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GOOD SURVIVAL OF BROADLEAF TREE SPECIES IN A FOUR-YEAR-OLD PLANTATION IN THE SLOVENIAN KARST

DOBRO PREŽIVETJE LISTOPADNIH DREVESNIH VRST V ŠTIRILETNEM NASADU NA SLOVENSKEM KRASU

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ABSTRACT

Six broadleaf tree species (*Celtis australis* L. – Mediterranean hackberry, *Quercus petraea* (Matt.) Liebl. – sessile oak, *Fagus sylvatica* L. – European beech, *Prunus avium* L. – wild cherry, *Juglans regia* L. – Persian walnut and *Acer pseudoplatanus* L. – sycamore maple) were planted in 2012 in a trial in the Slovenian Karst on two sites differing in productivity to test their suitability for use in the conversion of old pine stands into ecologically more stable broadleaf forests and to investigate their possible response to the harsher growth conditions predicted in the future. The selected economically interesting tree species have higher timber quality than broadleaves which regenerate naturally (e.g., *Ostrya carpinifolia*, *Fraxinus ornus*, *Quercus cerris*). Measurements were taken in 2017, after four growth seasons. All planted species except *Fagus sylvatica* had a high survival rate. In total, 70% of all seedlings survived, which shows promising potential. The survival rate was higher at the site on flat terrain than at the site on a slope. *Prunus avium* was the most successful of all planted species in terms of survival rate, at 83%, and other measured parameters (height, height increment, stem diameter, vitality and quality), and *Fagus sylvatica* was the least successful, with a survival rate of only 20%. *Celtis australis* had the highest survival rate, at 87%. *Acer pseudoplatanus* had the largest differences in measured parameters between the more and less productive sites among all planted species. *Quercus petraea* showed high resistance to xeric conditions and is expected to be the most successful in conversions. All planted species except *Fagus sylvatica* show favourable initial potential for the future conversion of Karst pine forests.

Key words: forest conversion, broadleaves, survival rate, seedlings quality, climate change

IZVLEČEK

Leta 2012 je bilo v poskusnem nasadu posajenih šest listopadnih drevesnih vrst (*Celtis australis* L. – navadni koprivovec, *Quercus petraea* (Matt.) Liebl. – graden, *Fagus sylvatica* L. – navadna bukev, *Prunus avium* L. – divja češnja, *Juglans regia* L. – navadni oreh, in *Acer pseudoplatanus* L. – gorski javor), ki je zajemal dve različno produktivni rastišči na Krasu v Sloveniji. Namen raziskave je bil ugotoviti katere drevesne vrste so primerne za premeno dotrajanih gozdov črnega bora v ekološko stabilnejše listopadne gozdove, hkrati pa tudi ugotoviti, ali so primerne za ostrejše rastne razmere, ki so napovedane za prihodnost. Izbrane drevesne vrste so ekonomsko zanimive in dosegajo višje vrednosti lesa na trgu kot vrste, ki se na območju naravno pomlajujejo (npr. *Ostrya carpinifolia*, *Fraxinus ornus*, *Quercus cerris*). Meritve so bile opravljene leta 2017, po štirih rastnih sezonah. Vse posajene sadike, z izjemo bukve, so imele visok delež preživetja. Skupno je preživelo kar 70 % sadik, večji delež preživelih je bil na rastišču v ravnini v primerjavi z rastiščem na pobočju. Glede na merjene parametre (preživetje, višina, višinski prirastek, premer 5 cm nad tlemi, vitalnost, kakovost) se je kot najuspešnejša izkazala divja češnja s 83-odstotnim deležem preživetja, kot najmanj uspešna pa navadna bukev z le 20-odstotnim deležem preživetja. Najvišji odstotek preživetja je imel koprivovec (87 %). Pri gorskem javorju so se pokazale največje razlike v merjenih parametrih med bolj in manj produktivnim rastiščem med vsemi vrstami. V premenah bo predvidoma najuspešnejši graden, saj je pokazal veliko odpornost na lokalne sušne razmere. V splošnem so vse vrste, z izjemo navadne bukve, izkazale potencial za prihodnjo premeno borovih gozdov.

