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NON-NATIVE TREE SPECIES IN THE VIEWPOINT OF CLIMATE CHANGE: CHANCES AND OPPORTUNITIES – CROATIA AS A CASE STUDY

ALOHTONE VRSTE S GLEDIŠTA KLIMATSKIH PROMJENA: PRILIKE I MOGUĆNOSTI U HRVATSKOJ

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Summary

The management of tree species non-native to Republic of Croatia has a certain tradition within Croatian forest management practice; nowadays, their potential should be regarded and re-evaluated in the new frame of climate changes and growing society demands for forest products and services. This paper is a contribution to non-native tree species (NNTS) introduction and use in Croatia, aiming at providing state of the art of NNTS as well as overview of studies and examples of possible management opportunities. Because of the complexity of the matter and growing need to further investigate risks and challenges of NNTS in Croatia, authors have continued their research and will publish the results in a separate paper. Amount of the area occupied by NNTS forest cultures point to the conclusion that the use of these tree species in forest practice is not reached by far and the nursery production does not back up the need for NNTS use. Paper also provides a comprehensive overwiev of different aspects and benefits of the use of NNTS in Croatia. For example, increased wood production and non-wood forest products; production of high quality timber in short–time periods; use of fast-growing tree species for bioenergy production in higher proportion and enhancement of ecosystem services. Increase of stability and adaptive capacity of forest stands by the use of NNTS is highlighted as new silvicultural option for facing climate change. Their use in reforestation or conversion of degraded forest to more valuabe and more resistant/resilient stands offers new possibilities. Integrated and site-specific management is a strategy, which seems to be an appropriate approach for guidelines for the introduction and management of NNTS in Croatia. The use of high productive, resistant NNTS presents new silvicultural solution especially important in terms of site amelioration and enhancement of resistance and resilience of forest stands, which is the most important component of adaptive forest management strategies.

KEY WORDS: new silvicultural options, adaptation strategies, forest landscape restoration.

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1. INTRODUCTION
UVOD

Introduction of non-native tree species (NNTS) to Europe dates back to the 17th and 18th century with the on-going industrialization of Europe, when new ideas for settling enormous demands for wood products had to be resolved. The management of tree species non-native to Republic of Croatia has a certain tradition within Croatian forest management practice; nowadays, their potential should be regarded and re-evaluated in the new frame of climate changes and growing society demands for forest products and services. Today, issues of adaptation to and mitigation of climate changes as well as the question whether these tree species could increase the adaptive capacity of forests to long-term climate change patterns have initiated a new and growing interest in NNTS. Thus, the variety of examples and ecological conditions opened the need for gaining insight into possibilities and complex management issues of NNTS in Croatia. Croatian Forest Research Institute (CFRI) initiated research activities on optimal NNTS for afforestation and plantation establishment during 1960's. Numerous trials set in different bioclimatic regions of the country served as permanent trials for the comparison of growth success of native vs. NNTS (Perić et al. 2006a). Nevertheless, no comprehensive overview on possibilities of the use of NNTS has been compiled so far.

Even though the definition of term NNTS is still not harmonised globally (e.g. Convention on Biological Diversity, International Union for Conservation of Nature, United Nations Environment Programme World Conservation Monitoring Centre), all existing definitions consider NNTS as present species, sub-species or lower taxon, introduced (i.e. by human action) outside its natural past or present distribution range. Despite the fact that each country (including Croatia) has different lists of NNTS, the members of COST Action FP1403 *Non-native tree species for European forests - experiences, risks and opportunities* (NNEXT) decided to focus on tree species with natural past or present distribution range outside of the European continent as a whole in a geographical sense. Discussions on issues concerning NNTS introduction and use in Croatia were initiated during the Training school (23rd–27th August 2016) organized in the frame of NNEXT. The school aimed at exploring chances, risks and challenges, which managers should overcome if they target the active use of those tree species (NNEXT 2016).

This paper is a contribution to NNTS introduction and use in Croatia, aiming at providing an overview of studies and examples of possible management opportunities. It tackles the question of why to introduce and use NNTS to Europe in general and specifically in the Republic of Croatia? Investigating their possible role in forest landscape restoration (FLR), which is the most prominent activity when it comes to mitigation of human influences on natural ecosystems (Stanturf et al. 2015) is especially promising, highlighting their role in preparing the site for native tree species. Despite all opportunities, possible threats, management risks and challenges derived from the use of some NNTS should be considered as a first step in decision making. Nevertheless, there are only a limited number of available scientific publications dealing with these issues, which strongly underlies the need for further research (Celesti-Grapow et al. 2009). Because of the complexity of the matter and growing need to further investigate risks of NNTS in Croatia, authors have continued their research and will publish the results in a separate paper.

