rapidly with irradiation time. The rate of change was higher during the initial exposure but later was found to decline. The Δ*E** values were maximal for uncoated wood (Δ*E** = 10), which however were found to reduce with the addition of different nanoparticle concentrations. Wood coated with >2 % nanoparticles showed a much lower increase in Δ*E** values (less than 6), which shows the better colour stabilization than at their respective lower concentrations. Wood samples coated with PU and CeO_2 dispersed in PU also showed an increase in ΔE* values with an increase in time. However, the extent of this increase was lower in the case of wood coated with 4 % and 6 % CeO_2 loadings (Δ*E**<6) in contrast to lower loadings (Δ*E** = 18 in PU control wood). The total colour change in uncoated and wood coated with higher nanoparticle concentrations exposed for 1000 h of UV light did not vary much

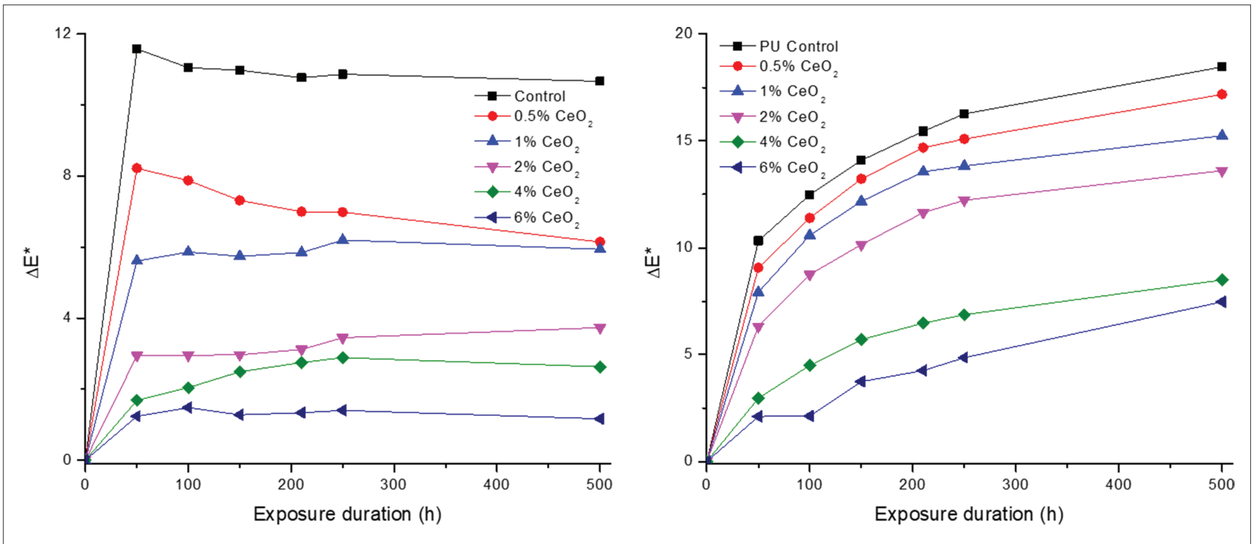

Figure 8. Effects of UV irradiation on the ΔE values of control and wood surfaces coated with different concentration of* CeO_2*.*

*Slika 8. Vpliv UV obsevanja na ΔE *vrednosti kontrolnih in površin lesa, prevlečenih z nanodelci z različnimi koncentracijami* CeO_2*.*

in comparison with 500 h of exposure. On visual observation, it can be noted that the yellowing of wood surfaces due to light exposure could not be controlled completely in wood coated with nanoparticles dispersed in PU. This may be attributed to the particle size of CeO_2 that was >100 nm, and also due to the degradation of the PU coating on light exposure.

In general, it was observed that in comparison to uncoated wood, wood with nanoparticles exhibits improved resistance to photodegradation, which increases along with the nanoparticle concentration. However, higher concentrations of nanoparticles greatly affect the transparency of the coating material.

4 CONCLUSIONS
4 SKLEPI

The efficacy of cerium oxide (CeO_2) nanoparticle-based coatings for photostabilization of rubberwood (*Hevea brasiliensis*) surfaces was studied. Nanoparticles were surface functionalized with an organic alkoxy silane (3-glycidyloxypropyltrimethoxy silane) to achieve uniform dispersion of nano metal oxide in isopropanol and polyurethane coatings. Isopropanol or polyurethane coating with a dispersed surface of functionalized nanoparticles of different concentrations (concentration (0.5–6) %) were applied to rubberwood. The coated samples were exposed to a UVA-340 nm light source in an accelerated weathering tester. Colour changes occurring due to UV light exposure were analysed at regular time intervals. Uncoated wood showed severe darkening and yellowing with the increase in exposure time, while the wood coated with nano-dispersions showed less darkening and yellowing. The results revealed that formulations with ≥2 % of nanoparticles can stabilize wood surfaces against UV degradation. It was thus shown that dispersion of nanoparticles in PU coatings can significantly restrict the colour changes and photodegradation of wood polymers.

5 SUMMARY

Surface functionalization of nanoparticles using 3-glycidyloxypropyltrimethoxy silane (GPTMS) was carried out. Modified nanoparticles were dispersed in isopropanol and/or polyurethane (PU) coating. The modified nanoparticles and their dispersion were characterized using UV-Visible absorption spectroscopy, X-ray diffraction, dynamic light scattering (DLS) and scanning electron microscopy (SEM). UV-Visible absorption spectra showed a broad and wide absorbance range for nanoparticles in the UV region. The results from SEM showed that modification with GPTMS was effective in reducing agglomeration and obtaining a homogenous distribution of nano metal oxides in the polymer matrix. The efficacy of CeO_2 nanoparticles for photostabilization of rubberwood (*Hevea brasiliensis*) surface was studied. Different concentrations of surface functionalized nanoparticles (concentration (0.5–6) %) were dispersed in isopropanol and polyurethane clear finish, and the obtained formulations were applied on wood. The coated and uncoated samples were exposed to a UVA-340 nm light source in an accelerated weathering tester for up to 500 h and 1000 hours. Colour changes occurring due to UV light exposure were analysed at regular time intervals. The dispersion of nanoparticles in coatings effectively restricted the colour changes and photodegradation of wood polymers, particularly at ≥2 % nanoparticle concentration.

5 POVZETEK

Izvedli smo površinsko funkcionalizacijo nanodelcev s 3-glicidiloksipropiltrimetoksi silanom (GPTMS). Modificirane nanodelce smo dispergirali v izopropanolu in poliuretanskem (PU) premazu. Obdelane nanodelce in njihovi disperziji smo okarakterizirali z UV vidno spektroskopijo, rentgensko difrakcijo, metodo dinamičnega sipanja svetlobe (DLS) in z vrstično elektronsko mikroskopijo (SEM). UV-vidni absorpcijski spektri so za nanodelce pokazali široko območje absorpcije UV svetlobe. Rezultati raziskav s SEM so pokazali, da je bila modifikacija nanodelcev z GPTMS učinkovita pri zmanjševanju aglomeracije in je omogočila homogeno porazdelitev nano kovinskih oksidov v polimerni osnovi. Nato smo proučili učinkovitost nanodelcev CeO_2 nanodelcev za foto-stabilizacijo površin lesa kavčukovca (*Hevea brasiliensis*). Pripravili smo disperzijo površinsko funkcionaliziranih nanodelcev v izopropanolu ali brezbarvni transparentni poliuretanski premaz z nanodelci (koncentracija od (0,5 – 6) %).

Pripravka smo nanesli na les. Površinsko obdelane in neobdelane preskušance smo v komori za umetno pospešeno staranje za 500 ur in 1000 ur izpostavili svetlobi tipa UV A (340 nm). Zaradi izpostavljenosti UV sevanju se je spremenila barva in spremembe le-te smo analizirali v rednih časovnih presledkih. Disperziji nanodelcev sta učinkovito omejili barvne spremembe in foto-degradacijo lesnih polimerov, zlasti pri koncentraciji nanodelcev, višjih od 2 %.

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VPLIV IZBRANIH PARAMETROV OBDELAVE LESA Z ATMOSFERSKO PLAZMO NA PROCES OBDELAVE IN OMOČLJIVOST LESA

THE INFLUENCE OF SELECTED TREATMENT PARAMETERS WITH ATMOSPHERIC PLASMA ON THE TREATMENT PROCESS AND WOOD WETTABILITY

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Izvleček / Abstract

Izvleček: *V prispevku je predstavljena uporaba nizkotemperaturne plazme, ustvarjene v zraku pri atmosferskem tlaku, za obdelavo površin lesa z namenom izboljšanja njihove omočljivosti. Uporabljena je bila naprava s plazemsko razelektritvijo s površinsko oviro, v konfiguraciji s plavajočo elektrodo. Izkazalo se je, da sta gostota in homogenost plazemske razelektritve, ki se je tvorila med izoliranima visoko napetostnima elektrodama in površino lesa smreke (*Picea abies *(L.) Karst.) in bukve (*Fagus sylvatica *L.), zelo odvisni od velikosti razmika med elektrodo in lesom. Meritve topografije s konfokalnim laserskim mikroskopom so pokazale, da obdelava lesa s plazmo na njegovi površini povzroči spremembe na submikroskopskem nivoju. Meritve stičnih kotov kapljic vode in premaza na vodni osnovi so pokazale izboljšano dovzetnost za omočitev obdelanih površin. Zaznati je bilo tudi razlike v omočljivosti površin, v odvisnosti od izbranih parametrov pri obdelavi: vrste lesa, podajalne hitrosti obdelovanca, razdalje med elektrodama, razdalje med elektrodama in obdelovancem ter debeline obdelovanca.*

Ključne besede: *les, omočljivost, plazma, stični kot, voda*

Abstract: *The paper presents the use of low-temperature plasma, generated in the air at atmospheric pressure, for treatment of wood surfaces to improve their wettability. For this purpose, a dielectric barrier discharge plasma device with a floating electrode configuration was used. The density and homogeneity of the plasma discharge, formed between the isolated high voltage electrodes and the surface of the spruce (*Picea abies *(L.) Karst.) and beech (*Fagus sylvatica *L.) wood, was shown to be highly dependent on the size of the gap between the electrode and wood. Topography measurements using a confocal laser microscope showed that exposure of wood to plasma causes changes on its surface at the sub-microscopic level. Measurements of the contact angles of water droplets and water-based coating showed the improved susceptibility to wetting of treated surfaces. Differences in surface wettability were also detected depending on the selected treatment parameters: type of wood, workpiece feed speed, the distance between the electrodes, the distance between the electrodes and workpiece, and workpiece thickness.*

Keywords: *wood, wettability, plasma, contact angle, water*

1 UVOD

1 INTRODUCTION

Plazma poleg trdnega, tekočega in plinastega, predstavlja četrto agregatno stanje snovi. Plazma predstavlja skupino nabitih, vzbujenih in nevtralnih delcev, kot so elektroni, ioni, atomi, molekule, radikali in fotoni. Z umetno ustvarjeno plazmo se dandanes srečujemo v vsakdanjem življenju, kot so na primer fluorescentne luči, plazemski zasloni in fuzijski procesi za proizvodnjo električne energije (Goldston & Rutherford, 1995). Glede na temperaturo ionov in elektronov poznamo visoko- in nizkotemperaturno plazmo, slednjo nadalje delimo na termično ravnovesno in neravnovesno plazmo. O termični plazmi govorimo, kadar imajo elektroni in težji delci enako temperaturo in so v termičnem ravnovesju, v neravnovesni plazmi imajo ioni in nevtroni veliko nižjo temperaturo kot elektroni in ta je blizu sobni (Kogelschatz et al., 1997; Bittencourt, 2004).

Tehnološko lahko plazemsko stanje snovi dosežemo z energetskim vzbujanjem (segrevanjem ali ustvarjanjem elektromagnetnega polja) pri nor-

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malnem ali znižanem tlaku okolice (Rossnagel et al., 1990; Panjan et al., 1998).

Plazma je lahko aktivacijski medij za različne fizikalno-kemijske procese. Visoka energija delcev v plazmi omogoča nastanek vrste različnih procesov (disociacija, ekscitacija in ionizacija atomov ter molekul), ki omogočajo in pospešujejo potek kemijskih reakcij (Junkar et al., 2006; Mozetič, 2019). Ob izpostavitvi trdnih snovi plinu v plazemskem stanju, zaradi bombardiranja molekul na površini in trkov z reaktivnimi delci, pride do sprememb v smislu migracije površinskih atomov, desorpcije nečistoč, kemijskih reakcij s cepitvijo kemijskih vezi, polimerizacije ali oksidacije površine itd. (Panjan, 1989; Panjan, 1999; Blanchard et al., 2009). To s pridom izkoriščamo za modifikacijo površin materialov, kot je čiščenje, sterilizacija, jedkanje, depozicija plasti drugih materialov in njihova funkcionalizacija (omočljivost, morfologija in adhezijske lastnosti) pred nadaljnjo obdelavo (Panjan, 1989; Mozetič & Panjan, 2000). Nastanek določene vrste plazme je tesno povezan s plazemskimi parametri (Cvelbar & Mozetič, 2007). Med parametre, ki jih lažje nadzorujemo in uravnavamo, spadajo tudi lastnosti izmeničnega toka (napetost, frekvenca in oblika signalov), lastnosti in dimenzije obdelanega materiala, sestava plazemskega plina, velikost razmika med izolirano elektrodo in površino obdelovanca, čas izpostavitve, itd.

Z vidika tehnoloških in ekonomskih vidikov je izvajanje tovrstnih postopkov najbolj smotrno pri atmosferskem tlaku ob prisotnosti različnih plinov. Tu poznamo tri načine generiranja plazme, in sicer koronske, tokovne oz. s šobami (angl. *jet*) in potencialne dielektrične (angl. *dielectric discharge*) razelektritve (Cvelbar & Mozetič, 2007). Slednje, imenovane tudi kot razelektritve s površinsko oviro, so v tuji literaturi in tehnoloških aplikacijah znane pod angleškim nazivom *dielectric barrier discharges* (kratica DBD) (Chirokov et al., 2005). V osnovi gre za konfiguracijo dveh elektrod, od katerih je vsaj ena prekrita z dielektrikom, ob dotoku električne napetosti v razmiku med elektrodama pride do razelektritve plina, pojava plazme (Wolf, 2013).

Obdelava s plazmo ima velik potencial tudi za modifikacijo lastnosti površin lesa in lesnih tvoriv (Rehn & Viöl, 2003; Gramlich et al., 2006; Petrič, 2013; Žigon et al., 2018). Pri trku vpadnega delca iz plazme s površino lesa pride do različnih kemijskih reakcij (Vesel & Mozetič, 2003; Drenik et al., 2005), pri tem tudi do povečanja proste površinske energije površin (Klampfer & Jesih, 1999; Žigon et al., 2019). Pri lesu to pozitivno vpliva na omočljivost in adhezijo nanesenih premaznih sredstev in lepil na vodni osnovi (Tóth et al., 2007; Prégent et al., 2015; Peters et al., 2017; Žigon et al., 2019).

Ena od različic DBD plazem je tudi DBD plazma s plavajočo elektrodo (Hoffmann et al., 2013). Ta se od osnovne DBD konfiguracije razlikuje v tem, da drugo elektrodo predstavlja prevodni objekt kot nosilec električnega naboja, t.i. plavajoči potencial (od tod ime). Tovrstna DBD plazma je bila večkrat raziskana za aplikacijo v medicinske namene (Fridman et al., 2006; Fridman et al., 2007; Cooper et al., 2010). Nasprotno elektrodo lahko predstavlja tudi les, ki je zaradi vsebnosti vlage do neke mere električno prevoden. Ker je električna prevodnost lesa pri ravnovesnih vlažnostih, ki so primerne za nadaljnjo obdelavo (t.j. 5 % - 12 %) prenizka, je prisotnost nasprotne (kovinske) elektrode kljub temu nujna. To lahko predstavlja npr. nosilec na spodnji strani obdelovanca (Žigon et al., 2019).

V splošnem obdelava s plazmo v zraku pri atmosferskem tlaku površine lesa očisti in povzroči njihovo oksidacijo, na kar nakazuje povečanje prisotnosti C-O, O-C=O in -OH komponent, ter zmanjšanje C-C in C-H komponent v celulozi, hemicelulozah in ligninu. Skupaj z nastankom različnih radikalov, kationov (npr. N^+, O^+, OH^+) in anionov (OH^- in O_2^-) pride do povečanja polarnega značaja površin (Avramidis et al., 2009; Hardy et al., 2015; Král et al., 2015). Vseeno velja, da je učinkovitost obdelave s plazmo razen od strukture in kemične sestave lesa odvisna tudi od časa izpostavitve. Hidrofilnost lesa se namreč poveča že po nekaj sekundah obdelave (Altgen et al., 2020). Daljši čas obdelave s plazmo in predvsem povečana dovedena moč lahko povzročita tudi spremembe v mikrostrukturi in jedkanje površine lesa (Jamali & Evans, 2011; Jamali & Evans, 2020).

Merjenje stičnega kota (SK) med tangento na površino kapljice tekočine in stično površino je enostavna in zanesljiva metoda za ugotavljanje omočljivosti določenega materiala. SK je poleg površinske napetosti tekočine v veliki meri odvisen od proste površinske energije in ostalih lastnosti površine (kemijska sestava, morfologija, poroznost) (Gardner et al., 1991; Liptáková & Kúdela, 1994; Wålinder & Gardner, 1999). Z vidika površinske zaščite lesa s premazi je povišanje proste površinske energije pred nanosom premaza seveda zelo zaželeno. Tako lahko s plazmo nadomestimo ostale postopke priprave površin lesa pred premazovanjem, kot sta brušenje in nanos temeljnih premazov (Wolkenhauer et al., 2009; Demirkir et al., 2014).

V prispevku bomo predstavili primer uporabe DBD plazme s plavajočo elektrodo za obdelavo površin lesa z namenom izboljšanja omočljivosti z vodo in izbranim premazom na vodni osnovi. Predstaviti želimo vpliv nekaterih nastavitev naprave pri obdelavi, kot tudi lastnosti obdelovancev na proces obdelave. Vpliv obdelave na morfologijo površin lesa smo proučili s primerjavo stanja površin na mikroskopskem nivoju pred obdelavo in po njej. Razlike v omočljivosti površin, ob spreminjanju izbranih parametrov obdelave, smo ugotavljali z merjenjem stičnih kotov kapljic vode in premaza.