Key words: premena gozda, listavci, delež preživetja, kakovost sadik, podnebne spremembe

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1 INTRODUCTION

1 UVOD

Many reports indicate that the effects of climate change on forests are likely to increase in frequency and intensity, mainly due to the more severe droughts predicted for the future (Teuling, 2018; Vitasse et al., 2019; Hari et al., 2020; Ma et al., 2020; Schuldt et al., 2020; Spinoni et al., 2020). In Europe, it is predicted that the intensity of extreme temperatures will increase, with the same number of hot days in central Europe as are currently experienced in southern Europe (Beniston et al., 2007). There are different scenarios, but even seemingly small changes can have significant impacts on ecosystems. According to Chmielewski and Rotzer (2001), a warming in early spring of only 1 °C causes the beginning of the vegetation period to be brought forward by about 7 days. The Slovenian Karst, which is located in the southwestern part of the country (ZGS-GGN14, 2012), already routinely experiences severe summer droughts. With its sub-Mediterranean climate, it is one of the most responsive regions to global change (Giorgi, 2006; Spinoni et al., 2020). Climate change effects (summer droughts) are additionally elevated due to the low water-holding capacity of often shallow soils on karst (limestone) bedrock. Thus, the area may be considered as a possible approximation of future conditions that might prevail in the country and also in parts of central and northern Europe. By conducting experiments with some of the common species that prosper in the cooler and more humid part of the country, we can at least to some extent approximate their behaviour in the predicted future conditions. In addition, there is a lack of forest trials or experimentally designed studies in different situations, where the success of conversion is quantified with respect to local site conditions.

The Karst, which was originally covered with a deciduous beech and oak-type forest, was deforested to a large extent in the 18th century due to overexploitation, overgrazing and logging (Zorn et al., 2015). As a result, only 15% of the forests remained in first half of the 19th century (Kladnik, 2011). Later, many afforestation attempts followed, and among all planted species, *Pinus nigra* proved to be the most successful. Consequently, more than 15,000 ha was afforested with this species. Today *Pinus nigra* is the most common tree species in the Karst, making up 25% of the growing stock. However, despite its good adaptation to poor site conditions, the species has several drawbacks. Its large and homogenous plantations are increasingly threatened by pests and are so highly prone to fire that they have facilitated the spread of several large fires in recent decades (Jakša, 1997; Šturm and Podobnikar, 2017; ZGS-GGN14, 2012). In addition, its timber does not achieve a high price on the market. Because of this and the improved soil conditions, many black pine plantations are now being colonized by the natural succession of native tree species such as *Fraxinus ornus*, *Ostrya carpinifolia*, *Prunus mahaleb* and occasionally *Quercus pubescens*. However, considering the long-term effects and current social demands on forests, these species might not fully meet expectations for timber quality, multi-purpose use, or succession direction and speed (Gajšek et al., 2015). Therefore, in addition to natural succession, other possible approaches are being considered for gradually converting pine plantations and accelerating the development of stands with the desired species structure. There is a noticeable lack of research on using broadleaves for forest conversion in the Mediterranean region and in karst areas in particular. The contribution of broadleaves to forest biodiversity (Spiecker et al., 2009) and their lower susceptibility to fire risk and diseases indicate promising potential (Juchheim et al., 2020). Moreover, higher species richness is known to increase resistance and/or resilience to disturbances and stresses, especially to pests, pathogens and other diseases (Jactel and Brockerhoff, 2007). The advantages of the conversion of artificially planted conifer forests into more stable broadleaf stands are being researched in some parts of Europe, e.g. in Belgium (Maddelein et al., 1990; Verstraeten, 2013), the Czech Republic (Vrška et al., 2017), Sweden (Felton et al., 2016) and Croatia (Topić, 1997).

When planning such conversions, awareness of future climate conditions is crucial. Decisions that are made today have a long-term impact. Trees take years to become established, and it is therefore important to make decisions carefully using knowledge from different areas. It is predicted that climate change will cause changes in species composition (Buras and Menzel, 2019) and that rising temperatures will cause currently widespread tree species such as *Fagus sylvatica* to migrate northward or to higher altitudes (Saltré et al., 2015). Phenotypic variation, the strength of selection, fecundity, interspecific competition and biotic interactions will be decisive in species success (Aitken et al., 2008). However, more in-depth research is required in order to make firm predictions.