2. STATE OF THE ART OF INTRODUCED TREE SPECIES IN CROATIA
STANJE ALOHTONIH VRSTA DRVEĆA U REPUBLICI HRVATSKOJ

Strong, nature-oriented forestry, left only little room for the use of NNTS in Croatia. To date, growing NNTS is mostly associated with scientific research, while only a small area of NNTS is used for practical purposes. Table 1 shows an overview of the most important NNTS in Croatia based on data from National Forest Management Plan (NFMP - "Croatian Forests", Ltd 2016 - 2025) and National Forest Inventory (NFI - Ministry of Agriculture 2010). Date of introduction of NNTS were compiled from forest chronicles. NFI does not provide CAI or MAI, but only growing stock at the time of measurement (2005-2009), and only for NNTS, which were included into the Inventory (some of them are possibly present, but in too small amount to be detected with this method). In NFI it is clearly stated that a small share of NNTS (in growing stock) is present in Croatia (< 4% in total, < 1% in private forests). Data from NFMP (2016 - 2025) shows that all listed NNTS are present in protected forest areas as well, but only area occupied by *Robinia pseudoacacia* (1.74%) is detected with this methodology. This is the reason why we present data on area occupied by NNTS by individual Forest management plans. The analysis reveals that the NNT species most used in forestry practice are *Robinia pseudoacacia* L. (12003.88 ha), followed by *Pinus strobus* L. (3218.69 ha), *Juglans nigra* L. (2376.66 ha), *Fraxinus pennsylvanica* Marshall. and *Fraxinus americana* L. (1099.77 ha), *Pseudotsuga menziesii* (Mirb.) Franco. (393,05 ha) and *Quercus rubra* L. (51,99 ha). A difference in data between NFI and NFMP comes from different methodologies of data sampling. Two non-native *Fraxinus* species are present in Croatia (Borzan et al. 2006). On the area of Pokuplje, Posavina and Podunavlje Kremer and Borzan (2009) found *Fraxinus pennsylvanica* Marshall and *F. pennsylvanica* var. *subintegerrima* (Vahl) Fernald, stating that several

Table 1 List of NNTS in Croatia with some background data
Tablica 1 Popis alohtonih vrsta u Republici Hrvatskoj s nekim osnovnim podacima

	Growing stock (area is not included in NFMP and NFI methodlology not suitable for detection of small amount of NNTS)	Mean annual increment (cu.m/ha/yr)	Silvicultural system/Date of introduction (forest chronicles)	Recommendation based on CFRI research
***Abies grandis* Lindl./Grand fir**	Good growth results. Only in research plots.	-	1969	Yes
***Picea sitchensis* (Bong.) Carr./Sitka spruce**	Only in research plots. Low growth rate.	-	1969	No
***Pinus contorta* Dougl./Lodgepole pine**	Only in research plots. Very low survival, slow growth.	-	1969	No
***Pinus ponderosa* Lawson & C. Lawson/Ponderosa pine**				
***Liriodendron tulipifera* L./Tulip tree**	This NNTS only in research plots. High succeptibility to browsing, otherwise good survival, production and regeneration.	-	1969	Yes
***Pseudotsuga menziesii* (Mirb.) Franco /Douglas-fir**	**181008 m^3 (0.04%)/ Increase of 64000 m^3	**3.36	Shelterwood/1890	Yes
***Robinia pseudoacacia* L./Black locust**	*13172000 m^3; share in total growing stock 2.39 %. **7284122 m^3(1.74%)/Decrease of 714000 m^3	**4.17	Shelterwood/1880 (forest chronicle).	Yes
***Pinus strobus* L./Eastern white pine**	*2758000 m^3 or 0.5 %; 348000 m^3 **989144 m^3 (0.24%)/ Decrease of 27000 m^3	**3.21	Shelterwood /Beginning of 20th century, documented in 1969	Yes (areas should be carefully considered)
***Thuja plicata* L./Pacific redcedar**	Decorative species in Croatia.	-	1969	Yes
***Cedrus atlantica (Endl.)* Manetti ex Carriere/Atlas cedar**	Not detected by NFI or NFMP. Found some examples (e.g. Kontija).	-	-	Further research
***Juglans nigra* L./Black walnut**	**284326 m^3 (0.07%)/ Decrease of 12000 m^3	**3.92	Shelterwood/Around 1970	Yes
***Populus deltoides* Marshall./ Eastern cottonwood**	**1740972 m^3(0.42%)/Decrease of 623000 m^3	**4.97	Shelterwood	Yes
***Populus canadensis* Moench./Hybrid black poplar**				
***Amorpha fruticosa* L./Indigobush**	This species possess invasive invasive potential / Spontaneous spread	-	-	Repressive control.
***Fraxinus americana* L./White ash**	**230344 m^3 (0.06%)/ Decrease of 33000 m^3	**3,93	19th century	Further research
***Fraxinus pennsylvanica* Marshall/Green ash**				
***Acer negundo* L./ Box-elder Maple**	This species possess invasive invasive potential / Spontaneous spread	-	-	Repressive control.
***Broussonetia papyrifera* (L.) L'Hér. ex Vent./ Paper mulberry**	This species possess invasive invasive potential / Spontaneous spread	-	-	Repressive control.
***Ailanthus altissima* (Mill.) Swingle/Tree of heaven**	This species possess invasive invasive potential / Spontaneous spread	-	Spontaneous spread.	Repressive control.