2 MATERIALI IN METODE

2 MATERIALS AND METHODS

2.1 LES

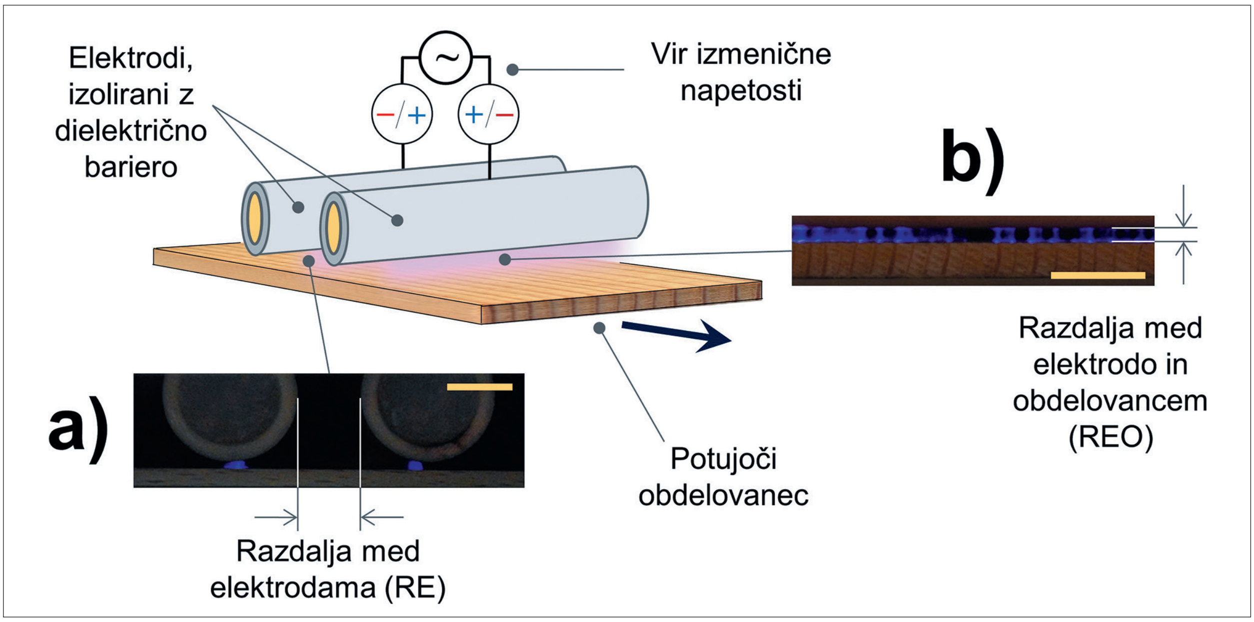
2.1 WOOD

V raziskavi je bil uporabljen les navadne smreke (*Picea abies* (L.) Karst.) in navadne bukve (*Fagus sylvatica* L.), iz katerega smo pripravili vzorce velikosti 60 mm × 30 mm × 3 mm (orientacija vlaken: longitudinalno × radialno × tangencialno). Nadalje analize so potekale na radialnih ploskvah. Vsi vzorci so bili pred začetkom klimatizirani v prostoru s temperaturo 20 °C in relativno zračno vlažnostjo 65 %. Pri tem so bukovi vzorci dosegli 12,1 %, smrekovi vzorci pa 10,8 % ravnovesno vlažnost (ugotovljeno gravimetrično).

2.2 OBDELAVA LESA Z DBD PLAZMO S PLAVAJOČO ELEKTRODO

2.2 TREATMENT OF WOOD WITH FLOATING ELECTRODE DBD PLASMA

Vhodne električne parametre v napravi krmilimo preko visokonapetostnega napajalnika, ki je priključen na električno omrežje. Pretvornik proizvaja visoko napetost do 15 kV z izhodno močjo do 300 W pri izbirni frekvenci 5 kHz. Na visokonapetostno stran tuljave sta priključeni elektrodi z določeno kapacitivnostjo, med katerima pride do razelektritve prisotnega plina. Elektrodi sta z namenom enakomerne razporeditve naboja v električnem polju in preprečitve preboja prekriti z dielektrično bariero. Prisotnost prevodnega ali dielektričnega obdelovanca z določeno električno prevodnostjo in kapacitivnostjo vpliva na lastnosti



Slika 1. Prikaz obdelave vzorca lesa z DBD plazmo s plavajočo elektrodo: stranski (a) in frontalni (b) pogled na tvorjeno plazemsko razelektritev. Merilni skali predstavljata dolžino 10 mm.
Figure 1. Schematic illustration of the treatment of a wooden sample with a floating electrode DBD plasma: side (a) and front (b) view of the generated plasma discharge. The length of scale bars represents 10 mm.

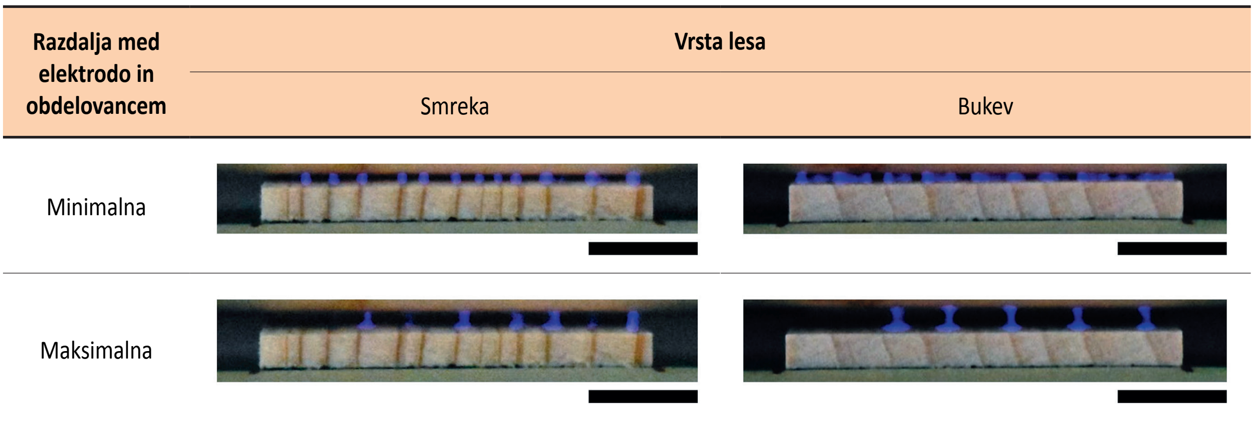
ustvarjenega električnega polja oz. plazemsko razelektritev. Nasprotno obdelava površine obdelovanca z nabitimi delci vpliva na lastnosti njegovih površin.

V raziskavi so bili vzorci lesa obdelani s plazmo tako, kot je prikazano na sliki 1. Medeninasti elektrodi premera 15 mm, vstavljeni v keramični (Al_2O_3) cevi (debelina stene 2,5 mm), sta bili priklopljeni na visoko napetostni napajalnik z nastavljenimi električnimi parametri. Plazemska razelektritev zraka se je tvorila med izoliranima elektrodama in površino obdelovanca, ki je pod njima potoval z določeno hitrostjo (1 $mm \cdot s^{-1}$ ali 3 $mm \cdot s^{-1}$). V nadaljevanju eksperimentalnega dela smo spreminjali tudi razdaljo med elektrodama (RE) (slika 1a), razdaljo med elektrodama in obdelovancem (REO) (slika 1b) ter obdelovali vzorce lesa različnih debelin (1,5 mm, 2,5 mm in 3,2 mm).

2.3 ANALIZA PLAZEMSKIH RAZELEKTRITEV
2.3 PLASMA DISCHARGE ANALYSIS

Heterogene reakcije med plazemskimi delci in površinami trdnih snovi v atmosferskih pogojih se odrazijo v obliki nastanka plazemskih pramenov (angl. *plasma streamers*), ki so porazdeljeni po dielektrični površini v razmiku med izolirano elektrodo in obdelovancem (Klampfer & Jesih, 1999; Cvelbar & Mozetič, 2007; Černák et al., 2009). Predhodne ugotovitve so pokazale vpliv razdalje med elektrodo in obdelovancem ter porazdelitve ranega in kasnega lesa na obdelanem lesu na tvorbo plazemskih razelektritev (Žigon & Dahle, 2019). Slika 2 prikazuje odvisnost gostote razelektritve in porazdelitve plazemskih pramenov od velikosti razmika med elektrodo in vzorcem. Jakost razelektritev je v primeru bukve zaradi večje gostote in višje ravnovesne vlažnosti lesa večja kot pri smreki (Todorović, 2019). Poleg tega se plazemski prameni večinoma tvorijo na območju gostejšega kasnega lesa, vendar se tik nad površino njihov premer poveča in zajame tudi del ranega lesa (Klein et al., 2001; Kogelschatz, 2002). Minimalna razdalja predstavlja razmik, pri katerem vzorec še nemoteno potuje pod elektrodama (približno 0,5 mm), maksimalna razdalja pa razmik, pri katerem se med vzorcem in elektrodo razelektritev še tvori.

Proučevali smo vpliv RE (5 mm, 6 mm, 8 mm in 10 mm), kot tudi REO (minimalna in maksimalna) na tvorbo plazemskih razelektritev. Te smo posneli s fotokamero (Olympus E520, Olympus, Tokio, Japonska), vedno pri enakih pogojih fotografiranja (velikost zaslonke 5,6, čas osvetlitve 0,1 s, hitrost ISO 8.000). Posnete fotografije smo analizirali s programom Fiji (ImageJ 1.46d, Madison, WI, ZDA), in sicer z meritvami sive vrednosti v območju razelektritve vzdolž širine posameznega vzorca (0 – popolnoma črna, 255 – popolnoma bela). Analize plazemskih razelektritev so bile opravljene na petih vzorcih za posamezen parameter.



Slika 2. Prikaz minimalne in maksimalne razdalje med elektrodo in vzorcem lesa, ob tvorbi plazemske razelektritve. Merilne skale predstavljajo dolžino 10 mm.

Figure 2. Demonstration of the minimum and maximum distances between the electrode and the wood sample upon formation of the plasma discharge. The length of scale bars represents 10 mm.

2.4 ANALIZA VPLIVA OBDELAVE LESA S PLAZMO NA TOPOGRAFIJO POVRŠIN LESA
2.4 ANALYSIS OF THE INFLUENCE OF PLASMA TREATMENT ON WOOD SURFACE TOPOGRAPHY

Spremembe v topografiji površin vzorcev zaradi obdelave s plazmo smo spremljali s konfokalnim laserskim mikroskopom LEXT OLS5000 (Olympus, Tokio, Japonska). Iz obeh vrst lesov smo pripravili vzorce dimenzij 10 mm × 10 mm × 3 mm, z drsnim mikrotomom smo poravnali njihove radialne površine. Analize površin so bile opravljene na istem mestu, in sicer pred, ter po 5 s, 10 s in 30 s obdelave s plazmo. Mikroskopiranje je bilo izvedeno z laserskim žarkom z valovno dolžino 405 nm, pri lateralni resoluciji 0,12 µm. Tridimenzionalne topografske slike površin so bile zajete pri 5×, 10× in 20× povečavi, aritmetična povprečna hrapavost površine (S_a) in njene spremembe so bile izračunane s programom OLS50-S-AA (Olympus, Tokio, Japonska). Analize topografije površin so bile opravljene na petih vzorcih posamezne lesne vrste.

2.5 MERJENJE STIČNIH KOTOV VODE IN PREMAZA
2.5 DETERMINATION OF WATER AND COATING CONTACT ANGLES

Ob predpostavki, da nastavitve določenih parametrov obdelave vzorcev lesa s plazmo vplivajo na spremembo omočljivosti lesa, smo proučili vpliv naslednjih parametrov: lesna vrsta, hitrost obdelave (v), RE, REO in debelina obdelovanca (d). Za analizo omočljivosti smo uporabili deionizirano vodo in komercialni pigmentiran akrilni premaz na vodni osnovi (Belinka Interier, Belinka belles d.o.o., Ljubljana, Slovenija). Površinska napetost vode je znašala 43,4 mN·m^{-1}, površinska napetost premaza pa 30,1 mN·m^{-1}. Oblike oz. obrise nanesenih kapljic, kot tudi analizo stičnih kotov (SK) med kapljicami destilirane vode oz. premaza in površino vzorcev smo izmerili z optičnim goniometrom Theta (Biolin Scientific, Oy, Espoo, Finska). SK so bili izmerjeni po načinu analize Young-Laplace, v programski opremi OneAttension različice 2,4 (r4931) (Biolin Scientific). Kapljice s prostornino 5 µL smo nanesli na štiri različna mesta na radialni površini posameznega vzorca. Analize omočljivosti so bile opravljene na treh vzorcih za posamezen parameter, skupno 12 meritev na serijo vzorcev. Opozoriti velja, da vplivi posameznih proučevanih parametrov med obdelavo na omočljivost lesov zaradi časovnih omejitev niso bili izvedeni sočasno. Meritve SK na vzorcih, obdelanih s plazmo, so bile izvedene takoj po obdelavi. Snemanje slike (1,3 slike na sekundo) se je začelo ob umiku konice pipete od kapljice in je potekalo 60 s. Meritve smo izvajali pri temperaturi 20 °C.

3 REZULTATI IN RAZPRAVA
3 RESULTS AND DISCUSSION

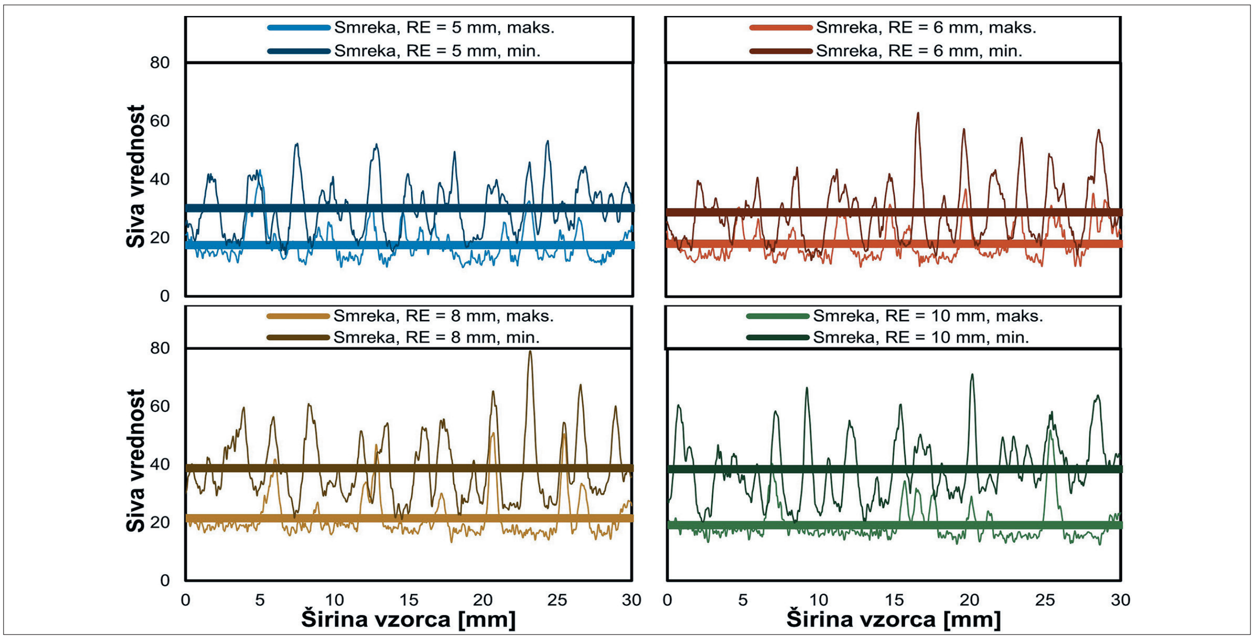
3.1 INTENZIVNOST PLAZEMSKIH RAZELEKTRITEV
3.1 INTENSITY OF PLASMA DISCHARGES

Iz slike 3 lahko razberemo porazdelitev plazemskih pramenov vzdolž širine vzorcev lesa smreke pri obdelavi s plazmo, kot tudi povprečne vrednosti izmerjenih sivih vrednosti pri določenih parametrih obdelave (RE in REO). Meritve so pokazale, da je pri minimalni REO povprečna izmerjena siva vrednost oz. svetlost tvorjene plazemske razelektritve višja kot pri maksimalni REO. To nakazuje na večjo jakost ustvarjenega električnega polja pri manjši REO. Izkazalo se je, da pri obdelavi lesa smreke s povečevanjem RE, narašča tudi povprečna siva vrednost. Vpliv RE je bil izrazitejši pri obdelavi lesa bukve (slika 4). Tu je s povečevanjem RE iz 5 mm na 6 mm, 8 mm oz. 10 mm, naraščala tudi izmerjena siva vrednost, tako pri minimalni (iz 33,7 na 41,8; 46,7 oz. 50,5), kot tudi pri maksimalni (iz 17,8 na 19,45; 22,3 oz. 20,8) REO. To pomeni, da se je plazemska razelektritev intenzivneje razvila pri obdelavi bukovine. Razlog za to sta najverjetneje višja ravnovesna vlažnost in gostota lesa ter posledično večja električna prevodnost bukovine.

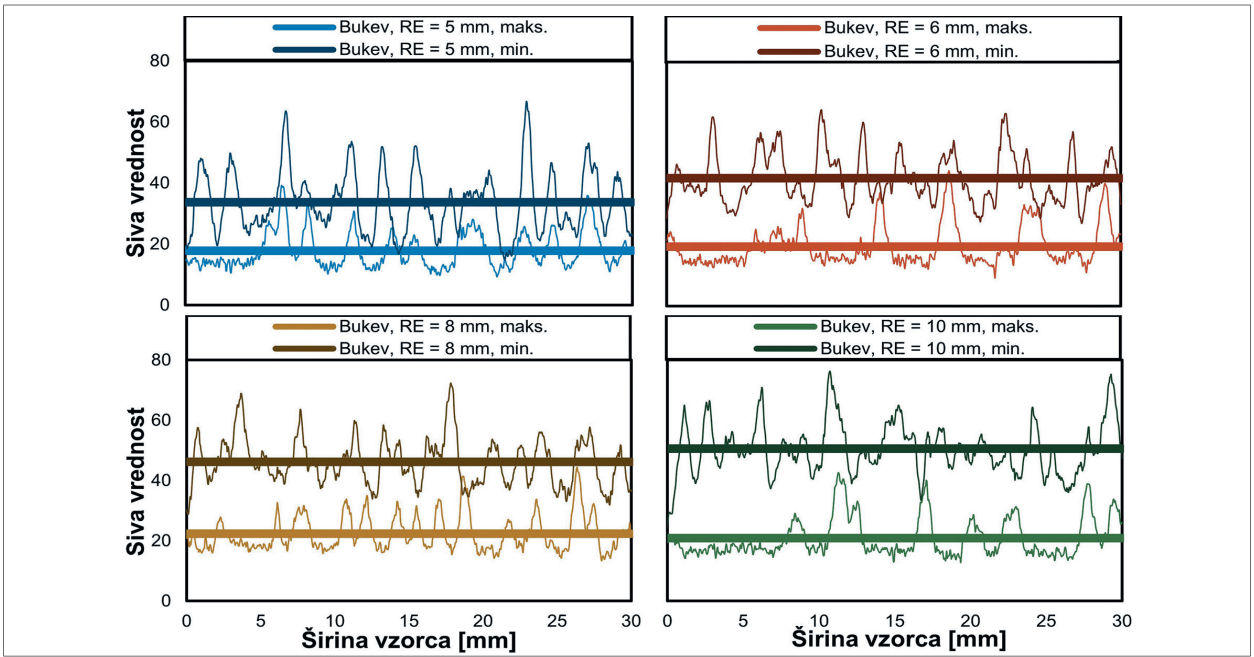
3.2 SPREMEMBE TOPOGRAFIJE POVRŠIN LESA
3.2 CHANGES OF WOOD SURFACE TOPOGRAPHY

V preglednici 1 so prikazane 3-dimenzionalne topografske slike površin lesov pred različno dolgimi obdelavami s plazmo in po njih, zajete pri 20× povečavi.