In 2012, six experimental plots were established within black pine stands in the Slovenian Karst, where warm winters and dry and hot summers are typical. For planting, six tree species were chosen in order to examine their adaptation ability and to create initial regeneration nuclei from which the introduced broadleaf species could later spread naturally into the old and partly degraded pine plantations. These species include European nettle tree (*Celtis australis* L.), sessile oak (*Quercus petraea* (Mattuschka) Liebl.), European beech (*Fagus sylvatica* L.), wild cherry (*Prunus avium* L.), common walnut (*Juglans regia* L.) and sycamore maple (*Acer pseudoplatanus* L.) (Gajšek et al., 2015).

The first measurements were performed in 2013, after the end of the first growing season. The total height and height increment of seedlings were measured, the vitality was assessed and the survival rate for each species was calculated. Based on their high survival rates after the first growing season, all tested species except *F. sylvatica* showed promising potential (Gajšek et al., 2015). Nevertheless, results after one year for the most part only indicate the success of the planting itself. To truly examine adaption to local conditions and to be able to make more solid predictions on the success of these species in sub-Mediterranean conditions, it is necessary to carry out regular successive measurements. In 2017, after four growth seasons, we repeated and expanded the research (by adding the measurement of stem diameter 5 cm above the ground and a quality assessment) in order to check the current success of planting, compare the performance of the tree species and determine their suitability and potential for the formation of future stands.

2 METHODS

2 METODE DELA

The plantation was established in 2012 near the town of Divača in the Slovenian Karst (Fig. 1) (Gajšek et al., 2015). The prevailing potential vegetation in the area was the forest association *Seslerio–Ostryetum*. Mature plantations of *Pinus nigra* were cut down in six plots. Each plot was 50 m × 100 m in size and was planted in November 2012 with six tree species: *Celtis australis*, *Quercus petraea*, *Fagus sylvatica*, *Prunus avium*, *Juglans regia* and *Acer pseudoplatanus*. Eighty seedlings of each species were planted on each plot. The position of individual species within the plot was randomized. In total, 2,880 seedlings were planted. *C. australis* seedlings were grown in containers, while *F. sylvatica* seedlings came from natural regeneration and were further cultivated in a tree nursery. The seedlings of *Prunus avium*, *Juglans regia* and *Acer pseudoplatanus* came from the Omorika tree nursery, seedlings of *Fagus sylvatica* and *Quercus petraea* from the Štivan tree nursery and seedlings of *C. australis* from northern Italy. The seedlings of all species except *C. australis* were bare rooted. All plots were enclosed by a 2 m high fence to prevent wildlife browsing.

The group of the first three plots was named the more productive site (Site 1) and the group of the second three plots the less productive site (Site 2) due to the difference in growing conditions between the two sites. Site 1 was located on flat terrain with a higher site index, while site 2 was established on a slope (SW aspect) and at a higher altitude (Table 1). Site 2 was also characterised by rockier conditions.

All plots were located on limestone bedrock with rendzina soil with the following horizons: Ol-Of-OhAh-A/AC/CA. Although according to Škrk (2018) site 1 is richer in organic matter, potassium, calcium and magnesium, there are no significant differences in soil parameters between the two sites.

The climate in the area is sub-Mediterranean, and according to data from the nearest meteorological sta-