*Source: NFI**Source: NFMP (2016 - 2025) / Change from last NFMP (2006 - 2015)

provenances were introduced in Croatia. *Fraxinus americana* L. has a lower share than *F. pennsylvanica* Marshall and was introduced in the 19th century (Kremer 2006).

Croatian forests Ltd. and private forest owners should use only those NNTS, provenances and varieties, whose impact on the ecosystem, genetic integrity of native tree species and local provenances is professionally evaluated and whose negative impact can be avoided or diminished (Ministry of Agriculture, 2005). NNTS could have a positive impact on rural areas, which is one of the basic targets of Croatian Development Strategy (Governement of the Republic of Croatia 2017).

3. CHANCES AND OPPORTUNITIES OF INTRODUCING AND USING NNTS
MOGUĆNOSTI INTRODUKCIJE I UZGOJA ALOHTONIH VRSTA

3. 1. Increased wood production and non-wood forest products and possibilities to increase the income from forestry sector – *Povećanje proizvodnje drveta i ostalih šumskih proizvoda te mogućnosti povećanja dobiti iz šumarskog sektora*

Demands on forestry products increase continuously and existing access to natural wood and timber resources may switch to exploitation and overstraining of forest capacities underlying permanent pressures by man-induced disturbances (Bengtsson et al. 2000). If recovery of those habitats is disordered profoundly, heavy damages such as degradation of land can follow. To stop degradation process, fast establishment of efficient forest ecosystems is a key management aim. To prepare forests for future purposes man-made impairments have to be compensated by artificial restoration of tree populations, which means reforestation with native or non-native tree species. Increase of productivity can provide higher income from forests, but this aspect should carefully be taken into consideration for each NNTS since some use can require additional costs.

3.1.1. Enhanced wood production and quality/ diversity of products – *Povećanje proizvodnje drveta i kvalitete i raznovrstnosti drvnih proizvoda*

In many cases NNTS have higher growth rates and are more easily managed than native tree species. Based on growth and yield (CFRI permanent research plots) and on the general vitality of NNTS explored in European beech-dominated sites introduction of eastern white pine, Douglas-fir and experimentally, grand fir and Pacific redcedar, have initially been recommended in Croatia (Dokuš et al. 1975, Dokuš and Gračan 1977, Dokuš 1981). In lowland area (Slatki potok locality) the most productive species are eastern white pine (478.72 m^3/ha) and Douglas-fir (163.83 m^3/ha) (Orlić et al. 1997, Orlić et al. 1985). Three decades after the establishment of experimental trials in different bioclimatic regions of Croatia (lowland and hilly areas), introduced Douglas-fir and eastern white pine displayed more intensive growth and better vitality compared with other NNTS (Orlić 1994, Orlić and Ocvirek 1993, 1995, Komlenović et al. 1995). Out of those NNTS, better results and vitality were demonstrated by *Abies grandis* Lindl. and *Thuja plicata* L. European larch and eastern white pine were the best height and diameter growers while Douglas-fir was the slowest grower. In year 23 after the trial establishment the most productive species are eastern white pine (average growing stock 478.72 m^3/ha), European larch (208.89 m^3/ha) and Douglas-fir (163.83 m^3/ha). Based of research on afforestation of fernery and heath areas, species to use under these conditions should be primarily Norway spruce and eastern white pine (Orlić and Ocvirek 1993, 1995, 1996). Douglas-fir is recommended on potentially most productive sites, and possibly mixed with Norway spruce or eastern white pine. The follow-up of early research had proved these species to be good silvicultural options both in the lowlands, hilly and coastal parts of the country (Perić et al. 2006b, 2009). Provenances of these species can greatly influence their growth and development in explored site conditions so strict recommendations are provided in order to select appropriate provenances and harmonise nursery production with requirements of practical afforestation (Perić et al. 2010).

According to NFI data, *Robinia pseudoacacia* L. also proved to be an appropriate choice for enhancement of productivity compared with native tree species. For example, the species has an annual increment of 8.13 m^3/ha in the lowland area (growing stock 3,079,000 m^3), 9.29 m^3/ha in hilly area (9,660,000 m^3), and 1.65 m^3/ha in Submediterranen-Epimediterranen area (7,540,000 m^3) (NFI 2010). From its first introduction to date this NNT species proved to be a significant component of Croatian forests, especially in terms of high productivity.

3.1.2. Increased production of high quality timber in short–time periods – *Povećanje proizvodnje visoko kvalitetnog drveta u kraćim ophodnjama*

Sitka spruce has been a fast and productive grower under quite short rotations in some European countries. Nevertheless, Croatian research results in several trial plots, established in different bioclimatic regions show the low productivity of this NNTS (Dokuš 1972b, 1981, Dokuš et al. 1972, 1975, Dokuš and Gračan 1977, Orlić and Perić 2001, Orlić 1998, 1994, Orlić and Ocvirek 1995, Perić et al. 2006a). Consequently, Sitka spruce should be avoided under Croatian conditions. A good choice for producing high quality timber is black walnut, whose wood reaches 106–800 EUR/m^3 on Croatian market. The rotation age of black walnut is

80 years, when it can reach 32 m height and 42 cm d.b.h. (Mayer and Rajković 2008). Diseases, insects and game rarely damage it. It dies off only in extremely bad habitat conditions, especially in morasses waterlogged over long periods. The silvicultural objective is to produce large diameter trees/logs in widely spaced rows in a short time. A further objective is to increase the area of black walnut plantations up to 2,500 ha, so that in the future, at rotation age of 80 years, around 30 ha, with a standing volume of ca. 300 m^3/ha can be clear-felled yearly. The share of industrial wood is very high and often exceeds 80% of the overall wood production.