V preglednici 2 so navedene vrednosti sprememb aritmetične povprečne hrapavosti površine (S_a) pred obdelavo lesa smreke in bukve in po njej, izmerjene pri različnih povečavah. Razbrati je mogoče, da je zaznana hrapavost neobdelanega lesa odvisna od uporabljene povečave in s tem velikosti površine pri opazovanju. Večja kot je bila površina analiziranega področja, večja je vrednost S_a, in obratno. Poleg tega je razvidno, da se vrednosti S_a, ne glede na uporabljeno povečavo, s po-

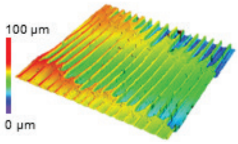
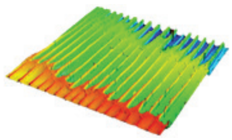
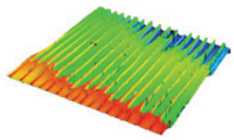
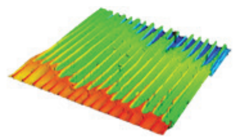
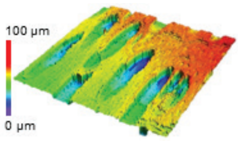
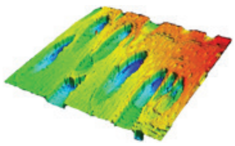
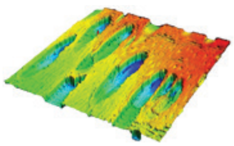
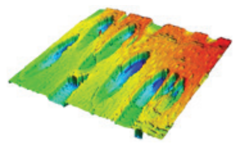


Slika 3. Povprečna siva vrednost plazemske razelektritve vzdolž širine obdelovancev smreke pri različnih RE (5 mm, 6 mm, 8 mm in 10 mm) ter minimalni in maksimalni REO (min. in maks.).
Figure 3. The average grey value of plasma discharge along the width of spruce workpieces at different distances between the electrodes (5 mm, 6 mm, 8 mm and 10 mm), and at the minimum or maximum distance between the electrode and the treated sample (min. and maks.).



Slika 4. Povprečna siva vrednost plazemske razelektritve vzdolž širine obdelovancev bukve pri različnih RE (5 mm, 6 mm, 8 mm in 10 mm) ter minimalni in maksimalni REO (min. in maks.).
Figure 4. The average grey value of plasma discharge along the width of beech workpieces at different distances between the electrodes (5 mm, 6 mm, 8 mm and 10 mm), and at the minimum or maximum distance between the electrode and the treated sample (min. and maks.).

Preglednica 1. Rekonstruirane 3-dimenzionalne topografske slike površin lesov pred obdelavo s plazmo in po njej.
Table 1. Reconstructed 3-dimensional topographic photos of the surfaces before and after treatment with plasma.

Vrsta lesa	Izgled površine pri 20× povečavi			
	Neobdelana	Obdelana s plazmo		
		5 s	10 s	30 s
Smreka				
Bukev				

*Velikost analiziranih področij: 640 μm × 640 μm

daljševanjem časa obdelave znižujejo. Ta pojav je sicer pri lesu bukve manj opazen kot pri lesu smreke. Pri obeh lesnih vrstah negativne spremembe S_a nakazujejo na znižanje hrapavosti površin. To bi lahko bila posledica bodisi jedkanja površin, čiščenja površin oz. odstranitve nečistoč in prahu, ali znižanja vsebnosti vlage v lesu v procesu obdelave s plazmo. Opozoriti velja, da to lahko trdimo le za mikroskopski nivo opazovanja. Namreč, na nižjem (npr. nanometrskem) nivoju opazovanja bi morda lahko zaznali tudi drugačen pojav s povečanjem hrapavosti površin po obdelavi s plazmo (Wolkenhauer et al., 2008).

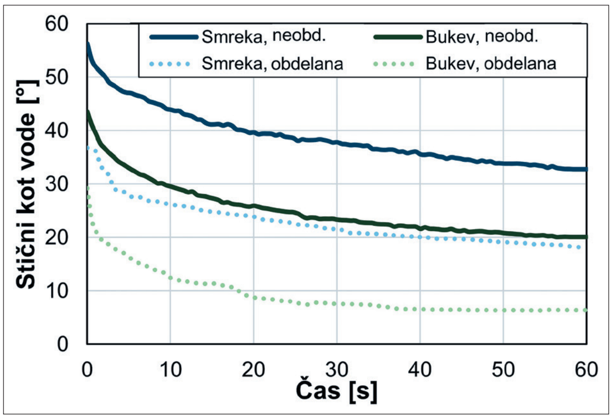
3.3 SK KAPLJIC VODE
3.3 WATER DROPLETS CONTACT ANGLES (CA)
3.3.1 Vpliv vrste lesa
3.3.1 The influence of wood species

SK kapljic vode, nanesenih na površino lesa, se s časom zmanjšuje. Takoj po nanosu se volumen kapljice začne zmanjševati zaradi vpijanja tekočine v higroskopno podlago. Dinamika sprememb SK kapljic vode na površinah lesov v odvisnosti od vrste lesa in predhodne obdelave s plazmo je prikazana na sliki 5. Obdelava s plazmo je potekala pri naslednjih parametrih: v = 3 mm·s^{-1}, RE = 5 mm, REO = 1 mm in d = 3,2 mm. Izkazalo se je, da

Vrsta lesa	Povečava	Vrednost S_a [μm]			
		Neobdelano	Obdelano s plazmo		
			5 s	10 s	30 s
Smreka	5×	22,25	-0,19	-0,36	-0,03
	10×	10,90	-0,06	-0,06	-0,02
	20×	9,82	-0,02	-0,06	-0,08
Bukev	5×	18,36	-0,02	-0,06	-0,09
	10×	12,69	-0,02	-0,05	-0,04
	20×	10,25	-0,01	-0,01	0,00

Preglednica 2. Aritmetična povprečna hrapavost površine (S_a) pred obdelavo lesa smreke in bukve s plazmo in po njej, izmerjena pri različnih povečavah.
Table 2. Surface arithmetic mean roughness (S_a) before and after treatment of spruce and beech wood with plasma, detected by different magnifications.

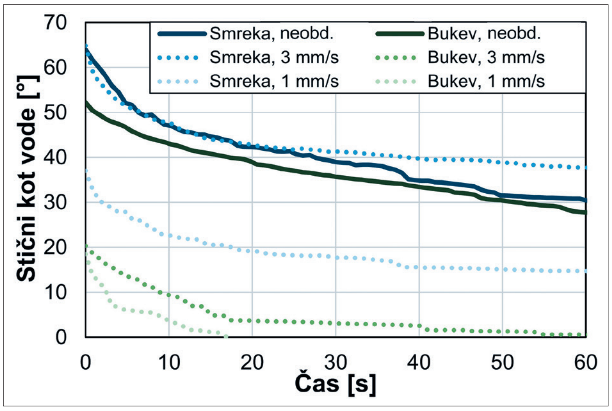
voda bolje omaka površino bukovine kot površino smrekovine, o čemer poročata tudi Papp in Csiha (2017). Vpliv obdelave s plazmo na SK vode je bil pri obeh vrstah lesa podoben. Po 60 s od nanosa se je pri smreki znižal z 32,8° na 18,2°, pri bukvi pa z 20,1° na 6,4°.



Slika 5. Odvisnost SK kapljic vode od vrste lesa.
Figure 5. Dependence of the water droplets' CA on the wood species.

3.3.2 Vpliv hitrosti obdelave
3.3.2 The influence of treatment feed speed

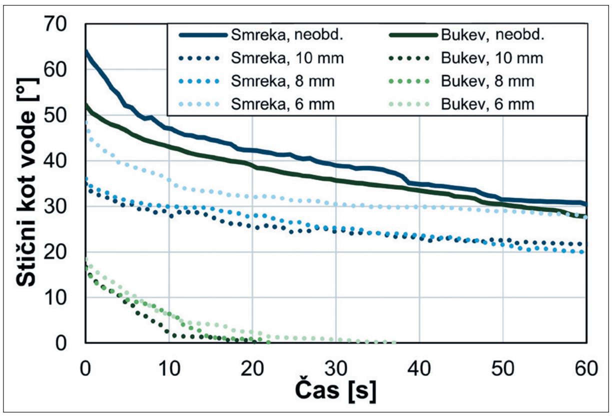
Hitrost pretoka obdelovanca skozi plazemsko razelektritev je sorazmerna s časom, v katerem je določen del površine obdelovanca izpostavljen trkom z aktivnimi delci plazme. Slika 6 prikazuje spremembe SK kapljic vode na površinah lesov v odvisnosti od podajalne hitrosti pri obdelavi s plazmo, pri kateri so bili ostali parametri sledeči: RE = 5 mm, REO = 1 mm in d = 3,2 mm. V splošnem obdelava lesa s plazmo pri nižji podajalni hitrosti (1 mm·s^{-1}) prispeva k boljši omočljivosti kot pri višji podajalni hitrosti (3 mm·s^{-1}). Vpliv podajalne hitrosti je bil pri obdelavi lesa bukve očitnejši kot pri lesu smreke. Pri smreki je k znižanju SK z začetnih 30,4° na 14,7° (po 60 s meritve) prispevala le obdelava s hitrostjo 1 mm·s^{-1}. Učinek obdelave s plazmo je bil pri bukovini vidnejši že pri podajalni hitrosti 3 mm·s^{-1}, kjer je bila po zaključku meritve zaznana popolna omočitev. Bukovi vzorci, obdelani pri podajalni hitrosti 1 mm·s^{-1}, so bili v povprečju popolnoma omočeni že po 17 s meritve.



Slika 6. Odvisnost SK kapljic vode od podajalne hitrosti lesa pri obdelavi s plazmo.
Figure 6. Dependence of the water droplets' CA on the feed speed of the sample during the plasma treatment.

3.3.3 Vpliv razdalje med elektrodama
3.3.3 Influence of distance between the electrodes

Razdalja med elektrodama (RE) pri uporabljeni konfiguraciji naprave z DBD plazmo vpliva na smer in gostoto ustvarjenega električnega polja med elektrodama. Pričakovati je torej, da to posredno vpliva tudi na učinek, ki ga ima plazma na obdelovanec (Žigon et al., 2019). Spremembe SK kapljic vode na površinah lesov v odvisnosti RE pri obdelavi s plazmo so prikazane na sliki 7. Tu so bili parametri obdelave naslednji: v = 3 mm·s^{-1}, REO = 1 mm in d = 3,2 mm. Pri obeh lesnih vrstah je s po-



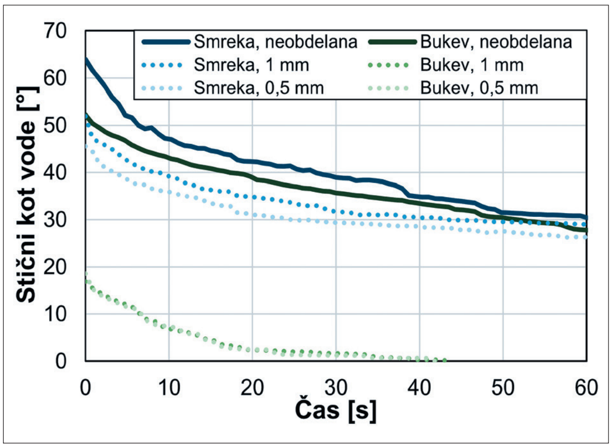
Slika 7. Odvisnost SK kapljic vode od RE pri obdelavi s plazmo.
Figure 7. Dependence of the water droplets' CA on the distance between the electrodes during the plasma treatment.

večevanjem RE omočitev z vodo postajala učinkovitejša. V primeru lesa smreke je po 60 s meritve zaznani SK vode pri RE 10 mm znašal 21,7°, pri RE 8 mm 19,7°, pri zmanjšanju RE na 6 mm se je ta zvišal na 27,4°. Pri obdelavi vzorcev bukovine z RE 10 mm je bila popolna omočitev zaznana po 21,3 s, ob RE 8 mm po 22,1 s, ob RE 6 mm po 37,1 s od nanosa kapljice vode.

3.3.4 Vpliv razdalje med elektrodama in obdelovancem

3.3.4 Influence of distance between the electrodes and the workpiece

Predhodne simulacije tvorbe električnega polja in analize plazemskih razelektritev so pokazale vpliv RE. Podobno so simulacije pokazale vpliv REO na lastnosti plazme (Žigon et al., 2019; Žigon & Dahle, 2019). Posledično bi bilo pričakovati, da ima vpliv na spremembo omočljivosti površin lesov tudi REO. Slika 8 prikazuje krivulje SK kapljic vode v odvisnosti od REO (približno 0,5 mm in približno 1 mm), pri čemer so bili ostali parametri, kot sledi: v = 3 mm·s^{-1}, RE = 5 mm in d = 3,2 mm. Vpliv REO na izboljšanje omočljivosti lesa je bil zaznan pri obdelavi lesa smreke; po 60 s meritve je SK vode pri manjši REO znašal 26,2°, pri večji REO pa 29,0°. Pri obdelavi lesa bukve so bile razlike ob različnih REO skoraj neznatne. Popolna omočljivost je bila namreč zaznana po 43,5 s (večja REO) oz. po 41,9 s (manjša REO).



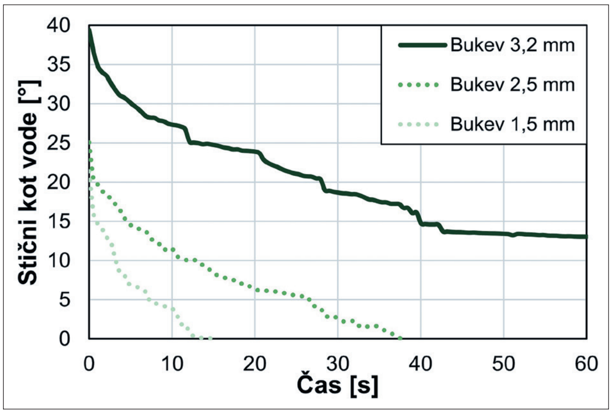
Slika 8. Odvisnost SK kapljic vode od REO pri obdelavi s plazmo.

Figure 8. Dependence of the water droplets' CA on the distance between the electrode and the workpiece by the treatment with plasma.

3.3.5 Vpliv debeline obdelovanca

3.3.5 Influence of the workpieces' thickness

Zaradi načina tvorbe razelektritev pri DBD plazmi s plavajočo elektrodo je pričakovan tudi vpliv debeline obdelovanca na spremembo omočljivosti po obdelavi. Za obdelovanec je namreč značilna določena kapacitivnost, ki med drugim zavisi tudi od njegovih fizičnih dimenzij (Saslow, 2002). V tem delu raziskave so bili uporabljeni zgolj obdelovanci lesa bukve, parametri obdelave so bili: v = 3 mm·s^{-1}, RE = 5 mm in REO = 1 mm. Kot je razvidno iz slike 9, je vpliv obdelave s plazmo na omočljivost lesa zelo odvisen od debeline obdelovanca. SK vode pri najdebelejših obdelovancih je po 60 s meritve znašal 13,0°, medtem ko so bili obdelovanci debeline 2,5 mm in 1,5 mm popolnoma omočeni po 37,9 s oz. po 15,3 s od začetka meritve.



Slika 9. Odvisnost SK kapljic vode od debeline obdelovanca pri obdelavi s plazmo.

Figure 9. Dependence of the water droplets' CA on the workpieces' thickness during the plasma treatment.

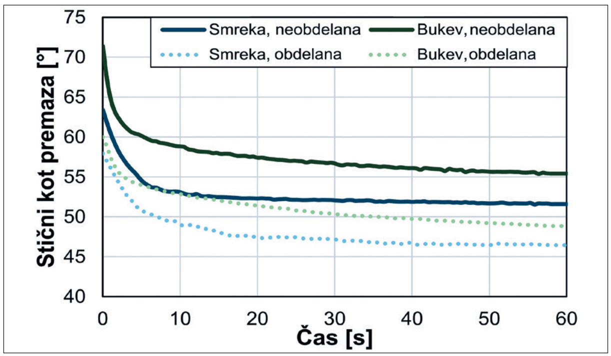
3.4 SK KAPLJIC PREMAZA

3.4 COATING DROPLETS' CA

3.4.1 Vpliv vrste lesa

3.4.1 The influence of wood species

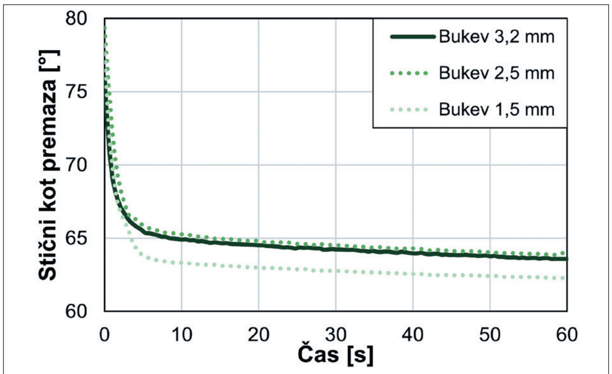
Pri meritvah SK premaza je bila zaznana podobna dinamika kot v primeru SK kapljic vode v odvisnosti od vrste lesa in predhodne obdelave (slika 10). V splošnem so vrednosti SK premaza sicer višje od vode, razlog za to so drugačne fizikalne lastnosti obeh tekočin (npr. površinska napetost). Obdelava s plazmo je potekala pri v = 3 mm·s^{-1}, RE = 5 mm, REO = 1 mm in d = 3,2 mm. Za razliko od vode je premaz nekoliko bolje omakal površino smrekovine kot površino bukovine, vpliv obdelave na razliko med omočljivostjo neobdelanih in obdelanih površin je bil pri obeh lesovih podoben. Po 60 s od nanosa se je SK pri smreki znižal z 51,6° na 46,4°, pri bukvi pa s 55,4° na 48,8°.



Slika 10. Odvisnost SK kapljic premaza od vrste lesa.
Figure 10. Dependence of the coating droplets' CA on the wood species.

3.4.2 Vpliv debeline obdelovanca
3.4.2 Influence of the workpieces' thickness

Vpliv debeline obdelovanca na učinek obdelave na spremembo omočljivosti lesa s premazom je bil manj izrazit (slika 11) kot pri SK vode; obdelava je bila izvedena sicer z enakimi parametri (v = 3 mm·s^{-1}, RE = 5 mm in REO = 1 mm). SK kapljic premaza pri obdelovancih debeline 3,2 mm in 2,5 mm je bil po 60 s meritve enak (64,0°), pri najtanjših obdelovancih se je ta za malenkost znižal (na 62,8°). Vpliv debeline obdelovanca je tu manj izrazit najverjetneje zaradi že omenjenih drugačnih fizikalnih lastnosti premaza v primerjavi z lastnostmi vode.



Slika 11. Odvisnost SK kapljic premaza od debeline obdelovanca pri obdelavi s plazmo.
Figure 11. Dependence of the coating droplets' CA on the workpieces' thickness during the plasma treatment.