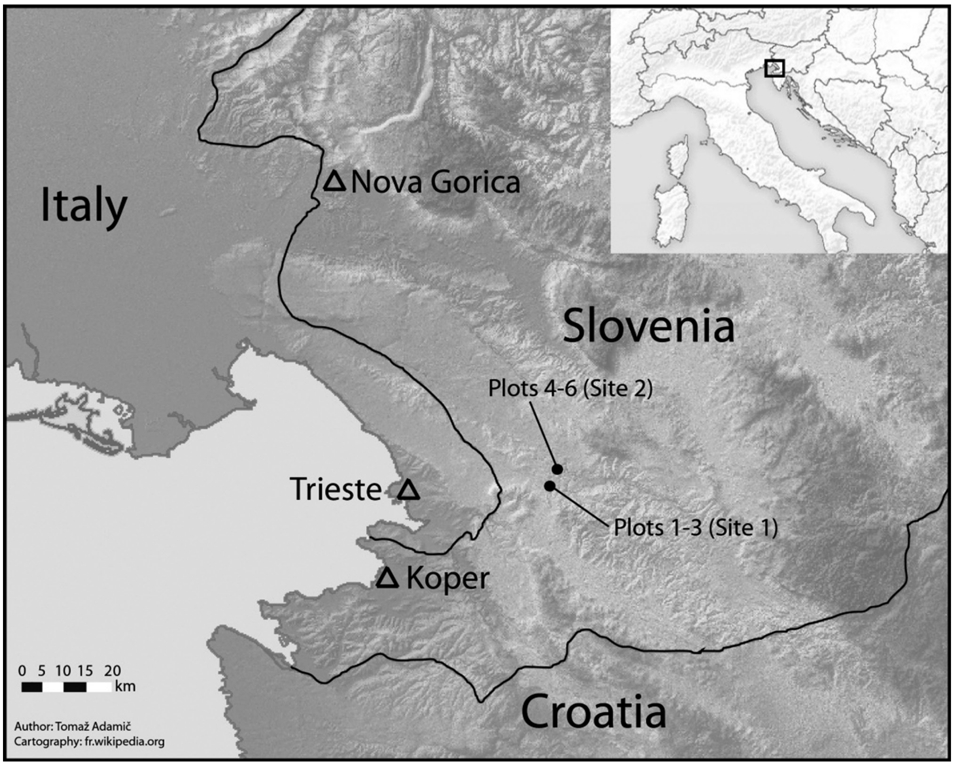

Fig. 1: Location of the plots (Gajšek et al., 2015)

Slika 1: Lokacija ploskev (Gajšek in sod., 2015)

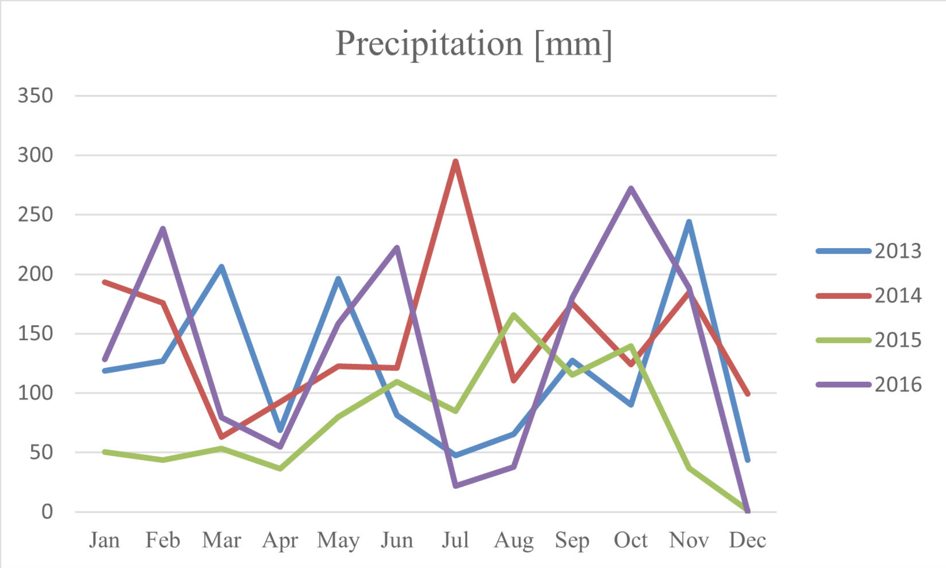

Fig. 2: Monthly cumulative precipitation values in the period 2013–2016 (ARSO, 2021)

Slika 2: Mesečna kumulativa padavin v obdobju 2013–2016 (ARSO, 2021)

tion of Škocjan pri Divači (45°39'50.30'', 13°59'34.23''), which lies at 420 m above sea level, total annual precipitation was 1582 mm in 2016 (ARSO, 2021). The amount of precipitation greatly differs between years, as can be seen in Fig. 2. Although annual precipitation in the previous growing season (2016) was relatively high, most of it was in the autumn. In the summer months, precipitation is usually in the form of torrential rainfall that runs off quickly. The year 2014 was an exception in the long-term average of July precipitation (ARSO, 2021).

The first measurements on the plots were performed in October 2013, after the end of the first growing season. The height and height increment of seedlings were measured. Seedling survival was determined (0 dead, 1 alive) and the survival rate was calculated. Vitality was assessed by using a 3-level scale. Also, the effect of shading from the surrounding pine trees was determined (Gajšek et al., 2015).