3.1.3. Use of fast-growing tree species for bioenergy production in higher proportion – *Povećanje uporabe brzorastućih vrsta drveća za proizvodnju bioenergije*

Apart from industrial wood production, NNTS also found a suitable place in short rotation forestry (SRF) for bioenergy production (e.g. plantations of poplar clones, eucalypts and black locust). The most important NNTS for bioenergy production in Balkan region are poplars (e.g. Klašnja et al. 2007, 2009; Stevanov et al. 2010). We should also develop a way to involve black locust and its excellent energy production properties, such as (Rédei et al. 2008): vigorous growing potential in juvenile phase, excellent coppicing ability, high wood density, high dry matter production, favourable wood combustibility, relatively fast drying, easy harvesting and wood processing. *Paulownia* hybrids, which gain on public attention in Croatia in the recent years, thus becoming among the most interesting species for plantation establishment among private forest owners and agriculturists. In our country this very productive hybrid is under the supervision of Ministry for Environment and Energy and currently can be used on agricultural land (it is on the list of agricultural species). To our knowledge, there are no *Paulownia* sp. plantations on state-owned forest land, but the number of private forest managers, interested in this

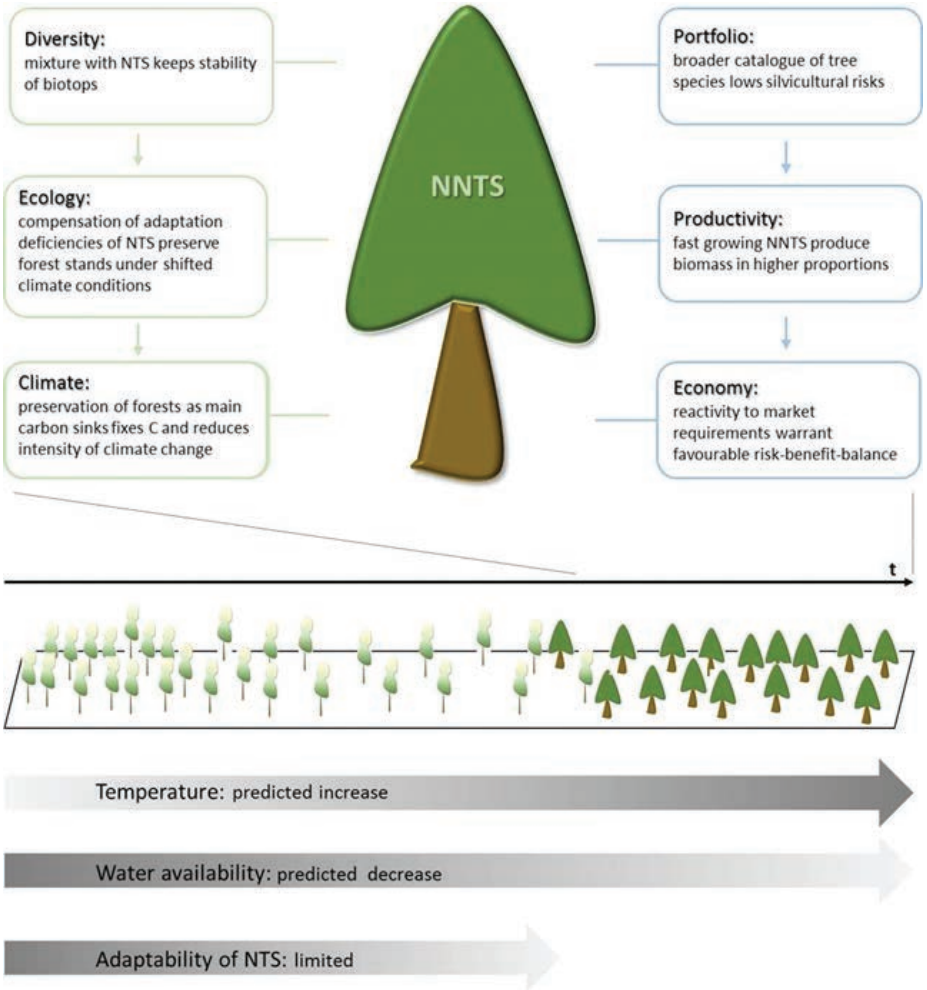

Figure 1 Correlation of abundance of native and NNTS with temperature and precipitation as primary affecting abiotic factors. Opportunities of the use of NNTS are shown as economic (blue-bordered boxes) as well as ecological (green-bordered boxes) benefits.