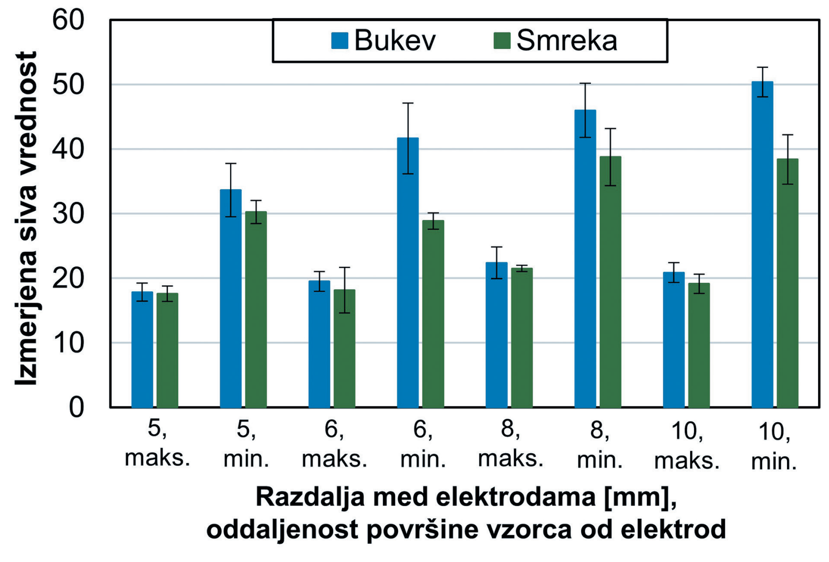
4 ZAKLJUČEK
4 CONCLUSION

Rezultati analize tvorjenih plazemskih razelektritev med izoliranima elektrodama in površinami obdelovancev obeh lesov so povzeti na sliki 12. Izkazalo se je, da z manjšanjem REO svetlost tvorjene plazemske razelektritve narašča. Pojav sovpada z značilnostmi DBD plazem, kjer je jakost električnega polja zelo odvisna od razdalje oz. razmika med nasprotnima elektrodama. To je verjetno povezano z gostoto električnega toka v plinski razelektritvi. Do električnega preboja namreč pride takoj, ko je jakost električnega polja v REO dovolj velika. Pri manjši REO se to zgodi malenkost prej kot pri večji REO, jakost električnega polja se pri tem ne razlikuje. Pri tem moč transformatorja ostaja omejena, zato mora biti napetost, ob enaki jakosti električnega polja, pri večji REO višja, tok se pri tem zmanjša. Po drugi strani s povečevanjem RE jakost razelektritev in s tem njihova intenzivnost narašča. Pri uporabljeni konfiguraciji DBD plazme s plavajočo elektrodo namreč RE vpliva na smer in gostoto električnega polja, ustvarjenega med elektrodama preko obdelovanca. Posledično, bolj kot sta bili elektrodi narazen, manj energije se je izgubilo neposredno med njima, večji so bili električni tokovi in energija v razelektritvi in večja je bila svetlost razelektritve zraka v razmiku med izolirano elektrodo in površino obdelovanca, opazovane s frontalne strani. Dognanja o ugotovljenih vplivih RE in REO na izmerjene sive vrednosti plazemskih razelektritev so se odrazila tudi pri ugotovitvah učinka le-teh na omočljivost lesov z vodo in premazom po obdelavi s plazmo.

Obdelava lesa s plazmo je vplivala na hrapavost površin lesa, ki se je sicer s podaljševanjem časa obdelave zniževala. Ker plazma velja za fizikalen pojav, so zaznane spremembe v topografiji površin lesa posledica njihovega jedkanja, čiščenja, sušenja ipd.

Drugi del raziskave je potrdil iz dosedanjih raziskav znano dejstvo, da obdelava premazov s plazmo, ustvarjeno v zraku in pri atmosferskem tlaku, izboljša omočljivost lesa z vodo (t.j. hidrofilnost) in s premazi na vodni osnovi (preglednica 3).

Nivo znižanja SK vode pri lesu smreke in bukve napram neobdelanemu lesu po obdelavi s plazmo je zelo podoben, in sicer za 15° do 20°. Obdelava lesa s plazmo pri nižji podajalni hitrosti prispeva k boljši omočljivosti obdelovanca kot pri



Slika 12. Povprečna izmerjena siva vrednost plazemske razelektritve vzdolž širine vzorcev lesa pri različnih RE ter minimalni in maksimalni REO.
Figure 12. The average measured grey value of plasma discharge along the width of wood samples at different distances between the electrodes and the minimum and maximum distance between the electrode and workpiece.

višji podajalni hitrosti, pri čemer je vpliv podajalne hitrosti očitnejši pri bukovini. V DBD plazmi s plavajočo elektrodo je ob dovajanju visoke napetosti v elektrodi jakost ustvarjenega električnega polja zelo odvisna od RE in od REO. Vpliv posameznega kot tudi vzajemnega spreminjanja teh dveh parametrov v procesu obdelave se je odrazil tudi na omočljivosti lesa. S povečevanjem RE se je hidrofilnost površine lesov povečevala, kar je bilo zaznati zlasti pri obdelavi lesa bukve. Spremembe REO iz približno 1 mm na približno 0,5 mm (in obratno) niso drastično povečale hidrofilnosti lesov, vendar je bil trend kljub temu opazen, tako pri lesu smreke kot tudi bukve. Izmed vseh proučevanih parametrov je največji vpliv na povečanje hidrofilnosti lesa bil zaznan ob spreminjanju debeline obdelovanca. Pri najdebelejših obdelovancih iz bukovine se je SK vode po 60 s meritev iz prvotnih 40° znižal na 13°, med tem, ko so bili tanjši obdelovanci (debeline 2,5 mm in 1,5 mm) popolnoma omočeni že pred potekom celotnih meritev (po 37,9 s oz. po 15,3 s).

SK kapljic premaza so višje od SK vode, razlog za to so drugačne fizikalne lastnosti obeh tekočin (površinska napetost, višja gostota in viskoznost premaza).

Preglednica 3. Slike in vrednosti SK kapljic vode in premaza, 1 s po nanosu na neobdelano in s plazmo obdelano površino lesa bukve. Merilne skale predstavljajo dolžino 2 mm.
Table 3. Figures and CA values of water and coating droplets, 1 s after deposition on untreated and plasma treated surfaces of beech wood. The length of scale bars represents 2 mm.

Vrsta tekočine	Površina lesa	
	Neobdelana	Obdelana s plazmo
Voda	60,6° 	28,5° 
Premaz	88,7° 	80,6° 

Razlike v hidrofilnosti lesa, v odvisnosti od vrste materiala in predhodne obdelave s plazmo, so se odrazile tudi pri dinamiki sprememb SK kapljic premaza. Vpliv obdelave s plazmo na relativno povečanje omočljivosti s premazom je bil pri obeh lesovih podoben. Za razliko od znatnega vpliva debeline obdelovancev na povečanje hidrofilnosti lesov po obdelavi s plazmo vpliv debeline obdelovancev na povečanje omočljivosti lesov s premazom ni bil tako očiten.

Izkazalo se je, da tehnologija obdelave površin lesa z DBD plazmo s plavajočo elektrodo, ki poteka v zraku in pri atmosferskem tlaku, predstavlja alternativen in okolju prijazen način za povečanje dovzetnosti površin obdelovanca za vpijanje vode in površinskega premaza. Kot je bilo prikazano, je učinek obdelave lesa s plazmo odvisen od vrste parametrov med obdelavo. V prispevku smo proučili le nekatere od njih, in sicer vrsto lesa, podajalno hitrost obdelovanca, razdaljo med elektrodama, razdaljo med elektrodama in obdelovancem in debelino obdelovanca. Izboljšana hidrofilnost lesa nadalje prispeva k boljšemu vpijanju premazov na vodni osnovi. Predvidevamo, da slednje doprinese tudi k izboljšanim lastnostim utrjenih filmov tovrstnih premazov (Petrič et al., 2007), tudi v daljšem časovnem obdobju (Gindl et al., 2004), kar imamo namen preizkusiti in predstaviti v prihodnje.

5 POVZETEK
5 SUMMARY

In the present research, treatment of wood with dielectric barrier discharge plasma with a floating electrode, generated in air and at atmospheric pressure, has been shown as an alternative and environmentally friendly technology to increase the susceptibility of workpiece surfaces to wettability with water.

On the one hand, it was shown that with decreasing distance between the electrodes and the workpiece (DEW), the brightness of the generated plasma discharge increases. The phenomenon coincides with the characteristics of the DBD plasma, where the strength of the electrical phenomenon is highly dependent on the distance between the two opposite electrodes. As the distance between the electrodes (DE) increases, the activation and kinetic energy of the travelling active species decrease. On the other hand, as the DE increases, the intensity of the discharges increases. In the DBD plasma with the floating electrode, the DE influences the direction and density of the electric field generated between the electrodes and the workpiece. As a result, when observed from the front, the more the electrodes were apart, the higher the brightness of the air discharge in the gap between the isolated electrode and the workpiece surface. These findings on the effects of DE and DEW on the measured grey values of plasma discharges were also reflected in the findings of their effect on the wood wettability with water and coating after plasma treatment.

Treatment with plasma affected the roughness of wood surfaces. It was found that the roughness of wood decreases with the prolongation of the processing time. Because plasma is considered as a physical phenomenon, the detected changes in the topography of wood surfaces are due to their etching, cleaning, drying, etc.

The second part of the research confirmed the known fact that treatment of wood with plasma, generated in air and at atmospheric pressure, improves the wettability of wood with water (i.e. hydrophilicity) and water-based coatings.

The water droplets' contact angles (CA) on wood surfaces showed that the level of CA reduction after plasma treatment for both spruce and beech wood is very similar, by 15° to 20°, respectively. Treatment of wood at a lower feed speed contributes to better wettability of the workpiece more than at a higher feed speed. The effect of feed speed was shown to be more evident for beech wood. When applying high voltage in the electrodes in floating electrode DBD plasma, the strength of the generated electric field is highly dependent on DE and DEW. The influence of the individual parameters, as well as the common alteration of these two parameters in the process, was also reflected in the wettability of wood. As the DE increased, the hydrophilicity of the wood increased, which was especially evident when processing beech wood. Changes in DEW from about 1 mm to about 0.5 mm (and vice versa) did not significantly increase the hydrophilicity of wood, but the trend was nevertheless noticeable for both spruce and beech. Of all the parameters

studied, the workpiece thickness had the greatest influence on the effect of plasma treatment on the hydrophilicity of wood. At the thickest beech wood workpieces, the water CA decreased from the original 40° to 13° after 60 s of measurement. However, the thinner (2.5 mm and 1.5 mm) workpieces were completely wetted before the end of measurements (37.9 s or 15.3 s after droplet deposition, respectively).

The coating CAs were found to be higher than the water CAs, due to the different physical properties of the two liquids.

Differences in the hydrophilicity of wood, depending on the material type and plasma pre-treatment, were also reflected in the dynamic changes of coating CA. The effect of plasma treatment on the relative enhancement in coating wettability was similar for both wood species. In contrast to the significant influence of workpiece thickness on the increase of wood hydrophilicity, the effect of workpiece thickness on the wettability enhancement of wood with coating was not so obvious.

As shown in the literature, the effect of plasma treatment depends on several parameters during processing, although only a few of them have been considered in the present paper. The improved hydrophilicity of wood can further contribute to better absorption of water-based coatings. It is anticipated that the latter will also contribute to the improved properties of coating cured films, even over a longer period of time, which we intend to test and present in the future.

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RAZVOJ IZDELKA V LESNI INDUSTRIJI Z METODO RAZVOJA FUNKCIJ KAKOVOSTI

PRODUCT DEVELOPMENT IN THE WOOD INDUSTRY WITH QUALITY FUNCTION DEPLOYMENT METHOD

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Izvleček / Abstract

Izvleček: *Prihodnost slovenske lesne industrije leži v fleksibilnih proizvodnjah, ki bodo sposobne hitro razviti in proizvesti visokokvalitetne in cenovno konkurenčne izdelke. Pri razvoju novega izdelka smo uporabili metodo razvoja funkcij kakovosti. Raziskavo smo končali z izgradnjo prvega nivoja hiše kakovosti, to je z določitvijo tehničnih zahtev izdelka, ki optimalno ustrezajo ciljni skupini kupcev, hkrati pa upoštevajo tehnološke zmožnosti in ekonomske zahteve podjetja. Raziskava je pokazala, da kupci želijo izbirati, saj s tem dosežejo maksimalno zadovoljstvo pri prilagajanju njihovim potrebam in željam, hkrati pa dobijo občutek pomembnosti, saj ne izbirajo samo izdelka, ampak tudi vplivajo na določene lastnosti svojega izbora. Pri jedilni mizi, ki je bila predmet naše raziskave, je to predvsem možnost izbiranja velikosti, materiala in površinske obdelave. Nov izdelek se mora kasneje pravilno tržiti, saj je potrebno na nekatere prednostne lastnosti, ki jih ima, kupca posebej opozoriti, ker na prvi pogled niso opazne.*

Ključne besede: *metoda razvoja funkcij kakovosti, razvoj izdelka, lesna industrija, jedilna miza*

Abstract: *The future of the Slovenian wood industry lies in flexible production, which is able to quickly develop and produce high-quality and competitive products. We used the quality function deployment method to develop a new product. The research was completed by building a house of quality matrix. This was carried out by determining the technical requirements of the product that optimally fit the target group of costumers, while taking into account the technological capabilities and economic requirements of the company. The survey showed that customers want to be able to make choices, so they can achieve maximum satisfaction in adapting the product to their needs and desires. This is especially important because certain features of the product have a greater impact on their purchase decisions. In the case of dining tables, these are primarily the size, material and surface treatment. The marketing strategy for new product should also work to highlight some strengths of the product which are not noticeable to costumers at first glance.*

Keywords: *quality function deployment method, product development, wood industry, dining table*

1 UVOD

1 INTRODUCTION

Problem nekonkurenčnosti nekaterih lesnih podjetij se med drugim kaže tudi v premajhnem, nepravilnem ali premalo intenzivnem vlaganju v razvoj izdelkov. Življenjski cikli izdelkov so vse krajši, kar povzroča potrebo po vedno intenzivnejšem razvijanju novih izdelkov ali posodabljanju že obstoječih (Potočnik, 2002). Lesna podjetja so lahko na zahtevnem svetovnem trgu konkurenčna le z razvojem inovativnih, sodobno oblikovanih, funkcionalnih, ergonomskih in estetskih izdelkov (Oblak, 2012).

Razmere v svetu silijo proizvodna podjetja, da začnejo uporabljati moč znanja za doseganje ciljev. Če pa želi podjetje zastavljene cilje uresničiti, ni dovolj samo to, da ima znanje, temveč je pomembno, kakšno je to znanje, kako ga izkorišča oz. kako dobro z njim upravlja. (Govers, 1996). Znanje in sodobne metode morajo podjetja uporabljati tudi pri razvoju novih izdelkov.

Razvoj izdelka je izjemno zahtevna naloga. Če želi biti podjetje pri razvoju novega izdelka uspešno, mora upoštevati številne dejavnike. Večina izdelkov, ki jih podjetja razvijajo, propade, še preden pridejo na trg. Vzroki za to so različni, najpogostejši vzrok pa so preslabo raziskane potrebe in želje trga. Če podjetje ne bi razvijalo novih izdelkov, bi sčasoma propadlo. Osnovni razlogi za razvijanje novih izdelkov so zastarevanje obsto-

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ječih izdelkov, sprememba okusa in navad kupcev, konkurenčni izdelki in tehnološki napredek (Kotler, 2003).

Razvoj novega izdelka poteka preko številnih stopenj, med katerimi so najvažnejše: iskanje, zbiranje in ocenjevanje idej, poslovno-tržna analiza, tehnološko-proizvodna analiza, tržno razvijanje in testiranje ter proizvodnja (Iacobucci, 2018).

2 MATERIALI IN METODE DELA
2 MATERIALS AND METHODS

2.1 MASIVNA JEDILNA MIZA
2.1 SOLID DINING TABLE

Cilj raziskave je razviti kvalitetno jedilno masivno mizo iz hrastovega in bukovega lesa za domačo uporabo, dobavljivo v kratkem časovnem roku in v čim več možnih dimenzijah. S temi lastnostmi bi ustvarili konkurenčen izdelek na zahtevnem globalnem trgu in posledično zadovoljnega kupca, ki bi za svoj denar dobil več kot je pričakoval. Za uspešno uvedbo mize na trg je potrebno podrobno raziskati potrebe uporabnikov, jo v skladu z njimi in razpoložljivimi proizvodnimi zmožnostmi razviti in jo kupcem ponuditi v čim krajšem času. Da bi presegli značilnosti konkurenčnih izdelkov, bomo morali najprej preučiti potrebe in želje kupcev in nato mizi določiti tehnične in trženjske značilnosti. Odločili smo se, da bomo pri razvoju novega izdelka uporabili metodo razvoja funkcij kakovosti.

2.2 METODA RAZVOJA FUNKCIJ KAKOVOSTI
2.2 QUALITY FUNCTION DEPLOYMENT METHOD

Metoda razvoja funkcij kakovosti zagotavlja podjetjem velike prednosti v razvoju tržno uspešnih izdelkov in storitev, pri čemer omogoča strnjeno shrambo ogromnega števila informacij v majhno, pregledno število dokumentov (Zairi, 1993). Bistven problem pri razvijanju novega izdelka je, kako vanj vključiti vse kupčeve izražene, neizražene, sedanje in prihodnje potrebe. Pri načrtovanju novih in izboljševanju obstoječih izdelkov je potrebno izpolnjevati tiste tehnične značilnosti, ki naj v največji možni meri zadovoljijo potrebe kupcev. Treba je torej identificirati specifične želje in potrebe ciljne skupine uporabnikov in le-te prevesti v pripravno rešitev, ki bodo uporabnike zadovoljile bolje kot rešitve konkurence. Metoda, ki pomaga povezati potrebe in zahteve kupca z možnostmi organizacije, je metoda razvoja funkcij kakovosti, v praksi znana tudi pod imenom hiša kakovosti (Starbek & Kušar, 1997). S to metodo se strukturira načrtovanje in razvoj izdelka. Z uporabo matrik je prikazana povezava med zahtevami in željami kupcev ter tehničnimi zmožnostmi organizacije. To je orodje, ki v procesu načrtovanja izdelka prevede zahteve in potrebe kupca v določene tehnične rešitve.

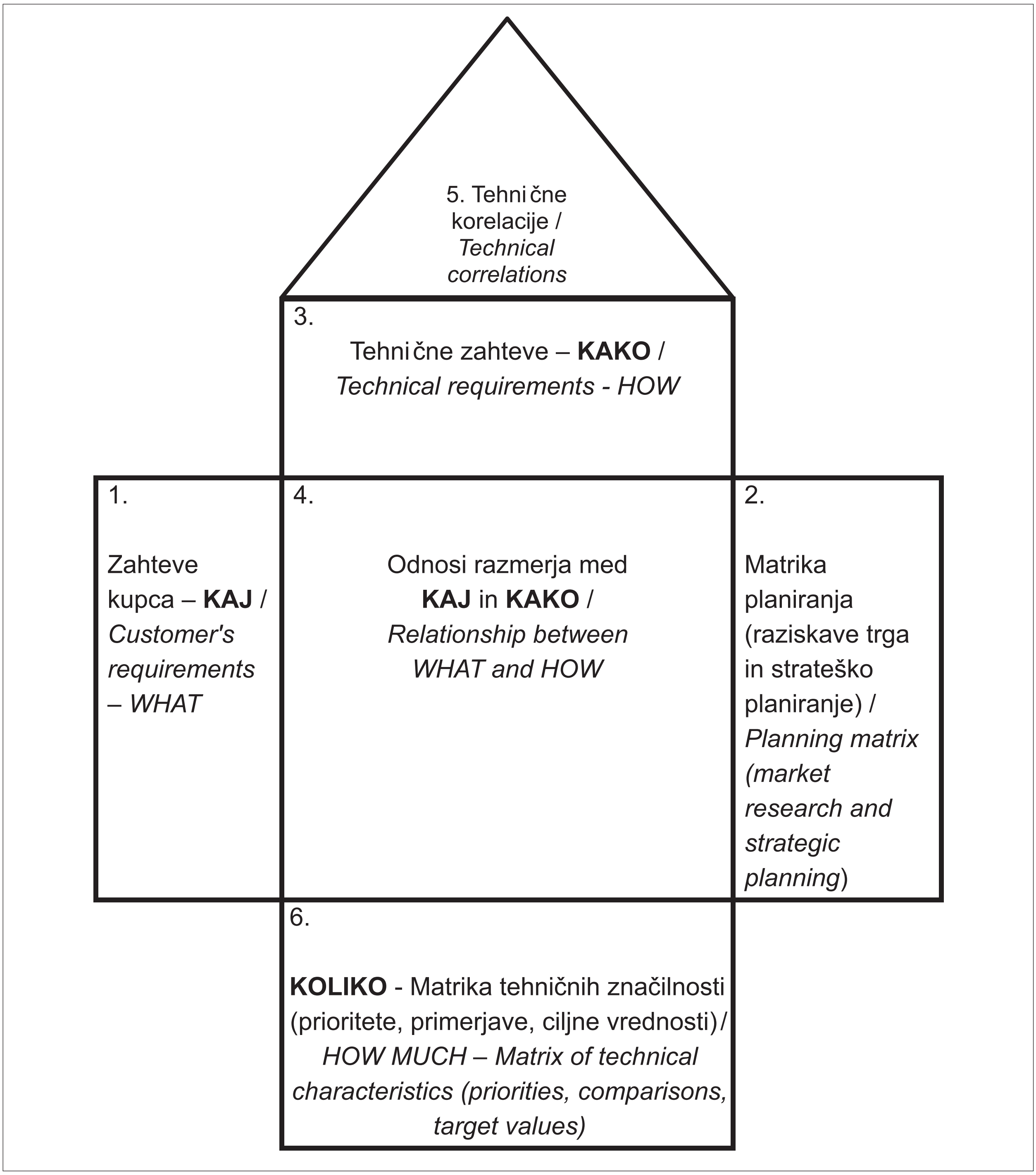
- Uvedba metode razvoja funkcij kakovosti pri razvoju izdelka omogoča:
- boljši časovni izkoristek pri uvajanju novih izdelkov na trg,
- zmanjšanje sprememb dizajna med procesom razvoja,
- zmanjšanje stroškov dizajna in izdelave,
- izboljšanje načrtovanja kakovosti izdelkov,
- osredotočanje zgolj na tiste lastnosti izdelkov, ki so za kupce pomembne,
- pomoč pri identificiranju tistih lastnosti izdelka, ki jih kupci cenijo manj,
- izdelavo izdelkov ‚po merah kupcev' in
- sistematično razvijanje izdelka skladno s potrebami in zahtevami kupca.