Slika 1 Korelacija pokrovnosti autohtonih i alohtonih vrsta s temperaturom i oborinama kao primarnim abiotičkim čimbenicima. Mogućnosti uporabe alohtonih vrsta prikazane su kao ekonomske (kvadrati ograđeni plavom bojom) i ekološke koristi (kvadrati ograđeni zelenom bojom).

species is increasing. Research projects on growing *Paulownia* sp. in Croatia are in their initial phase (Drvodelić et al. 2016).

3.2. The use of NNTS as new silvicultural options for facing climate change and increasing ecological services of forest stands – *Adaptacija na klimatske promjene i povećanje ekološke funkcije šumskih sastojina uporabom alohtonih vrsta kao novo šumskouzgojno rješenje*

Climate change (CC) is expected to have a profound, but selective effect on forests in temperate and Mediterranean bioclimatic zones (Hlásny et al. 2014). Several studies conducted for the regions of Balkan and Central Europe have shown that CC might significantly affect future production and distribution range of main tree species (Kutnar and Kobler 2011; Stojanović et al. 2014). Forests fulfil multiple functions, but in light of expected CC it is uncertain if they will be able to cover all presumable needs. Indeed, forest trees populations generally contain a high genetic diversity (Porth and El-Kassaby 2014); nevertheless their abilities and adaptive capacities are limited (Lindner et al. 2010). Generally, species are not able to adapt to environmental conditions that do not coincide with genetically fixed physiological optimum. In the future, tree species that can adapt to specific local stand conditions will dominate the composition of forest stands, may they be native or non-native to Europe (Lindner et al. 2010). To guarantee resilience capacities of forests and woodlands to predicted CC a variety of species should be planted as mixed stands, and in the case of pure stand management a broad spectrum of genotypes enables the ecosystem to recover faster. Problematically, disturbances such as fire, windthrow or outbreak of pests and diseases affect species-poor stands more intense and may cause severe economic losses. In the worst case, large areas of land remain bare and exposed to erosion and degradation (EAA 2008). In that context, the use of NNTS may offer chances and opportunities for future forestry and help to adapt European forests to climate change as major challenge in the future (EAA 2008). Opportunities of the use of NNTS are shown in Figure 1.

The lack of natural regeneration of NNTS, in particular a certain sterility of Douglas-fir and eastern white pine could be advantageous in terms of reducing the need for silvicultural/control activities and lowering competition with natural regeneration of native species. In stands where Douglas-fir as individual trees or in small groups is recorded, problems with pollination can be detected. This phenomenon can be explained by high proportion of sterile seeds, by damages to female flowers caused by late frosts, as well as by damages of its seedling colonisations caused by game species or the invasive *Hymenoptera* species *Megastigmus spermotrophus* Wachtl. (Kinský and Šika 1987; Bušina 2007). Most studies performed by the CFRI on this topic focus rather on the survival of seedlings and saplings in recently established stands than on the regenerative potential of adult trees. However, an investigation carried out in Forest District Delnice and belonging to pilot study "Rogi" revealed that the natural regeneration of domestic European beech and silver fir was more prolific and even dominated the regeneration of introduced species such as Douglas-fir and eastern white pine (NNEXT 2016).

3.2.1. Enhancement of the catalogue of suitable species for forestry in terms of increase of diversity, reduce silvicultural risks and filling the stand gaps after disturbances – *Povećanje broja prikladnih vrsta s ciljem poboljšanja bioraznolikosti, smanjenja šumskouzgojnih rizika i većih mogućnosti sanacije nakon šumskih šteta*

Diverse climate scenarios highlight the enhancement of pests and diseases as a severe risk for forestry that has to be solved. Enrichment of stands with the aim of protection, biodiversity and stability is recognized as a target silvicultural option in some European countries. The management of Croatian forests should be performed according to the principles of sustainable management but climatic disturbances and pest damages raised two questions recently: (i) can native species adapt quickly enough and (ii) to what extent they can adapt to new conditions? Conversion of low productive coppice forests and degraded forests, together with broader possibilities of NNTS use in afforestation of abandoned agricultural land and other available areas refers to the possibility of using the improvement potential of NNTS species. The growing problems of management of native tree species, combined with the potential wider use of NNTS in relation to predicted CC should be the focus of further research. In addition, the existance of available land for afforestation in Croatia could be important (Tijardović & Perić 2013).

Thus, introduction of NNTS in Croatia is proposed in cases of significant tree mortality of native tree species (limited conditions due to CC), when they can serve as alternatives and could play a significant role in adaptation measures. *Fraxinus pennsylvanica* and *F. americana* L. are spreading spontaneously in Croatia, on areas where native *Fraxinus angustifolia* declined (Kremer and Borzan 2009). They found hybrids between these species, while hybrids with native *F. angustifolia* were not found pointing to the conclusion that this latter species could represent a good option for reforestation after forest dieback in the lowlands. Norway spruce dieback is one of the most pressing situations where different alternative species should be provided; in this respect, coastal Douglas-fir (*Pseudotsuga menziesii menziesii*) seems to be a good option to meet the future needs (Cremer et al. 2016). Though, Douglas-fir was badly affected by the fungal pathogens *Phaeocrytopus gäumanni*

and *Rhabdocline pseudotsugae* (Stephan 1981). In Croatia, large-scale problems with these pathogens were not found. Even though Douglas fir have shown slow initial growth, the quick further growth and development of this NNTS in Croatia in the plain, hilly and mountainous areas (eight different trials) support European research conclusions that Douglas-fir could be a very good silvicultural option (Dokuš 1972a, 1981, Dokuš et al. 1975, Dokuš and Gračan 1977, Orlić 1979, 1981, 1983, 1994, Orlić et al. 1985, 1997, Orlić and Ocvirek 1993, 1995, 1996, Komlenović et al. 1995, Perić et al. 2004, 2006a, 2006b, 2009, 2011). In addition, Douglas-fir provenances growing quickly are also the ones with better quality and less prone to frost and low temperatures; conversely, the ones growing slowly have a lower quality and are more sensitive to low temperatures (Orlić and Ocvirek 1996). Despite their good success, primary role of forest cultures of NNTS should be preparation of site for establishment of native tree species. Therefore, following good example of Dubravac et al. (2006) these should also be monitored with the aim of recording spontaneous appearance of native tree species.

In this respect the use of NNTS, especially those with low regeneration potential, can serve as a good solution for soil improvement thus preparing the site for more favourable native climax tree species. A good example of NNTS productivity and their special use for soil improvement is baldcypress (*Taxodium distichum* (L.) Rich.) forest culture (Management unit "Mirna", sub-compartment 4 b, 0.63 ha) located inside the special nature reserve "Motovunska šuma" (The Motovun forest). In here, even not used for soil improvement initialy, baldcypress has been very successful and it could be suitable and commercially interesting for introduction to similar sites.

3.2.2. New options in restoration of highly degraded areas and alternatives in the areas with frequent and severe drought events – *Nove mogućnosti za sanaciju degradiranih i devastiranih šumskih površina i područja čestih i jakih suša*

As the range and competitive potential of existing, native tree species decline with CC, NNTS may benefit due to greater ability to thrive in altered environmental conditions. Ehrenfeld (2010) stated that many NNT species have higher values of resource-acquisition traits (e.g. morphological, physiological, and chemical) related to performance than native tree species. Additionally, Willis et al. (2010) showed that NNTS may have greater ability to respond to novel climatic conditions by adjusting their phenology. Thorpe et al. (2006) believed that a new rationale for introduction of NNTS is their possible role in retention of the economic and environmental values associated with forest, especially in the drought-prone regions. Such areas are present in Croatia along the coast, where higher temperatures and more frequent occurrence of droughts and forest fires are predicted in the future. A need for restoration of such areas is constantly present, as well as the need for better silvicultural solutions. *Cedrus atlantica* is one of the NNTS that showed very good success in solving risks-related issues in plantations established in the coastal area (e.g. 55 year-old stand in forest area "Kontija", management unit "Lim" - NNEXT 2016). Reforestation of degraded lands with a mix of NTS and NNTS is a promising method to re-establish trees and stabilize forests. This solution facilitates recovery of secondary native vegetation (Maestre and Cortina, 2004) and soil structure and diversity of soil microorganisms get the chance to recover (Hankin et al. 2015).

On the other hand, the use of NNTS on degraded areas, with degraded soils, can be suitable for some NNTS (Pilipović et al. 2003). The establishment of short rotation coppices (SRC) could be a first step in the restoration process. Besides vigorous growth and high biomass production, hybrid poplars are used in different systems of phytoremediation. Most often poplars are used to clean up sites and groundwater contaminated with Volatile Organic Compounds (VOCs), but they can also be used for the phytoremediation of heavy metals from the soil, uptake of contaminants present in groundwater (e.g. pesticides, fertilizers), nitrate phytoremediation, etc. (Felix et al. 2008). In addition, reforestation with black locust on sandy soils in northern Croatia ("Đurđevački pesci") started at the end of the 19th century with the purpose of sand fixation and preparation of site conditions for natural regeneration of other species.

3.2.3. Possibilities of harmonisation and development of nursery production with needs in forestry practice – *Mogućnosti usklađenja i razvoja rasadničke proizvodnje s potrebama u praksi*

Seed stands/seed orchards for the production of FRM of NNTS in Croatia include Douglas-fir, black walnut, black locust, northern red oak, baldcypress (Ministry of Agriculture 2017). Nevertheless, data from the Supervision of nursery production of forest seedlings shows very low production of NNTS seedlings in Croatia in the last 25 years (Perić et al. 2008, 2009, 2010, 2013a, 2013b, 2014, 2017). Recently, NNTS FRM was partially covered by import, mainly of seeds (e.g. in 2015 around 30,000 kg of black walnut seeds and ca 3 kg of Douglas-fir seeds imported from the U.S.A.). According to the data of CFRI, in 2010-2015, 7 kg seeds of Douglas-fir were imported from the Netherlands, Austria, Slovenia, Hungary and France while 4,000 seedlings were imported from Austria. In the same period (only in 2011), eastern white pine seeds were imported from Slovenia (6 kg), while 183,600 seedlings of black walnut were imported from Hungary. These data clearly show both insignificant efforts of NNTS afforestation in Croatia, but low intensity of production of FRM of NNTS as well.