Bistvena prednost uporabe metode razvoja funkcij kakovosti je tudi zmanjšanje sprememb izdelka med fazo proizvodnje, saj je večina sprememb narejenih že v fazi razvoja izdelka. Na ta način se bistveno znižajo stroški sprememb in prihrani čas razvoja, saj se v kasnejših fazah stroški sprememb bistveno povečajo (Franceschini, 2002).

Glavna orodja metode razvoja funkcij kakovosti so matrike in tabele. Matrike so osrednje orodje metodologije razvoja funkcij kakovosti. Matrika je pravokotna mreža, sestavljena iz vrstic in stolpcev. Polja, ki povezujejo vrstice in stolpce matrike, omogočajo zapis informacije, ki zadeva presek vsebin vrstice in stolpca. Prvenstveno so to simboli ali številke, ki govorijo o vrsti povezave med vsebinami, ki je lahko zelo močna, srednje močna, šibka ali pa je sploh ni. Tabele se uporabljajo za uvajanje in zbiranje posameznih delov podatkov za specifično kategorično listo – v našem primeru jih bomo uporabljali za analizo kupčevih izjav. So pripravljalne tabele za analizo in sintezo različnih vrst informacij v posameznih fazah načrtovanja in proizvodnje izdelka (Šivic, 2005).

Obstajajo štirje nivoji hiše kakovosti, vendar se bomo v naši raziskavi usmerili le na izdelavo prvega nivoja. Že z izdelavo tega lahko dosežemo bistvene izboljšave pri razvoju izdelka.

Osnovna oblika hiše, ki jo bomo uporabili v našem primeru, ima šest glavnih segmentov (matrik), imenovanih tudi sobe, ki so na različne načine med seboj povezane. Vsaka matrika vsebuje informacije, ki so povezane z drugimi matrikami (slika 1).



Slika 1. *Struktura hiše kakovosti (Lipuščček & Tratnik, 2004)*
Figure 1. *Structure of the house of quality (Lipuščček & Tratnik, 2004)*

Struktura hiše kakovosti ima šest delov. Prva soba ali **»**soba KAJ**«** predstavlja hierarhično urejen zapis kupčevih želja in potreb, ki se jih kupec zaveda ali pa tudi ne, vanjo pa so lahko vključeni celo predpisi in zakoni. Avtorji hiše kakovosti priporočajo, da v tej sobi ni več kot 30 zahtev kupca, sicer postane hiša kakovosti preveč zapletena, nepregledna in neobvladljiva. Hierarhično urejen zapis kupčevih potreb in želja lahko dobimo s pomočjo afinitetnega diagrama, drevesnega diagrama ali AHP metode. Druga soba, ki se imenuje »soba analiz konkurenčnosti**«** ali matrika tržnih ocen, predstavlja matriko planiranja. Trenutna rešitev izdelka se po posameznih lastnostih primerja s konkurenčnimi izdelki. Vsebuje tri vrste informacij:

- kvantitativne podatke o trgu, prikaz relativne pomembnosti potreb za kupca in stopnjo izpolnjevanja kupčevih zahtev v primerjavi s konkurenco,
- strateške cilje za nov izdelek ali storitev ter
- izračune za razvrščanje kupčevih želja in potreb.

Tretja soba ali **»**soba KAKO**«** predstavlja tehnične zahteve v obliki strukturiranega zapisa pristopov, s katerimi naj bi bile izpolnjene zahteve kupca. Enako kot pri kupčevih zahtevah tudi v tej sobi avtorji ne priporočajo več kot 30 vrst tehničnih zahtev. Za vsak pristop se s puščico navede smer izboljšav sedanjega stanja proti ciljni vrednosti. Četrta soba, ki jo imenujemo tudi »soba medsebojnih povezav**«**, je jedro hiše kakovosti. Predstavlja matriko povezav med »sobo KAJ« in »sobo KAKO«. Vsebuje ocene ekipe o povezanosti posamezne zahteve oziroma želje kupca s posameznim elementom tehnične zahteve. Povezave so prikazane z grafičnimi simboli, ki predstavljajo moč povezave. Peta soba je »streha hiše**« in** predstavlja križne povezave tehničnih zahtev. Kaže vpliv sprememb posamezne tehnične značilnosti na druge tehnične značilnosti. Povezava je lahko močno pozitivna, šibko pozitivna, šibko negativna, močno negativna ali pa je ni. Konfliktne situacije (šibko negativna, močno negativna) opozarjajo na prave priložnosti za izboljšanje kakovosti izdelka. V tem primeru je potrebno skleniti kompromis oziroma pogledati, katera tehnična značilnost ima za kupca večji pomen. Šesta soba, imenovana tudi **»**soba KOLIKO**«,** predstavlja matriko tehničnih značilnosti in prikazuje absolutno in relativno pomembnost posameznih tehničnih značilnosti za zadovoljitev kupca. V tej sobi so prikazane primerjalne vrednosti proučevanega in konkurenčnih izdelkov in na osnovi ciljnih vrednosti tudi mesta možnih izboljšav ter prioritete. Končen rezultat hiše kakovosti so karakteristične vrednosti izdelka, ki so potrebne za zadovoljitev potreb kupca (Šivic, 2005).

3 REZULTATI IN RAZPRAVA
3 RESULTS AND DISCUSSION

Osnova pri konstruiranju mize je upoštevanje dimenzijskih standardov in tehničnih zahtev. Razvoj jedilne masivne mize s pomočjo metode razvoja funkcij kakovosti bomo izvedli v dvanajstih korakih, v katerih bomo zgradili hišo kakovosti.

3.1 1. KORAK: OPREDELITEV OSNOVNIH POJMOV PROJEKTA RAZVOJA FUNKCIJ KAKOVOSTI
3.1 STEP 1: DEFINITION OF THE BASIC CONCEPTS OF THE PROJECT OF THE DEVELOPMENT OF QUALITY FUNCTION

Projekt se bo osredotočal na razvoj masivne jedilne mize. Glavne značilnosti mize bodo možnost izbire različnih dimenzij miz, različnih materialov, površinske obdelave in kratki dobavni roki. Izdelek bo pozicioniran v srednji cenovni razred. Za primerjavo bosta uporabljeni dve konkurenčno primerljivi jedilni mizi. Ugotovitve raziskave bodo pokazale, katere lastnosti jedilne mize so za kupce najpomembnejše in kako je mogoče zmanjšati stroške za lastnosti, ki za kupce niso pomembne.

3.2 2. KORAK: OPREDELITEV CILJNE SKUPINE KUPCEV
3.2 STEP 2: DEFINITION OF THE TARGET GROUP OF CUSTOMERS

Osnovna opredelitev ciljne skupine kupcev je, da so potencialni kupci vsi tisti, ki potrebujejo kakovostno masivno jedilno mizo ter pohištvo kupujejo v pohištvenih salonih in ne v velikih trgovskih centrih ali pri mizarjih. To so kupci srednjega in višjega sloja, ki zahtevajo višjo kvaliteto izdelka in pričakujejo višjo ceno. Trženjske poti do kupcev bodo torej vodile do trgovcev s pohištvom, ki ponujajo pohištvo v pohištvenih salonih, kjer je potreben individualen razgovor in predstavitev izdelka končnemu kupcu.

3.3 3. KORAK: PROUČEVANJE POTREB IN ŽELJA KUPCEV
3.3 STEP 3: STUDYING THE CUSTOMERS' NEEDS AND WISHES

Ta korak je začetek gradnje hiše kakovosti. Najprej smo z metodo brainstorming poskušali ugotoviti vse zahteve, ki naj bi jih miza vsebovala. Zahteve morajo biti usklajene s standardi, ki veljajo za jedilne mize. Nato smo pripravili anketo za končne kupce, s katero smo želeli pridobiti odgovore o želenih lastnostih, ki naj bi jih miza imela. Anketo smo izvedli na sejmu Ambient Ljubljana, sejem pohištva in notranje opreme, in sicer v obliki vprašalnika in poglobljenega pogovora z anketiranci. Po analizi ankete je bilo možno narediti dokončen seznam kupčevih potreb in želja. V grobem smo jih razdelili v štiri skupine: funkcionalnost, estetske lastnosti, nakupni dejavniki in ponakupni dejavniki. V vsaki skupini je več zahtev, ki so jih kupci izpostavili. Pri funkcionalnosti mize so tako poudarili naslednje pomembne lastnosti: udobnost uporabe, pripravnost uporabe z vidika ergonomičnosti, varnost mize, prilagodljivost uporabe, lahko vzdrževanje, trpežnost mize in prilagodljivost prostoru. Med estetske lastnosti smo glede na odgovore anketirancev uvrstili obliko, barvo, strukturo ter skladnost z opremo. Pri nakupnih dejavnikih sta najpomembnejša cena in dobavni rok, pri ponakupnih pa trajnost, popravila ter možnost kasnejše obnove mizne plošče.

3.4 4. KORAK: OCENJEVANJE POTREB IN ŽELJA KUPCEV
3.4 STEP 4: EVALUATING CUSTOMERS' NEEDS AND WISHES

Ker vse zahteve kupcev niso enako pomembne, je bilo treba vsako zahtevo oz. željo oceniti na podlagi obsežne ankete. Za absolutno ocenjevanje zahtev smo izbrali ocene od 1 do 5, kjer je 1 najmanj pomembna, 5 pa najbolj pomembna. Pri tem ocenjevanju je bolj kot sama ocena pomembna primerljivost med ocenami za posamezne zahteve, saj tako dobimo hierarhično lestvico pomembnosti posameznih zahtev. Ocene so prikazane v preglednici 2.

Preglednica 1. *Ocene pomembnosti posameznih zahtev kupcev*
Table 1. *Evaluation of customers' requirements*

Funkcionalnost / *Functionality*	
Udobnost uporabe (del ergonomičnosti) / *Comfort of usage (part of ergonomics)*	3
Pripravnost uporabe (del ergonomičnosti) / *Usage suitability (part of ergonomics)*	4
Varnost (stabilnost, brez možnosti poškodb uporabnika) / *Safety (stability, without risk of injuries)*	3
Prilagodljivost uporabe (fleksibilnost) / *Adaptability (flexibility)*	4
Lahko vzdrževanje (čiščenje, brisanje) / *Easy to maintain (cleaning, wiping)*	2
Trpežnost (konstrukcije, plošče) / *Toughness (structure, board)*	3
Prilagodljivost prostoru (dimenzije) / *Space adaptability (dimensions)*	5
Estetika / *Aesthetics*	
Lepa oblika / *Beautiful design*	4
Lepa barva, struktura lesa / *Beautiful colour, structure of the wood*	3
Lep sijaj / *Beautiful shine*	2
Estetska skladnost z opremo (kuhinje) / *Aestetic compatibility with the rest of the furniture (kitchen)*	5
Ostali faktorji nakupa / *Other purchase factors*	
Cenejši izdelek / *Cheaper product*	3
Krajši dobavni rok / *Shorter delivery time*	3
Ponakupni faktorji / *Post-purchase factors*	
Trajnost (predvideni rok trajanja) / *Durability (estimated shelf life)*	2
Popravila / *Repairs*	3
Možnost kasnejše obnovitve mizne plošče / *Possibility of board restoration*	4

3.5 5. KORAK: PRIMERJALNA PRESOJA (BENCHMARKING)

3.5 STEP 5: BENCHMARKING COMPARATIVE ASSESSMENT

Na podlagi kupčevih zahtev smo s pomočjo ankete izvedli benchmarking ali primerjalno analizo, ki se uporablja za primerjanje podjetja ali izdelka z drugimi podjetji ali izdelki z namenom izboljšanja svoje konkurenčnosti. Je ena izmed najbolj pogosto uporabljenih metod za neprestano izboljševanje konkurenčnosti podjetja. Večina podjetij nenehno spremlja dogajanje na trgu in dejavnosti svojih konkurentov ter nato tudi sama uvajajo novosti, ki se jim zdijo smiselne. Pri tem pa se pogosto niti ne zavedajo, da se pravzaprav poslužujejo benchmarkinga. Del ankete je bil sestavljen tako, da so anketiranci primerjali med seboj primerljive mize. Pri tem je imela miza, ki smo jo razvijali, oznako A, miza B je bila miza iz masivnega lesa, brez podaljškov in brez možnosti izbire dimenzij po želji, z dolgim dobavnim rokom, vendar zelo stabilna, masivna in modernih oblik, v hrastovi in bukovi izvedbi, miza C pa je bila masivna miza, ki je po sami obliki precej spominjala na mizo, ki smo jo razvijali, bila je elegantna, s podaljški, skritimi pod mizno ploščo, a brez možnosti izbire dimenzij in nekoliko daljšim dobavnim rokom. Rezultat primerjalne presoje je ocena kupcev glede na primerjavo fotografij in lastnosti, ki smo jim jih predstavili. Prikazani so v preglednici 2.

Preglednica 2. *Rezultati primerjalne presoje (benchmarkinga)*
Table 2. *The results of the benchmarking comparative assessment*

ŽELJE IN POTREBE KUPCA / *CUSTOMER WISHES AND NEEDS*	KUPČEVA OCENA / *CUSTOMER EVALUATION* brez / *without* 0	1	2	3	4	odlično / *excellent* 5
Funkcionalnost / Functionality						
Udobnost uporabe (del ergonomičnosti) / *Comfort of usage (part of ergonomics)*				○	△□	
Pripravnost uporabe (del ergonomičnosti) / *Usage suitability (part of ergonomics)*			□	○	△	
Varnost (stabilnost, brez možnosti poškodb uporabnika) / *Safety (stability, without risk of injuries)*			□	△○		
Prilagodljivost uporabe (fleksibilnost) / *Adaptability (flexibility)*		□		△	○	
Lahko vzdrževanje (čiščenje, brisanje) / *Easy to maintain (cleaning, wiping)*			□		△○	
Trpežnost (konstrukcije, plošče) / *Toughness (structure, board)*				○	△	□
Prilagodljivost prostoru (dimenzije) / *Space adaptability (dimensions)*			□	○		△
Estetika / Aesthetics						
Lepa oblika / *Beautiful design*				□	△○	
Lepa barva, struktura lesa / *Beautiful colour, structure of the wood*				○	△	□
Lep sijaj / *Nice shine*				□○	△	
Estetska skladnost z opremo (kuhinje) / *Aestetic compatibility with rest of the furniture (kitchen)*			○		△□	
Ostali faktorji nakupa / Other purchase factors						
Cenejši izdelek / *Cheaper product*			□		○	△
Krajši dobavni rok / *Shorter delivery time*			□	○		△
Ponakupni faktorji / Post-purchase factors						
Trajnost (predvideni rok trajanja) / *Durability (estimated shelf life)*			○	□		△
Popravila / *Repairs*	□○					△
Možnost kasnejše obnovitve mizne plošče / *Possibility of board restoration*			○	□		△

Legenda / Legend:

Proučevani izdelek / *Product*	Simboli-bencmarking / *Symbol-benchmarking*
A	△
B	□
C	○

Iz preglednice 2 je vidno, da je Miza A v prednosti predvsem z vidika ostalih faktorjev nakupa in ponakupnih faktorjev. Poleg tega je najbolje ocenjena tudi z vidika prilagodljivosti prostoru, najslabše pa sta ocenjena varnost in prilagodljivost uporabe.

3.6 6. KORAK: IZDELAVA SEZNAMA TEHNIČNIH ZAHTEV
3.6 STEP 6: MAKING A LIST OF TECHNICAL REQUIREMENTS

V okvir tehničnih zahtev lahko spadajo oblikovne, konstrukcijske in tehnološke zahteve. V tem koraku smo prevedli kupčeve zahteve v tehnične specifikacije oziroma karakteristike izdelka tako, da smo za vsako kupčevo zahtevo določili vsaj eno tehnično značilnost, s katero je ta zahteva dosežena. Poleg tehničnih značilnosti smo dodali še oznake vrednosti (↑ - več, ↓ - manj, O - nespremenjeno), ki povedo, ali je za izdelek potrebna višja, nižja ali sedanja vrednost tehnične zahteve.

Tehnične značilnosti smo dobili tako, da smo na osnovi zahtev kupcev ugotavljali, katere karakteristike masivne jedilne mize bi izpolnile te zahteve. Poiskali smo povezave med zahtevami in tehničnimi karakteristikami in pazili, da smo s seznamom tehničnih karakteristik zajeli vse tiste, ki pomembno vplivajo na kupčeve zahteve. Pri tem smo upoštevali, kakšen pomen oziroma vpliv ima posamezna lastnost na zahteve kupcev ter koliko kupcem pomeni in kakšno korist vidijo v njej. Upoštevali smo tudi trud, zahtevnost in sredstva, ki jih mora podjetje vložiti za zagotovitev posamezne tehnične karakteristike. Seznam tehničnih zahtev je prikazan v preglednici 3.