Table 2 Chances and opportunities of the use of NNTS in Croatia
Tablica 2 Mogućnosti i koristi uzgoja alohtonih vrsta u Republici Hrvatskoj

POSSIBLE CHANCES AND OPPORTUNITIES OF THE USE OF NNTS	
Increase of wood production, non-wood products and income from forestry sector	
Enhanced wood production and quality/diversity of forest products	Impact on market prices and higher income from forests
Introduction of new forest products and production technologies	Enhancement of capacity utilization (available/bare land)
Increased production of high quality timber in short periods/options for bioenergy production	Possibility for increase of added value of forest stands
Expansion on or creation of new local markets	Better opportunities for small and medium entrepreneurs and private forest owners
New silvicultural options	
Enlargement of the suitable catalogue of species in term of lowering silvicultural risks	Enrichment of stands / opportunities of species mixtures
Possible decrease of intensity of silvicultural treatments due to favourable biological features	Creating better options for stability and biodiversity at landscape level
Less intensive site preparation activities when afforesting the area	Different success rates of species/provenances in different bioclimatic regions
Broader possibilities of use on unused agricultural land and other available areas	Diseases: reaction of disease outspreads,
New options in reforestation of highly degraded areas (e.g., queries, landfills, depots)	Lowering connectivity of pests/diseases/burning material /increase of resistances to those threats
New options in the areas of extreme harsh conditions (i.e., coastal areas)	Reducing risks for disturbancies (windthrows, bark beetles, fires)
Filling the gaps in the forests after disturbances/ possibility of cost-efficient restoration	Restitution – pressure for new forest owners
New options in conversion/replacement (e.g. of highly susceptible tree species)	Help to natural regeneration of native tree species in case of shifting limits due to CC
Enhancement of ecological and biosphere functions	
Could cover all ecological characteristics (sites) in the country (areas of harsh conditions)	Fulfilling different remaining ecosystem services (e.g. aesthetics, welfare, water protection)
Enhanced options for water, soil and health protection (e.g. in rural areas)	Could provide better general stability of stands against biotic and abiotic threats
Enhancement of soil fertility/soil improvement and beneficial influence on local climate	Mixture with NTS – stability of biotopes/stands, keep chances for NTS to recover/regenerate
Solving certain problems (e.g. drying swamps, stabilisation of flying sands, soil erosion…)	Help in sustainability of forest stands, soils and ecosystem services
New species for phytoremediation	Increase and preservation of biodiversity and landscape value
Provide forest cover/quicker afforestation on areas, where NTS cannot adapt to CC	Lowering risks for carbon pools and help in sustainability of carbon sinks
Enhancement of social functions and preservation of traditional value of forests	
Enhancement of services such as aesthetics, welfare, recreation, sports and education	NNTS create a need for further research and education provided by forest extension service
Enhancement of horticultural/arboriculture options	Cultural and historical – only for NNTS with long history since introduction (e.g. *Robinia pseudoacacia*)
Positive impact in rural areas (employment and rural development)	

3.3. Enhancement of biosphere, social functions and preservation of traditional values of forests – *Povećanje opće korisnih funkcija i očuvanje tradicijske vrijednosti šuma*

NNTS can provide a variety of non-wood forest products and services to society (Table 2). Example of non-wood forest functions provided by NNTS in Croatia is black locust. Their exotic appearance, lack of serious natural enemies in the artificial range, fast growth and high production of nectar made these species commonly used for firewood, erosion control, amelioration and reclamation of disturbed sites, as well as for honey production, animal forage and as an ornamental tree (Cierjacks et al. 2013). Furthermore, some NNTS play an important economic role in Europe, a potential which is not by far reached in Croatia yet. Also, the use of biomass from SRC can reduce greenhouse gas emissions as a consequence of reduced fossil fuel inputs and increased carbon sequestration (Aylott et al. 2008). The study aimed to compare the benefits for carbon (C) sequestration of afforestation with a multifunctional oak–beech forest vs. a poplar SRC showed that coppice forest reduces emissions with 24.3-29.3 t CO2 ha^{-1} yr^{-1} while the mixed forest reduces with only 6.2-7.1 t CO^2 ha^{-1} yr^{-1} (Deckmyn et al. 2004). Even though non-native poplars are used in Croatia, their use is limited to certain specific areas neglecting other potential uses than wood production (e.g. phytoremediation). In addition, the public perception of NNTS in Croatia is often negative and the area and cultural significance of some NNTS is neglected. An example of NNTS, which besides good wood production has a great social and historical value is a 120-years old Douglas-fir stand in Zelendvor (Management unit „Krči").

6. CONCLUSIONS
ZAKLJUČCI

Following climate and silviculture management scenarios, NNTS may be an interesting and important option for Croatian forestry in the next decades providing numerous opportunities compared with to NTS. The overview of introduction and use of NNTS in Croatia as a case study shows that in spite of good growth and yield results and vitality of some NNT species, a large gap lays between their introduction and active use in management practice. While one can find ample examples of NNTS introduction both in Europe and in Croatia (mostly in trials), the effective use of NNTS is rare and complex. The need for changing public perception and to disseminate the knowledge on NNTS to decision makers, harmonisation of production of NNTS seedlings with the needs and the potential of NNTS use in forestry practice and change of legislation underline basic problems for the active use of NNTS. We strongly propose that decisions upon NNTS should be based on comparisons between NNTS and NTS both in further research activities and in practical forestry. Thus, integrated and site-specific management is a strategy, which seems to be an appropriate approach for guidelines for the introduction and management of NNTS in Croatia. Tolerated and actively used in selected areas, but strictly eradicated in others (e.g. valuable sites) is considered to be the best option.