Preglednica 3. *Seznam tehničnih zahtev*
Table 3. *List of technical requirements*

Tehnične značilnosti (dizajn) / *Technical characteristics (design)*	Oznake vrednosti / *Value tags*
Izbira prave dolžine miz, plošče / *The proper table and board length*	↓
Izbira prave širine miz, plošče / *The proper table and board width*	↓
Debelina mizne plošče / *Thickness of table board*	o
Oblika mizne plošče / *Design of table's board*	o
Odpornost mizne plošče / *Table's board resistence*	↑
Gladkost površine plošče / *Smoothness of the board's surface*	o
Možnost izbire podaljška / *The possibility to choose an extension*	o
Možnost izbire predala / *The possibility to choose a drawer*	↓
Izbira površinske obdelave / *Choosing the surface treatment*	↑
Izbira vrste lesa / *Choosing the wood type*	↑
Možnost izbire stolov / *The possibility of choosing chairs*	↑
Dimenzije nog / *Legs dimensions*	o
Oblika nog / *Legs design*	↑
Odpornost konstrukcije / *Structural resistance*	↑
Ostale oblikovno konstrukcijske možnosti / *Other structural design options*	↑
Možnost servisa / *Possibility of servicing*	o

3.7 7. KORAK: MATRIKA RAZMERIJ
3.7 STEP 7: RATIO MATRIX

Z matriko razmerij smo ugotavljali povezave med tehničnimi značilnostmi izdelka in željami kupca. Vsaka kupčeva potreba je morala biti povezana z vsaj eno tehnično značilnostjo izdelka. Če take povezave ni bilo, je bilo potrebno najti novo tehnično značilnost, ki je izpolnjevala to kupčevo potrebo. Seveda pa je veljalo, da je morala imeti tudi vsaka tehnična značilnost vsaj eno povezavo z željo kupca, sicer je bila nepomembna za izdelek oziroma celo škodljiva, saj je zviševala stroške. Pri tem smo pazili, da ne bi z odstranitvijo neke tehnične značilnosti negativno vplivali na druge. Za identifikacijo pomembnih lastnosti izdelka smo ugotavljali povezave med tehničnimi značilnostmi izdelka in potrebami kupca (Preglednica 4). Vsako kupčevo zahtevo smo primerjali z vsako tehnično značilnostjo izdelka. Glede na dejansko moč povezave smo uporabljali ponderje 1, 3, ali 9, v matriki smo to označili z grafičnimi simboli (◦, ϴ ,☺).

Preglednica 4. *Matrika razmerij*
Table 4. *Ratio matrix*

ŽELJE IN POTREBE KUPCA / *CUSTUMER WISHES AND NEEDS* — TEHNIČNE ZNAČILNOSTI (DIZAJN) / *TECHNICAL CHARACTERISTICS (DESIGN)*	Izbira prave dolžine miz, plošče / *The proper table and boards length*	Izbira prave širine miz, plošče / *The proper table and boards width*	Debelina mizne plošče / *Thickness of table board*	Oblika mizne plošče / *Shape of table board*	Odpornost mizne plošče / *Table board resistence*	Gladkost površine plošče / *Smoothness of the board surface*	Možnost izbire podaljška / *The possibility to choose an extension*	Možnost izbire predala / *The possibility to choose a drawer*	Izbira površinske obdelave / *Choosing the surface treatment*	Izbira vrste lesa / *Choosing the wood type*	Možnost izbire stolov / *The possibility of choosing chairs*	Dimenzije nog / *Legs dimensions*	Oblika nog / *Legs shape*	Odpornost konstrukcije / *Structural resistance*	Ostale oblikovno konstrukcijske možnosti / *Other structural design options*	Možnost servisa / *Possibility of servicing*
Funkcionalnost / *Functionality*																
Udobnost uporabe (del ergonomičnosti) / *Comfort of usage (part of ergonomics)*	☺	☺		•		☺		•	•		ϴ	☺	ϴ		☺	
Pripravnost uporabe (del ergonomičnosti) / *Usage suitability (part of ergonomics)*	☺	☺	•	ϴ	ϴ	•	•	ϴ	•			•	•	ϴ	ϴ	•
Varnost (stabilnost, brez možnosti poškodb uporabnika) / *Safety (stability, without risk of injuries)*	•	•	ϴ	☺	•		ϴ					ϴ	☺	☺	☺	ϴ
Prilagodljivost uporabe (fleksibilnost) / *Adaptability (flexibility)*	☺	ϴ	•	•	ϴ		☺	☺	•					•	•	•
Lahko vzdrževanje (čiščenje, brisanje) / *Easy to maintain (cleaning, wiping)*				•	ϴ	☺			☺	ϴ					•	•
Trpežnost (konstrukcije, plošče) / *Toughness (structure, board)*			☺	•	☺	•		•	ϴ	ϴ		☺	•	☺	ϴ	•
Prilagodljivost prostoru (dimenzije) / *Space adaptability (dimensions)*	☺	☺		ϴ			☺						•			
Estetika / *Aesthetics*																
Lepa oblika / *Beautiful design*	ϴ	ϴ	ϴ	☺			•	•				ϴ	☺		☺	
Lepa barva, struktura lesa / *Beautiful colour, structure of the wood*									ϴ	☺					•	
Lep sijaj / *Beautiful shine*						ϴ			☺							
Estetska skladnost z opremo (kuhinje) / *Aestetic compatibility with rest of the furniture (kitchen)*	ϴ	ϴ	•	ϴ		•	•		☺	☺	☺	ϴ	ϴ		ϴ	
Ostali faktorji nakupa / *Other purchase factors*																
Cenejši izdelek / *Cheaper product*	•	•	•	•	•	•	ϴ	ϴ	•	•	•	•	•	•	•	☺
Krajši dobavni rok / *Shorter delivery time*							•	•	•							
Ponakupni faktorji / *Post-purchase factors*																
Trajnost (predvideni rok trajanja) / *Durability (estimated shelf life)*			ϴ		☺	•	•		ϴ	ϴ		•		☺	ϴ	☺
Popravila / *Repairs*																☺
Možnost kasnejše obnovitve mizne plošče / *Possibility of restoration of the board*			ϴ						•	ϴ				ϴ	•	ϴ

3.8 8. KORAK: DOLOČITEV CILJNIH VREDNOSTI
3.8 STEP 8: DETERMINATION OF TARGET VALUES

Vsaki tehnični zahtevi smo določili ciljne vrednosti tako, da so bile kupčeve potrebe izpolnjene v najvišji možni meri. Pri tem so bile ciljne vrednosti v merljivi in opisni obliki, ob tem pa smo upoštevali standarde, ki veljajo za jedilne mize.

Preglednica 5. *Ciljne vrednosti*
Table 5. *Target values*

Tehnične značilnosti (dizajn) / ***Technical characteristics (design)***	**Ciljna vrednost /** ***Goal value***
Izbira prave dolžine miz, plošče / ***The proper table and board length***	možnost izbire 14 različnih dolžin / *the possibility of choosing between 14 different lengths*
Izbira prave širine miz, plošče / ***The proper table and board width***	možnost izbire 4 različnih dolžin / *the possibility of choosing between 4 different lengths*
Debelina mizne plošče / ***Thickness of table board***	40 mm/ *40 mm*
Oblika mizne plošče / ***Design of table board***	pravokotna z zaobljenimi robovi / *rectangular with rounded edges*
Odpornost mizne plošče / ***Table board resistence***	prenese nadpovprečno uporabo / *withstands above average usage*
Gladkost površine plošče / ***Smoothness of the board surface***	gladek, prijeten otip / *smooth, pleasant on touch*
Možnost izbire podaljška / ***The possibility to choose an extension***	pod ploščo, 4 različne dimenzije podaljškov / *4 different dimensions of extensions under the board*
Možnost izbire predala / ***The possibility to choose a drawer***	predal / *drawer*
Izbira površinske obdelave / ***Choosing the surface treatment***	lužena, oljena, voskana, lakirana (mat, natur) / *peeled, oiled, waxed, varnished (matte, natural)*
Izbira vrste lesa / ***Choosing the wood type***	hrast, bukev, javor / *oak, beech, maple*
Možnost izbire stolov / ***The possibility of choosing chairs***	dve različni obliki stolov / *two different shapes of chairs*
Dimenzije nog / ***Legs dimensions***	dolžina: 750 mm, 68 x 68 mm / *length: 750 mm, 68 x 68 mm*
Oblika nog / ***Legs design***	pravokotna z zaobljenimi robovi / *rectangular with rounded edges*
Odpornost konstrukcije / ***Structural resistance***	prenese statično obremenitev 100 kg / *withstand a static load of 100 kg*
Ostale oblikovno konstrukcijske možnosti / ***Other structural design options***	prilagojenost širokemu spektru uporabnikov / *adjustment to a wide range of users*
Možnost servisa / ***Possibility of servicing***	servis v roku 1 tedna / *servicing within 1 week*

* SIST EN 1251:2016 Pohištvo - Trdnost, trajnost in varnost - Zahteve za mize za domačo uporabo

3.9 9. KORAK: OCENA ZAHTEVNOSTI IZVEDBE
3.9 STEP 9: EVALUATION OF PERFORMANCE COMPLEXITY

V tem koraku smo ocenjevali težavnost izvedbe posameznega tehničnega parametra od sedanje proti ciljni vrednosti. Uporabljali smo ocene od 1 do 5, kjer je bila ocena 1 namenjena najlažje izvedljivim spremembam, ocena 5 pa najtežje izvedljivim spremembam tehničnih značilnosti. Ocene so prikazane v preglednici 6.

Preglednica 6. *Ocena zahtevnosti izvedbe tehničnih značilnosti glede ciljnih vrednosti*
Table 6. *Evaluation of performance complexity according to goal values*

Tehnične značilnosti (dizajn) / ***Technical characteristics (design)***	**Ciljna vrednost /** ***Goal value***	**Zahtevnost izvedbe (1-manj zahtevna, 5-bolj zahtevna) /** ***Complexity of performance (1-less demanding, 5-more demanding)***
Izbira prave dolžine miz, plošče / ***The proper table and board length***	možnost izbire 14 različnih dolžin / *the possibility of choosing between 14 different lengths*	5
Izbira prave širine miz, plošče / ***The proper table and board width***	možnost izbire 4 različnih dolžin / *the possibility of choosing between 4 different lengths*	4
Debelina mizne plošče / ***Thickness of table board***	40 mm / *40 mm*	2
Oblika mizne plošče / ***Design of table's board***	pravokotna z zaobljenimi robovi / *rectangular with rounded edges*	2
Odpornost mizne plošče / ***Table board resistence***	prenese nadpovprečno uporabo / *withstands above average usage*	3
Gladkost površine plošče / ***Smoothness of the board surface***	gladek, prijeten otip / *smooth, pleasant on touch*	4
Možnost izbire podaljška / ***The possibility to choose an extension***	pod ploščo, 4 različne dimenzije podaljškov / *4 different dimensions of extensions under the board*	5
Možnost izbire predala / ***The possibility to choose a drawer***	predal / *drawer*	5
Izbira površinske obdelave / ***Choosing the surface treatment***	lužena, oljena, voskana, lakirana (mat, natur) / *peeled, oiled, waxed, varnished (matte, natural)*	5
Izbira vrste lesa / ***Choosing the wood type***	hrast, bukev, javor / *oak, beech, maple*	4
Možnost izbire stolov / ***The possibility of choosing chairs***	dve različni obliki stolov / *two different shapes of chairs*	2
Dimenzije nog / ***Legs dimensions***	dolžina: 750 mm, 68 x 68 mm / *length: 750 mm, 68 x 68 mm*	2
Oblika nog / ***Legs design***	pravokotna z zaobljenimi robovi / *rectangular with rounded edges*	2
Odpornost konstrukcije / ***Structural resistance***	prenese statično obremenitev 100 kg / *withstand a static load of 100 kg*	4
Ostale oblikovno konstrukcijske možnosti / ***Other structural design options***	prilagojenost širokemu spektru uporabnikov / *adjustment to a wide range of users*	4
Možnost servisa / ***Possibility of servicing***	servis v roku 1 tedna / *servicing within 1 week*	3

3.10 10. KORAK: BENCHMARKING TEHNIČNIH ZNAČILNOSTI
3.10 STEP 10: BENCHMARKING OF TECHNICAL FEATURES

Za tržno pozicioniranje proučevanega izdelka smo opravili primerjalno analizo tehničnih značilnosti proučevanega izdelka s konkurenčnimi. Stopnjo izpolnjevanja tehničnih zahtev smo označili z lestvico od 1 do 5, kjer je 1 pomenila neizpolnjevanje tehničnih zahtev, ki zelo odstopajo od ciljnih vrednosti, 5 pa zelo dobro izpolnjevanje tehničnih zahtev, ki dosegajo oziroma celo presegajo ciljne vrednosti. S to analizo smo preverili skladnosti matrike razmerij (korak 7) in podatke primerjalnega benchmarkinga (korak 5). V tem koraku smo preverili tudi njihovo skladnost, saj se je visoka ocena izpolnjevanja določene kupčeve zahteve morala ujemati tudi z visoko oceno izpolnjevanja tistih tehničnih značilnosti, s katero so te zahteve povezane. V primeru, da ni bilo tako, je bil to znak napačne povezave v matriki razmerij.

Preglednica 7. *Benchmarking tehničnih značilnosti*
Table 7. *Benchmarking of technical features*

		Izbira prave dolžine miz, plošče / *The proper table and board length*	Izbira prave širine miz, plošče / *The proper table and board width*	Debelina mizne plošče / *Thickness of table board*	Oblika mizne plošče / *Shape of table board*	Odpornost mizne plošče / *Table's board resistence*	Gladkost površine plošče / *Smoothness of the board surface*	Možnost izbire podaljška / *The possibility to choose an extension*	Možnost izbire predala / *The possibility to choose a drawer*	Izbira površinske obdelave / *Choosing the surface treatment*	Izbira vrste lesa / *Choosing the wood type*	Možnost izbire stolov / *The possibility of choosing chairs*	Dimenzije nog / *Legs dimensions*	Oblika nog / *Legs design*	Odpornost konstrukcije / *Structural resistance*	Ostale oblikovno konstrukcijske možnosti / *Other structural design options*	Možnost servisa / *Possibility of servicing*
Ocena tehničnih strokovnjakov / *Technical experts' evaluation*	5	△				□		○	△		□				□		△
	4		△	□	△		△○	△		□△		△	□	△○		△	
	3				○	△	□			○	△	□	△		△		
	2			△○	□	○					○	○	○	□	○	○□	
	1																
	0	○□	○□					□	○□								○□

Legenda / Legend:

Proučevani izdelek / *Product*	Simboli-bencmarking / *Symbol-benchmarking*
A	△
B	□
C	○

3.11 11. KORAK: DOLOČITEV ABSOLUTNE IN RELATIVNE VREDNOSTI POSAMEZNE TEHNIČNE ZNAČILNOSTI
3.11 STEP 11: DETERMINATION OF ABSOLUTE AND RELATIVE VALUES FOR EACH TECHNICAL FEATURE

V tem koraku smo za vsako tehnično značilnost izdelka, na osnovi faktorja pomembnosti kupčeve zahteve in razmerij med kupčevimi potrebami in tehničnimi značilnostmi, določili absolutno in relativno tehnično pomembnost. Absolutno vrednost tehnične pomembnosti smo izračunali z enačbo (Starbek et al., 2000):

$$AVTP_J = \sum_{I=1}^{N} (FP_I * UR_{IJ})$$, kjer je:

AVTPJ absolutna vrednost tehnične pomembnosti j-te tehnične značilnosti.
FP I faktor pomembnosti i-te zahteve kupca.
UR JI utež razmerja i-te zahteve kupca in j-te tehnične značilnosti
N število zahtev kupca

Relativno vrednost tehnične pomembnosti pa smo izračunali z enačbo (Starbek et al., 2000):

$$RVTP_J = AVTP_J / \sum_{I=1}^{N} AVTP_J$$, kjer je:

AVTPJ relativna vrednost tehnične pomembnosti j-te tehnične značilnosti.
m število vseh tehničnih značilnosti

Relativno vrednost smo podali v % (abs. pom. * 100/Σ vseh abs. pom.).

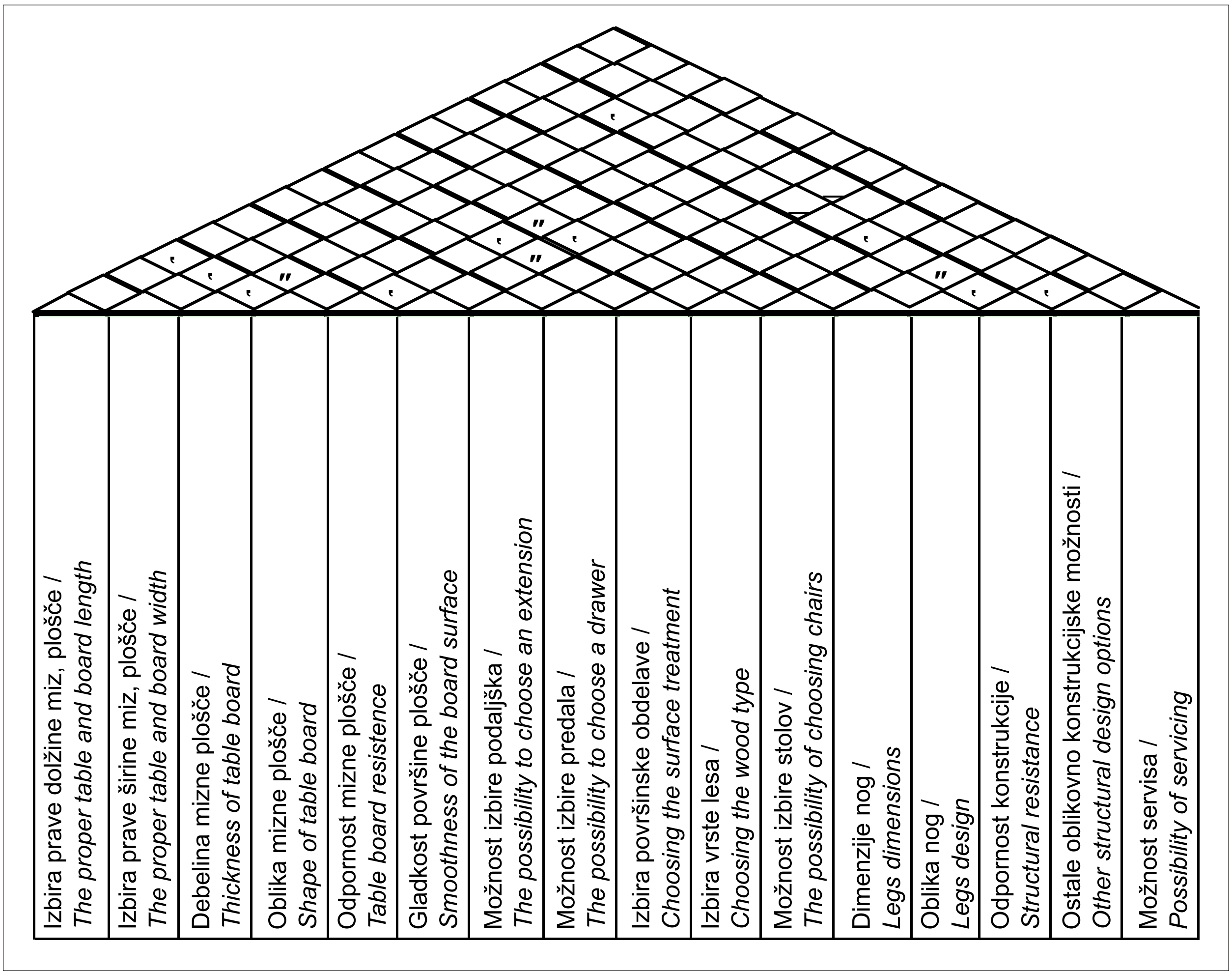
Preglednica 8. *Določitev absolutne in relativne vrednosti posameznih tehničnih značilnosti*
Table 8. *Determination of absolute and relative values for each technical feature.*

Tehnične značilnosti (dizajn) / ***Technical characteristics (design)***	**Absolutna pomembnost /** ***Absolute importance***	**Relativna pomembnost (v %) /** ***Relative importance (%)***
Izbira prave dolžine miz, plošče / *The proper table and board length*	216	8,6
Izbira prave širine miz, plošče / *The proper table and board width*	204	8,1
Debelina mizne plošče / *Thickness of table board*	153	6,1
Oblika mizne plošče / *Design of table board*	192	7,7
Odpornost mizne plošče / *Table board resistence*	123	4,9
Gladkost površine plošče / *Smoothness of the board surface*	108	4,3
Možnost izbire podaljška / *The possibility to choose an extension*	171	6,8
Možnost izbire predala / *The possibility to choose a drawer*	117	4,7
Izbira površinske obdelave / *Choosing the surface treatment*	192	7,7
Izbira vrste lesa / *Choosing the wood type*	147	5,9
Možnost izbire stolov / *The possibility of choosing chairs*	72	2,9
Dimenzije nog / *Legs dimensions*	153	6,1
Oblika nog / *Legs design*	156	6,2
Odpornost konstrukcije / *Structural resistance*	141	5,6
Ostale oblikovno konstrukcijske možnosti / *Other structural design options*	210	8,4
Možnost servisa / *Possibility of servicing*	153	6,1

Tehnična značilnost, ki je dosegla najvišjo stopnjo vrednosti relativne tehnične pomembnosti, je v največji možni meri zadovoljevala kupčeve potrebe in s tem bistveno vplivala na oceno in pričakovan uspeh izdelka.

3.12 12. KORAK: DOLOČITEV TEHNIČNIH KORELACIJ
3.12 STEP 12: DETERMINATION OF TECHNICAL CORRELATIONS

Sprememba določene tehnične značilnosti navadno vpliva na spremembe drugih tehničnih značilnosti v pozitivnem ali v negativnem smislu in te medsebojne vplive smo prikazali v matriki tehničnih korelacij (slika 2). Ocena pozitivne in negativne odvisnosti posameznih tehničnih značilnosti je odvisna od vpliva na spremembe določene značilnosti na smer spremembe druge značilnosti. Pozitivne odvisnosti so bile tiste, kjer je sprememba ene značilnosti pripeljala do izboljšanja druge. Pri tem smo uporabili grafične simbole, ki so prikazani v legendi slike 2.



Slika 2. *Določitev tehničnih korelacij*
Figure 2. *Determination of technical correlations*

Legenda / Legend:

Povezava	Simboli tehničnih korelacij
Močno pozitivna	″
Šibko pozitivna	‛
Brez odvisnosti	prazna celica
Šibko negativna	–
Močno negativna	*

Z dvanajstim korakom je bila končna podoba prve hiše kakovosti končana. Le-ta zajema informacije o:
- kupčevih potrebah in zahtevah z oceno njihovih pomembnosti,
- primerjalnih ocenah preučevanega izdelka v primerjavi s konkurenčnimi,
- povezavah med zahtevami kupca in tehničnimi značilnostmi izdelka,
- prioritetah oziroma vrstnem redu možnih izboljšav izdelka ter
- konfliktnih situacijah med spremembami tehničnih značilnosti, ki opozarjajo na dodatne raziskave in možnosti inventivnih rešitev.

Razvoj nadaljnjih nivojev je v našem primeru nesmiseln, saj se spušča v tehnične podrobnosti, kar pa je naloga tehničnega tima. Prvi nivo hiše kakovosti je osnova za nadaljnji tehnološki razvoj po metodi razvoja funkcij kakovosti, pridobljene podatke pa je možno uporabiti tudi v kakšni drugi metodi.

4 POVZETEK
4 SUMMARY

Market and competitive conditions are tightening and the dynamics of external influences are forcing companies to adapt to this changing situation in a flexible and timely manner. Only companies which are able to quickly develop and market high-quality and affordable products can survive and grow. Due to the importance of new product development, it makes sense to do this according to a certain process that can be adapted for the development of particular items. This can save time and money and improve the performance of new products, which depends primarily on the costumers' requirements. It is very important to adjust new products to meet these requirements using the technological and economic abilities of the company which makes the product.

In our research we tried to find out whether it makes sense to develop a dining table in serial production and at the same time give the buyers an opportunity to choose the size of the table, type of wood, the possibility of drawers and offer after-sales services. We used the quality function deployment method, which can help companies in developing commercially successful products and services. The method allows the collection and analysis of requirements (all the customers' expressed, unexpressed, present and future needs) followed by translating these requirements into product features. It is also very flexible and allows quick changes of characteristics in the process of development, and therefore reduces both the costs and time needed for development.

The resulting house of quality gave us an answer to the basic question as to whether the concept of the table was appropriate, and we were satisfied with the response. With talking to buyers we came to the conclusion that it means a lot to people when they have the choice and chance to get post-sales services. The value of the table increases in their eyes and they are prepared to pay a higher price. At first glance our table did not seem to be anything special, but after presenting people with all the possible features they could choose before buying it, they evaluated it as more desirable.

It appeared that the main disadvantage of the table was the detachable table extension, since this needs to be stored separately. We had previously considered this, but it did not seem to be as important a factor in the end. One interesting fact is that the respondents felt that a drawer is unnecessary for a dining table, so we decided to remove it.

A surprisingly small percentage of people found the short delivery time to be very important, but in our opinion this service will become an advantage later when potential buyers compare it with offers in other stores.

The concept of this kind of dining table is a novelty in our market. Although the offer of dining tables is large it is rigid in terms of being able to choose different dimensions, materials and surface treatments. Therefore, the proper marketing strategy is necessary if we want to become successful in a challenging global market. This means that every potential buyer must receive a detailed explanation from an expert on all possible characteristics of the table.

The next phase of actually launching the dining table to market is not the topic of our research. A business-market analysis would be necessary to determine whether the sales would be large enough to generate a satisfactory profit. If the product passes this test, then market development of the table would follow, which would determine features such as packaging and marketing name. The final phase would then be market testing and at the end the launch of regular production.

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FRITZ HANS SCHWEINGRUBER, 1936-2020, JE PREMIKAL MEJE ANATOMIJE LESA IN DENDROKRONOLOGIJE

FRITZ HANS SCHWEINGRUBER, 1936-2020, WHO MOVED THE BOUNDARIES OF WOOD ANATOMY AND DENDROCHRONOLOGY

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UDK 630*902.1
In memoriam

Izvleček / Abstract

Izvleček: *Prof. dr. Fritz Hans Schweingruber (29. 2. 1936 – 7. 1. 2020) je bil ključen lesni anatom in dendrokronolog, učitelj in organizator poletnih terenskih šol, ki je vzpostavil obsežno omrežje znanstvenic in znanstvenikov, napisal referenčne knjige, prispeval k izgradnji javno dostopnih baz podatkov, populariziral in nakazal neslutene možnosti razvoja in uporabe anatomije lesa ter dendrokronologije. Zasnoval je intelektualno zapuščino, ki bo še dolgo navdihovala njegove sledilce po vsem svetu.*

Ključne besede: *anatomija lesa, dendrokronologija, poučevanje, knjige, terenski tedni*

Abstract: *Prof. Dr. Fritz Hans Schweingruber (29 February 1936 – 7 January 2020) was a key wood anatomist and dendrochronologist, teacher and organiser of summer field schools, who established an extensive network of scientists, wrote key books, contributed to the construction of publicly accessible databases, popularised and revealed unimaginable possibilities for the development and use of wood anatomy and dendrochronology. He established an intellectual legacy that will inspire his followers around the world for a long time to come.*

Keywords: *wood anatomy, dendrochronology, teaching, books, fieldweeks*

Slika 1. Fritz Hans Schweingruber, Mašun, Slovenija 2000
Figure 1. Fritz Hans Schweingruber, Mašun, Slovenia 2000

7. januarja 2020 je svetovno dendrokronološko javnost presenetila vest, da nas je zapustil prof. dr. Fritz Hans Schweingruber (slika 1), ključen lesni anatom in dendrokronolog, ki je z navdušenjem izuril na tisoče študentov in udeležencev poletnih terenskih šol. Zasnoval je svetovno mrežo znanstvenic in znanstvenikov, napisal ključne knjige, prispeval k izgradnji javno dostopnih baz podatkov ter populariziral in nakazal neslutene možnosti razvoja in uporabe anatomije lesa in dendrokronologije. Obenem pa je spletel človeške vezi med vsemi, ki delujejo na omenjenih področjih, in zasnoval intelektualno zapuščino, ki bo še dolgo navdihovala njegove sledilce po vsem svetu. Na vse, ki smo ga kdaj srečali ali z njim sodelovali, je naredil izjemen vtis, ker je bil osebno preprost in topel. Zato nam ostaja v spominu kot naš Fritz.

Fritz Hans Schweingruber se je rodil 29. februarja 1936 blizu Berna v Švici. Do leta 1965 je bil učitelj, nato je nadaljeval s študijem in leta 1972 dok-

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toriral iz botanike na Univerzi v Baslu ter leta 1976 postal univerzitetni profesor. Svojo vseživljenjsko kariero je nadaljeval v Švicarskem zveznem raziskovalnem inštitutu WSL (Eidgenossische Forschungsanstalt für Wald, Schnee und Landschaft) v Birmensdorfu. Po formalni upokojitvi leta 2001 je ostal neutruden znanstvenik, povezan s kolegicami in kolegi iz celega sveta. Aktiven in radoveden je ostal do zadnjega dneva. Kot lesni anatom in dendrokronolog ima glavne zasluge za promocijo in razvoj obeh disciplin, ki sta danes široko uporabljani na mnogih področjih, od proučevanja klime in okolja do zgodovine človeštva. Bil je velik povezovalec ljudi vseh starosti, profilov in narodnosti in ima zasluge, da smo vsi, ki delujemo na področju dendrokronologije, med seboj dobro povezani. Z mednarodnimi sodelavkami in sodelavci je zasnoval mrežo dendrokronoloških podatkov za severno poloblo, pri čemer je nenehno zagovarjal in skrbel, da so bili pridobljeni podatki javno dostopni in na razpolago vsem in v splošno dobro. Kot lesni anatom je dendrokronologijo povezal z anatomijo lesa, kar je med drugim pripomoglo k razvoju novih raziskovalnih vej dendroekologije in paleoklimatologije. Naredil je tudi preboj pri proučevanju anatomije in dendrokronologije stebel grmovnih vrst. Z navdušenjem je izuril na tisoče študentov, od katerih so mnogi postali vodilni znanstveniki, ki so ostali zvesti dendrokronologiji in jo razširili na druge discipline. Slovel je kot pisec številnih knjig in predvsem kot odličen učitelj in motivator. Še posebej je slovel po znamenitih terenskih tednih.

Po njegovem slovesu so njegovi številni učenci in sodelavci iz vsega sveta objavili že več člankov o njegovi življenjski poti, publicističnem delu in prispevku za znanost (Crivellaro & Fiorentino, 2020; Crivellaro & Gärtner, 2020), njegovi genialnosti, neutrudni radovednosti in trdoživosti (Büntgen et al., 2020) in o njegovih nepozabnih dendroekoloških terenskih tednih (Urbinati et al., 2020). Spomine nanj so predstavili tudi na konferencah in v družbenih medijih. Rdečo nit vseh spominov pa pred-

Slika 2. F. H. Schweingruber: naslovne strani nekaj izbranih publikacij
Figure 2. F. H. Schweingruber: The covers of some selected books

stavljajo osebne izkušnje s Fritzem, kakor smo ga vsi klicali. Imel je neverjeten spomin za ljudi in je z nami znal vzpostaviti trajen in prijateljski odnos. Vsi smo ga oboževali in se čudili njegovi neverjetni energiji, produktivnosti in navdušenju za znanost.

Kot avtorica tega zapisa tudi jaz ne morem mimo osebnih spominov na Fritza. Kot mlada znanstvenica in učiteljica anatomije lesa sem najprej spoznala njegovo knjigo »Microsopic Wood Anatomy« (Schweingruber, 1978) (slika 2), ki nas je navdušila s kakovostnimi fotografijami in dostopno ceno in je bila napisana v kar treh jezikih: angleščini, nemščini in francoščini. Knjigo v anatomskem laboratoriju še danes dnevno uporabljamo, poleg angleške spletne verzije, s katero je Fritz ob upokojitvi poskrbel, da je prosto dostopna vsem, ki jo potrebujemo (Schoch et al., 2004). Pri našem delu je nepogrešljiva tudi njegova knjiga Anatomy of European Woods (Schweingruber, 1990), ki na kar 800 straneh predstavlja mikroskopsko zgradbo večine evropskih lesnih vrst.

Ko smo vstopali v dendrokronologijo, je bila nepogrešljiva temeljna knjiga Tree rings - basics and applications of dendrochronology (Schweingruber, 1988) ali njena nemška predhodnica Der Jahrring (Schweingruber, 1983). Poleg omenjenih je temeljnega pomena še Multilingual Glossary of Dendrochonology (Kaennel & Schweingruber, 1995).

V nadaljevanju so bile objavljene še številne knjige. Izbrane knjige so na primer povezale branike in okolje (Schweingruber, 1996), zgradbo lesa in okolje (Schweingruber, 2007), predstavile anatomijo stebel zeliščnih, grmovnih in drevesnih vrst (Schweingruber et al., 2011; 2013; Schweingruber & Börner, 2018; 2019), posvetil pa se je tudi vse pomembnejši anatomiji tkiv skorje (Crivellaro & Schweingruber, 2013).

Fritz tudi po upokojitvi ni nehal delovati in objavljati, knjige pa izhajajo še po njegovi smrti. V letu 2020 sta izšli že dve knjigi. Posebej zanimiva je knjiga Design over 400 million years (Schweingruber & Schweingruber, 2020), ki jo je Fritz pripravil v soavtorstvu s soprogo Elisabeth, ki mu je vsa leta zvesto stala ob strani ter podpirala njega, njuno družino s tremi sinovi ter vnukinjami in vnuki ter Fritzovo veliko mednarodno dendrokronološko družino.

Fritza sem osebno spoznala, ko sva se s Tomom Levaničem kot mlada dendrokronologa leta 1995 udeležila Dendroekološkega terenskega tedna v smučarskem središču Monte Bondone v Italiji. Terenski teden je soorganizral Carlo Urbinati in so ga zaradi velikega interesa morali izvesti v dveh zaporednih tednih, vsakič za 50 udeležencev (Urbinati et al., 2020). Tudi mene je presenetil in očaral prvi stik s Fritzem, ki je prerasel v trajno prijateljstvo. Na tem dendroekološkem tednu smo

Slika 3. Fritz v tipični pozi med razlago, kako je treba predstaviti znanstveno delo.
Figure 3. Fritz in a typical pose explaining how to present a scientific work

udeleženci med drugim spoznali, da za navdušenje za znanost ni omejitev kot so starost (udeleženci so bili stari od 18 do 65 let), status (od študenta do upokojenca), narodnost (ljudje iz vsega sveta) in jezik (govorili smo vse mogoče jezike, uradni jezik je bila angleščina, s poudarkom na Fritzovi »Swiss English«). Udeleženci smo skupaj preživeli zelo aktiven teden v Italijanskih Alpah. Naučili smo se, kako prepoznati in opredeliti znanstveni problem in cilje raziskave, kako izvesti raziskavo od vzorčenja na terenu, priprave vzorcev, dendrokronoloških ter anatomskih analiz, do obdelave podatkov ter interpretacije in prikaza rezultatov. Delali smo v majhnih skupinah. Fritz nas je ves čas motiviral z geslom »*science is fun*«. Zadnji dan je bilo po tradiciji potrebno predstaviti rezultate, pri čemer smo se naučili, kako napisati povzetek znanstvenega dela, kako narediti plakat ter kako ustno predstaviti svoje delo. Pri tem sta bila ključna razdelitev in organizacija dela, saj smo si bili člani skupin zelo različni. Fritz je bil eden redkih, ki nas je učil, kako naj se izražamo, kako glasno naj govorimo, kako naj se med predavanjem obrnemo in kam naj gledamo, kako velike naj bodo črke in koliko besedila sodi na plakat ter predvsem to, da so pri predstavitvi najbolj pomembni poslušalci, ki jim svoje delo predstavljamo in razlagamo. Na teh zgodnjih dendoekoloških tednih pri delu (še) nismo uporabljali računalnikov, tako da smo se lahko povsem usmerili v način in cilje dela ter predstavitev. S tem nam je dal neprecenljivo popotnico in prav zato smo mnogi (p)ostali znanstveniki in učitelji.

Slika 4. Fritz (drugi z desne v drugi vrsti) z udeleženci dendroekološkega tedna, Mašun, Slovenija, 2000.
Figure 4. Fritz (second from the right in the second row) with participants of the Dendroecological Week, Mašun, Slovenia, 2000.

Na takih dendroekoloških tednih so se vedno stkale prijateljske vezi, ki so pogosto prerasle v sodelovanje. Kdor se je enkrat udeležil dendroekološkega tedna, si je želel, da bi izkušnjo lahko ponovil. Zato smo nekateri postali redni udeleženci, za terenske tedne pa smo navdušili tudi sodelavce in tja pošiljali svoje študente. S Tomom Levaničem sva bila tudi (so)organizatorja zelo uspešnega dendroekološkega tedna na Mašunu v letu 2000 (slika 3). Mnoge takratne udeleženke in udeleženci so danes znanstvenice in znanstveniki, s katerimi sodelujemo pri mednarodnih projektih, izmenjavah in številnih objavah.

Ob Fritzovi upokojitvi so njegovi mladi sodelavci v septembru 2001 organizirali veliko konferenco v Davosu, na kateri so se zbrali znanstveniki iz celega sveta. Tu se je videlo, kako veliko in pestro omrežje je spletel Fritz. Na konferenci je dal tudi pobudo za ustanovitev društva ATR (Association of Tree-Ring Research) in pobudo za konferenco TRACE (Tree Rings in Archaeology, Climatology and Ecology), ki naj bi predvsem omogočila aktivno udeležbo mladim znanstvenikom. Društvo ATR je tako postalo osrednje društvo za dendrokronologijo, redna letna konferenca TRACE pa eno najpomembnejših srečanj v Evropi, kjer so dobrodošli tudi člani in udeleženci iz drugih kontinentov. Fritz je bil tudi med pobudniki konference Eurodendro, ki je redno na sporedu že več kot 30 let. Tudi njegovi terenski tedni živijo še danes. Sodelavke in sodelavci WSL vsako leto organizirajo dva terenska tedna, enega s poudarkom na dendroekologiji in enega s poudarkom na anatomiji lesa. Trenutno sta v pripravi 31. Evropski dendroekološki terenski teden 2021 (31st European Dendroecological Fieldweek 2021), ki ga koordinira Kerstin Treydte in 20. mednarodni tečaj anatomije lesa in dendroekologije (20th International Course on »Wood Anatomy and Tree-Ring Ecology«), ki ga koordinirata Holger Gärtner in Alan Crivellaro in bo predvidoma izveden v kraju Klosters v Švici, v novembru 2020.

Fritz je do zadnjega dneva ostal mladosten in aktiven ter povezan z mednarodno skupnostjo, ki jo je zgradil. Vsi, ki smo ga poznali, se ga s hvaležnostjo spominjamo, njegova neverjetna intelektualna zapuščina pa nas bo še dolgo navdihovala.

Slika 5. Fritz v laboratoriju WSL, Brimensdorf, Švica v letu 2014, med predstavitvijo novih tehnik v anatomiji lesa

Figure 5. Fritz in the laboratory of WSL, Brimensdorf, Switzerland in 2014, presenting new techniques in wood anatomy

POVZETEK
SUMMARY

The dendrochronological community is mourning the loss of Prof. Dr. Fritz Hans Schweingruber (29 February 1936 - 7 January 2020). His life, publishing, contribution to science, his world of inspiration and famous dendroecological fieldweeks have been remembered in a list of publications (Büntgen et al., 2020; Crivellaro & Fiorentino, 2020; Crivellaro & Gärtner, 2020; Urbinati et al., 2020). The community remembers him at conferences and on social media. Common to all the memories are, however, our personal experiences with Fritz, as we all called him.