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SAŽETAK

Gospodarenje alohtonim vrstama ima tradiciju u hrvatskome **šumarstvu, ali njihov potencijal se treba ponovno razmotriti i ocijeniti u novonastali**m okvirima klimatskih promjena te rastućim potrebama društva za šumskim proizvodima i uslugama. Unatoč činjenici da svaka država ima svoj popis introduciranih vrsta, uključujući i Hrvatsku, autori prihvaćaju definiciju COST Akcije FP1403 NNEXT te rad baziraju na šumskim vrstama drveća kojima se prirodni areal nalazi izvan granica Europe. Ovaj pregledni rad doprinos je saznanjima o introdukciji i aktivnoj uporabi alohtonih vrsta u zemlji, a obuhvaća dostupne znanstvene i stručne studije te primjere uspješne uporabe u gospodarenju šumama. Zbog složenosti ove problematike autori će objaviti pregled rizika i izazova uporabe alohtonih vrsta u zasebnome radu. Dostupni podaci o prisutnosti alohtonih vrsta na pokusnim objektima te u šumarskoj praksi ukazuju kako se u praksi koristi tek manji broj vrsta (Tablica 1), dok su stvarni potencijal i njihove koristi daleko veće. Analiza podataka ukazuje kako su najzastupljenije alohtone vrste u šumarskoj praksi: *Robinia pseudoacacia* L. (12003.88 ha), *Pinus strobus* L. (3218.69 ha), *Juglans nigra* L. (2376.66 ha), *F. pennsylvanica* Marshall. i *Fraxinus americana* L.(1099.77 ha), *Pseudotsuga menziesii* (Mirb.) Franco. (393,05 ha) i L *Quercus rubra*. (51,99 ha). Podaci o proizvodnji šumskoga reproduk-

cijskog materijala navedenih vrsta ukazuje da rasadnička proizvodnja nije usklađena s potencijalom njihove uporabe u praksi. U radu se daje i iscrpan pregled različitih gledišta i koristi uzgoja alohtonih vrsta u Hrvatskoj. Samo neke od njih su (Slika 1, Tablica 2): nove mogućnosti proizvodnje visoko kvalitetnog drveta u kraćim ophodnjama, kao i drveta za bioenergiju, novih drvnih proizvoda i tehnologija; socijane koristi (mali i srednji poduzetnici, privatni šumoposjednici); povećanje stabilnosti i adaptabilnosti šumskih sastojina, ali samo u slučajevima velikih šteta i male plastičnosti i otpornosti domaćih vrsta; smanjenje intenziteta šumskouzgojnih radova, kao i uloženih sredstava na pripremi staništa prilikom pošumljavanja; ostvarivanje većih mogućnosti uporabe zapuštenoga poljoprivrednog zemljišta i ostalih prikladnih površina; sanacija progala ili većih površina nakon šteta u sastojinama domaćih vrsta (npr. obične smreke); supstitucija osjetljivih vrsta otpornijim i plastičnijim vrstama (mogućnosti mješovitih ili obogaćenih sastojina otpornijim alohtonim vrstama) te umanjenje negativnog djelovanja biotskih i abiotskih čimbenika. Njihova uporaba u sanaciji površina te konverziji degradiranih i devastiranih šuma pruža nove mogućnosti posebice na područjima s nepovoljnim ekološkim uvjetima, za koja se predviđa da će biti najpogođenija područja Hrvatske u budućnosti. Alohtone vrste mogu osigurati i niz opće korisnih funkcija šuma (npr. povećanje vezanja ugljika, fitoremedijacija zagađenih tala). Zbog složenosti problematike preporučujemo da se odluke o uporabi alohtonih vrsta donose na osnovi usporedbe s domaćim vrstama za svako stanište te na osnovi pregleda potencijalnih koristi, ali i rizika i izazova. Ističemo kako pojedine alohtone vrste treba poticati, dok neke zbog svoga invanzivnog potencijala trebaju biti strogo ograničene. Uporaba visokoproduktivnih, otpornijih i plastičnijih alohtonih vrsta predstavlja nova šumskouzgojna rješenja, koja su posebice važna u smislu pripreme staništa za prihvat autohtonih vrsta te povećanja otpornosti i plastičnosti šumskih sastojina, što je neizostavna komponenta adaptacijskih strategija gospodarenja šumama. Ipak, daljnja znanstvena istraživanja potrebna su kako bi se kvantificirala uporabljivost svake alohtone vrste, ali i olakšalo donošenje odluka u praksi.

KLJUČNE RIJEČI: nova šumskouzgojna rješenja, adaptacijske strategije, obnova šumskih krajolika.