Fritz is remembered as the author of numerous books and databases, an excellent teacher and motivator and organiser of exceptional dendroecological fieldweeks. He has always amazed science enthusiasts of all generations and from all over the world as an incredible scientist, teacher and person.

As the author of this text, I would like to share some personal memories of Fritz. I first met him as a young scientist and teacher of wood anato-

my indirectly through the book *Microsopic Wood Anatomy* (Schweingruber, 1978), which impressed with high-quality photos of wood structures and especially because it was written in three languages, English, German and French, which were at that time important for the Slovenian wood community. The book is still in use daily in our wood anatomy laboratory, as well as its on-line version in English (Schoch et al., 2004). Equally important are his numerous other books.

I first met Fritz in person when Tom Levanič and I, as novices in dendrochronology, attended our first Dendroecological Fieldweek in Monte Bondone, Italy in 1995 co-organised by Carlo Urbinati (Urbinati et al., 2020). There we learned that there are no limits to enthusiasm for science. We appreciated how Fritz taught us how to identify and define a research problem and objectives (i.e., the research question), how to conduct consistent research in terms of field sampling, sample preparation, dendrochronological and anatomical analyses, data processing, interpretation and presentation of the results, even if both time and resources are limited. We liked the work in small groups and how Fritz motivated us with his personal involvement, enthusiasm and the motto "*science is fun*". On the last day, according to tradition, the results had to be presented, and the small team composed of people from all over the world, who first met a few days before, had to practice how to write a summary, how to make a poster, and how to present the work orally. We had to learn how to divide and organise the work of such a heterogenous group. Fritz was at that time one of the few who taught us how to speak, how big the letters on the poster should be, how much text belongs on the poster and above all that those to whom we present our work are the most important in the presentation. It is unbelievable that all that work could be done without computers and any other technology in those early dendoecological weeks.

Many of us who attended a dendroecological fieldweek wished to become regular participants of the event. We recommended it to other colleagues and our students. Tom Levanič and I were also (co-) organisers of the dendroecological week in Mašun, Slovenia in 2000. This fieldweek was also considered very successful, and many participants, at that time the beginners, are now established scientists with whom we fruitfully collaborate on various projects and have co-authored numerous publications.

Upon Fritz's official retirement, his colleagues organised a large conference in Davos (2001) that brought together scientists from around the world. Here one could see how large and varied a network of people was woven by Fritz. At the conference, he also initiated the establishment of the Association of Tree-Ring Research (ATR) and proposed the initiative for the TRACE (Tree Rings in Archaeology, Climatology and Ecology) conference, which is primarily intended to enable the active participation of young scientists. The ATR Society and the annual TRACE conference are very successful, and continue to grow. Fritz was also among the pioneers of the Eurodendro conferences, which are regularly organised and attended by dendrochronologists from all over the world. Moreover, the dendroecological fieldweeks supported by the WSL are still alive and vibrant. The 31st European Dendroecological Fieldweek, coordinated by Kerstin Treydte, is scheduled for 2021, and the 20th International Course on "Wood Anatomy and Tree-Ring Ecology", coordinated by Holger Gärtner and Alan Crivellaro, will be held in Klosters, Switzerland in November 2020.

In addition to the above, the international dendro-community remembers Fritz with contributions at meetings (including video conferences), and the sharing of memories on social media.

Finally, I would like to share my sympathies with Fritz's wife Elisabeth and his family. For all of us Fritz will be remembered as a friend, teacher and scientist whose intellectual legacy will continue to inspire scientists around the world for a long time to come.

VIRI
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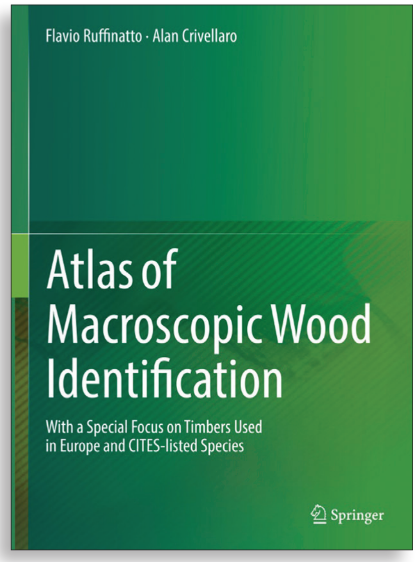

Atlas za makroskopsko identifikacijo lesa

s posebnim poudarkom na lesu, ki se uporablja v Evropi in na vrstah, ki so uvrščene na seznam CITES

Atlas of Macroscopic Wood Identification

With a Special Focus on Timbers Used in Europe and CITES-listed Species

Ruffinatto, Flavio & Crivellaro, Alan (2019).
Atlas of Macroscopic Wood Identification, With a Special Focus on Timbers Used in Europe and CITES-listed Species. Springer Nature Switzerland AG, 439 pp., ISBN 10.1007/978-3-030-23565-9, ISBN 10.1007/978-3-030-23566-6 (e-knjiga), https://link.springer.com/book/10.1007%2F978-3-030-23566-6

Knjiga, ki sta jo napisala avtorja Flavio Ruffinatto in Alan Crivellaro, je izšla ob koncu leta 2019 pri založbi Springer. Vključuje predstavitev 335 lesnih vrst, ki nastopajo na evropskem trgu, s poudarkom na makroskopski zgradbi lesa in prepoznavanju posamezne vrste.

Knjiga je razčlenjena na dva dela in 13 poglavij. Prvi del predstavlja anatomsko zgradbo lesa in kako les pripravimo za makroskopsko opazovanje s prostim očesom in različnimi povečevalnimi lečami. Predstavi tudi, kako so pripravili les in posnetke za knjigo ter kakšnim načelom so sledili pri opisu posamezne lesne vrste. Obsežno poglavje je namenjeno makroskopskim znakom zgradbe lesa, ki so bogato ilustrirani z barvnimi fotografijami in ključno dodatno literaturo ter kako jih uporabimo za makroskopsko prepoznavanje lesa, ločeno za iglavce in listavce. Pri obravnavanju makroskopske zgradbe lesa avtorja sledita nedavno objavljenemu seznamu makroskopskih anatomskih znakov za prepoznavanje lesa.

Predstavitve lesnih vrst sledijo abecednemu redu latinskih imen lesnih vrst (iglavcev in listavcev). Nabor vrst vsebuje 335 vrst iz 292 rodov, ki so pomembne za evropski trg lesa. Vključene so tudi vrste s seznama CITES. Vsaka vrsta je najprej predstavljena z barvnimi makroskopskimi posnetki glavnih prerezov lesa. Za posamezno vrsto je poleg latinskega imena navedeno angleško, italijansko, francosko in nemško poimenovanje ter ali je vrsta ogrožena. Podane so splošne značilnosti in kombinacije znakov za makroskopsko identifikacijo. Poleg anatomskih znakov so podani tudi podatki o naravni odpornosti, fizikalno mehanskih ter drugih lastnostih in glavne rabe.

Pri vsaki vrsti so navedene posebnosti, dodatne opombe oz. navodila za makroskopsko identifikacijo ter regija, kjer vrsta uspeva. Rodovi so opisani glede na število vrst, geografsko razširjenost in komercialni pomen, podane pa so tudi podrobnosti o tem, v kakšnem obsegu je mogoče vrsto znotraj rodu določiti z makroskopsko in mikroskopsko analizo in o morebitnih zavajajočih trgovskih imenih.

Knjigo zaključuje seznam z uvrstitvijo predstavljenih vrst v botanične družine ter kazalo vrst, razporejenih po latinskem in po angleškem imenu.

Avtorja Flavio Ruffinatto in Alan Crivellaro sta svetovno znana in priznana lesna anatoma mlajše generacije z obsežnimi referencami. Flavio Ruffinatto je magistriral in doktoriral na Univerzi v Torinu v Italiji, kjer tudi deluje. Raziskovalno se je zelo zavzel za napredek na področju makroskopske in mikroskopske identifikacije lesa, forenzično identifikacijo lesa, diagnostiko in ohranjanje lesene kulturne dediščine. Ima bogate izkušnje s poučevanjem anatomije in tehnologije lesa na univerzi ter aktivnostmi za poklicno usposabljanje strokovnjakov, ki potrebujejo specifično zanje o lesu.

Alan Crivellaro je diplomiral in doktoriral na Univerzi v Padovi v Italiji. Deloval je kot asistent in raziskovalec Inštituta Trees and Timber Institute of the Italian National Research Council ter na Univerzi v Padovi. Trenutno deluje kot raziskovalec na Univerzi Cambridge. Alan Crivellaro poučuje anatomijo lesa in ekologijo rastlin na mednarodnih ekoloških tednih. Je znan predavatelj in organizator poletnih šol. Sodeluje tudi s kolegi iz Univerze v Ljubljani.

Oba avtorja sta kot pisca članka poznana tudi bralcem revije Les/Wood.

Avtorja delujeta na področju makroskopske identifikacije lesa in sta nedavno objavila članek z naslovom „Review of macroscopic features for hardwood and softwood identification and a proposal for a new character list = Pregled makroskopskih značilnosti za identifikacijo lesa listavcev in iglavcev in predlog za nov seznam znakov“ (Ruffinato, Crivellaro, Wiedenhoeft, IAWA Journal 2015, 36 (2), 208-241), ki je ključna referenca na tem področju.

Atlas zapolnjuje pomembno nišo na področju anatomije in makroskopske identifikacije lesa ter predstavitve lesnih vrst. Je dragocen vodnik za vse, ki se ukvarjamo z lesom, od trgovcev do naravovarstvenikov, inšpekcijskih ter carinskih služb, ki sodelujejo pri izvajanju evropske uredbe o lesu in inšpekcije CITES, ter za študente, učitelje in raziskovalce, restavratorje ter sodelavce služb za varstvo naravne in kulturne dediščine, skratka vse, ki potrebujejo ali jih zanima hitro in zanesljivo orodje za prepoznavanje lesa brez zahtevne priprave vzorcev.

Knjiga je naprodaj v tiskani in e-obliki preko spletne strani založnika
https://link.springer.com/book/10.1007%2F978-3-030-23566-6

This useful and interesting book, written by Flavio Ruffinatto and Alan Crivellaro, was published by Springer at the end of 2019. It includes a presentation of 335 wood species important for the European market, with an emphasis on the macroscopic structures of their wood and macroscopic identification.

The book is divided into two parts and 13 chapters. It presents the anatomical structure of wood and how it is prepared for macroscopic observation with the naked eye and various magnifying lenses, and the principles the authors followed in the presentation and description of each species. An extensive chapter is also devoted to the macroscopic features of wood structure, which are richly illustrated with colour photographs and additional literature, and explanations of how they are used for macroscopic identification of softwoods and hardwoods. The presentations of 335 wood species from 292 genera are arranged alphabetically by scientific names, and CITES species are also included. Each species is first represented by colour images of the main anatomical-sections of the wood. For each species, the English, Italian, French and German vernacular names are also given. The general characteristics and combinations of macroscopic identification features are included as well. In addition, data on wood properties, like resistance, physical-mechanical properties and main uses are given.

For each species special features are also reported, along with additional notes and instructions for macroscopic identification and the data on geographical distribution. The genera are described in terms of number of species, geographical distribution and commercial importance, and to what extent the species can be identified within the genus by macroscopic and microscopic analysis, while possibly misleading trade names are given too.

The book concludes a list classifying the presented species into botanical families, and indexes of the presented species arranged by scientific and English names.

The authors Flavio Ruffinatto and Alan Crivellaro are world-renowned and recognised wood anatomists of the younger generation, with long lists of references.

Flavio Ruffinatto has an MS in Forestry and Environmental Sciences and a PhD in Agricultural, Forestry and Food Sciences (University of Turin, Italy). His professional and research interests include macroscopic and microscopic wood identification, forensic timber identification, wooden cultural heritage diagnostics and conservation. He has extensive experience teaching wood technology and wood identification to both academic students and vocational training bodies.

Alan Crivellaro obtained his degree in Wood Science and Technology (2002), a BSc in Forestry (2008) and a PhD (Doctor Europaeus) in Ecology in 2012 at the University of Padova (Italy). In 2002 he joined the Trees and Timber Institute of the Italian National Research Council as an assistant researcher, and was involved in a research program on timber strength classification until 2007, when he focused on his PhD. From 2015 to 2018 he was assistant professor of Wood Science at the Department of Land, Environment, Agriculture and Forestry at the University of Padova. Crivellaro teaches wood anatomy and plant ecology at international fieldweeks and summer schools. He is currently working as a researcher at the University of Cambridge. He also collaborates with colleagues from the University of Ljubljana.

The authors have been working together on macroscopic wood features and published the "Review of macroscopic features for hardwood and softwood identification and a proposal for a new character list" (Ruffinato, Crivellaro, Wiedenhoeft, IAWA Journal 2015, 36(2), 208-241), which is a key reference in the field.

Both authors are also known to the readers of *Les / Wood* journal.

The atlas fills an important niche in the field of macroscopic wood anatomy and identification, and the presentation of the main properties of important wood species. It is a valuable guide for all working in the field of timber trade and verification according to the European Timber Regulation and CITES. It is valuable for scientists, teachers, students, restorers, and all who work with wood or are simply passionate about and interested in wood. It is a fast and reliable tool for wood identification without time-consuming and demanding need for sample preparation.

The book is for sale in print and e-format on Springer's website https://link.springer.com/book/10.1007%2F978-3-030-23566-6

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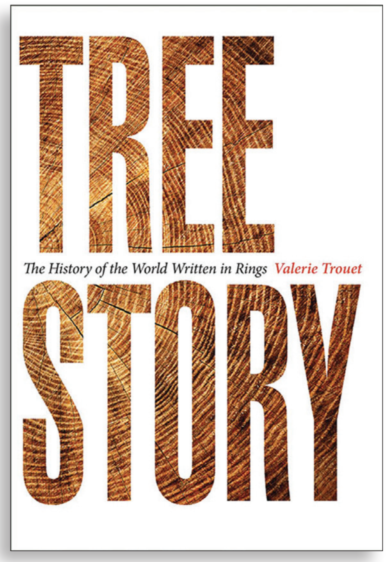

Zgodba o drevesih:
Zgodovina sveta, napisana v branikah

Tree Story:
The History of the World Written in Rings

Trouet, Valerie (2020).
Tree Story: The History of the World Written in Rings, Johns Hopkins University Press, 256 pp.,
ISBN: 9781421437774,
https://jhupbooks.press.jhu.edu/title/tree-story

Knjigo, ki bi bila v slovenskem prevodu naslovljena kot »Zgodba o drevesih: Zgodovina sveta, napisana v branikah«, je napisala Valerie Trouet, vrhunska in svetovno priznana dendrokronologinja in profesorica na Univerzi v Arizoni, ki je poklicno življenje posvetila drevesom in branikam in njihovi povezanosti s podnebjem in gozdnimi ekosistemi. Valerie Trouet izvira iz Belgije, kjer je študirala in opravila doktorat s področja bioznanosti in inženirstva, v knjigi pa pove, kako se je prvič srečala z branikami in dendrokronologijo.

Knjiga je posvečena drevesom in branikam in pripoveduje, kako dendrokronologi prevajamo zgodovino, zapisano v lesu, v znanstvene in splošno razumljive zgodbe. Čeprav knjiga govori o znanstvenih principih in dosežkih, jo lahko beremo kot zanimivo in navdušujočo zgodbo. Bralec tako skozi različna izjemna odkritja in dosežke spoznava, kako deluje znanost in kako znanstveniki in znanstvenice razmišljajo in čutijo, ko se spopadajo z uspehi in razočaranji.

Predstavljen je princip dendrokronologije in njena povezanost s številnimi različnimi področji znanosti, od klimatologije do zgodovine in umetnosti, s čimer se je močno izboljšalo tudi naše razumevanje podnebne zgodovine Zemlje in vpliv podnebja v zadnjih tisočletjih na razvoj civilizacij.

Dendrokronologija je opisana od njenih samih začetkov v ZDA. Pojasnjena so načela dendrokronologije, kako drevesa rastejo v različnih okoljih od ZDA do Evrope ali tropske Afrike. Avtorica je delovala v različnih okoljih, zato lahko v prvi osebi opisuje, kako je mogoče sestaviti dolge kronologije z analizo branik, pridobljenih iz dreves in „mrtvega“ lesa, ohranjenega v zgodovinskih objektih ali zakopanega v vlažnih tleh. Knjiga poudarja velike dosežke raziskav podnebja in podnebnih sprememb ter njihovega vpliva na zgodovino človeštva od egiptovskih faraonov, preko Rimskega cesarstva, Džingiskana, ameriških pueblov, epidemij kuge v Evropi, brodolomov ladij, piratov in hurikanov.

Knjiga nas vodi skozi glavne dosežke dendrokronologije, ki so predstavljeni v številnih znanstvenih člankih v najrazličnejših revijah. Valerie Trouet jih predstavlja kot povezano, skladno, razumljivo in privlačno zgodbo. Zgodbe piše v prvi osebi in predstavlja tudi znanstvenike in znanstvenice ter ozadja velikih dosežkov. Pri mnogih od njih je sodelovala.

Knjiga me je navdihnila tudi osebno, ker jo je napisala znanstvenica in ker ji je uspelo znanost predstaviti na originalen in privlačen način. Avtorico sem prvič spoznala kot mlado raziskovalko, ko se je udeležila enega od znamenitih dendroekoloških terenskih tednov Fritza Schweingruberja na Mašunu, ki sem ga leta 2000 soorganizirala s Tomom Levaničem.

Ob knjigi sem kot bralka uživala, saj je pokazala, kako predstaviti znanost v obliki pripovedi, ki je popestrena z osebnimi vtisi in anekdotami. Toplo priporočam knjigo in avtorico Valerie Trouet kot nadarjeno pripovedovalko in svetovno znano znanstvenico dendrokronologinjo. Knjiga bo zanimiva za znanstvenike in znanstvenice, strokovnjake in strokovnjakinje, študente in študentke ter vse, ki jih zanima življenje dreves ter delo dendrokronologov in dendrokronologinj.

The book *Tree Story: The History of the World Written in Rings* by Valerie Trouet was published in April 2020. It has been presented and reviewed on numerous forums, websites and social media and attracted a lot of attention.

Valerie Trouet is an accomplished and globally recognised dendrochronologist, and a professor at the University of Arizona. Her professional life is dedicated to tree rings, and especially to studying past climates, forest ecosystems, and their interactions. She completed her studies and PhD in Belgium in the field of Bioscience Engineering. The book is a balanced presentation of both science and an engaging narrative. We learn of various remarkable discoveries and achievements, how science is done, and how scientists think and feel when they cope with success and disappointment.

The book inspired me personally, especially because it is written by a successful woman in tree-ring science, whom I first met at the dendroecological field week of Fritz Schweingruber in Mašun in 2000, which I co-organised with Tom Levanič. I enjoyed how Valerie Trouet presents the science in the form of a narrative, and how all the stories are sprinkled with personal impressions and anecdotes. Therefore, I warmly recommend the book and the author Valerie Trouet as a talented story-teller to scientists, professionals and students, and all those who are curious about the lives of trees and the work of dendrochronologists.

A longer book review is published in *Tree Ring Research*, Volume 76, Number 2 (2020), https://treeringresearch.org

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