Repeated and expanded measurements of the seedlings were performed in March 2017, after four growing seasons. Seedling height, increment, stem diameter 5 cm above the ground, vitality and quality were measured or estimated. The height of seedlings was measured from the ground level at the base of the stem to the highest point of the seedling. For the increment, we measured the last annual height increment of the terminal shoot of a seedling (from growing season 2016). Due to the different growing rhythms of the species, the relative increment was calculated to enable direct comparison.

The increments were relativized by dividing the seedling increment of the last growing season with its obtained height until last growing season (without the last increment).

For assessment of vitality and quality, we used a 3-level scale (1 - good; 2 - medium; 3 - low) (Table 2)

Table 1: Basic characteristics of the research sites (Gajšek et al., 2015; Škrk, 2018)

Preglednica 1: Osnovne značilnosti raziskovalnih ploskev (Gajšek in sod., 2015; Škrk, 2018)

	SITE 1		SITE 2	
coordinates	Plot 1	45°41'17.05"N; 13°58'49.31"E	Plot 4	45°42'08.79"N; 13°59'31.70"E
	Plot 2	45°41'13.66"N; 13°58'57.74"E	Plot 5	45°42'11.62"N; 13°59'31.83"E
	Plot 3	45°41'16.86"N; 13°58'56.65"E	Plot 6	45°42'15.16"N; 13°59'25.44"E
terrain	plane		slope - southwest exposition	
stone/rockiness (%)	5		10	
wood stock before cutting (m^3/ha)	241		166	
site index (SI_{100})	21 m		18 m	
altitude (m)	440		540–640	
inclination (°)	0–5		15	
organic matter (%)	20.9–38.8		13.7–24.3	

Table 2: Evaluation criteria

Preglednica 2: Kriteriji ocenjevanj

	Vitality	Quality
1 - good	Seedlings with normally developed crown, height and with normal or large increment.	High quality seedlings that are well developed, healthy, undamaged and are the future carriers of the stands.
2 - medium	Low height development, damage to terminal and lateral shoots, broken stems.	Seedlings that are still growing and will most likely survive, but are forked or damaged.
3 - low	Dry seedlings with new shoots and seedlings with small or zero increment.	Significantly damaged seedlings that will most likely not survive.

$$Relative\ increment = \frac{height\ increment\ from\ 4th\ growing\ season}{total\ height\ of\ a\ seedling - height\ increment\ from\ 4th\ growing\ season}$$

(Gajšek et al., 2015; Črnigoj, 2016).

For the measurements, we used a measuring stick, tape measure and caliper. For the rating scale, we used standards that were used in a previous study (Gajšek et al., 2015) in order to enable direct comparisons.

Differences between the measured parameters between sites were tested with a Chi square test for survival rate, and with the Mann-Whitney U test and Kruskal-Wallis test for vitality and quality. The effect of site production on height, height increment and stem diameter was determined with a nested analysis of variance where plots (P) were nested within sites (R). In the model Y = R + P(R) + ε, the factor (R) is fixed. All computations were performed with IBM® SPSS® Statistics software.

3 RESULTS
3 REZULTATI

After four growing seasons, 70% of all planted seedlings survived. The species with the highest survival rate were *Celtis australis* (87% on average) and *Prunus avium* (83%), while *Fagus sylvatica* had the lowest survival rate (20% on average) (Table 3). All species had a higher survival rate on the more productive site. The difference in survival rate between the more productive and less productive site was largest in seedlings

Table 3: Average values of measured parameters from tree species for survival, height, height increment in the last year, relative height increment, stem diameter and modes for vitality and quality on both sites from 2017 (site number 1 refers to the more productive site on flat terrain, while site number 2 refers to the less productive site on a slope)

Preglednica 3: Povprečne vrednosti ocenjenih in merjenih parametrov: preživetje, višina, višinski prirastek, relativni višinski prirastek, premer, vitalnost in kakovost v letu 2017 (št. 1 označuje bolj produktivno rastišče v ravnini, št. 2 pa manj produktivno rastišče na pobočju)

Tree species	Site	*Celtis australis*	*Quercus petraea*	*Fagus sylvatica*	*Prunus avium*	*Juglans regia*	*Acer pseudoplatanus*
Survival rate (%)	1	96	87	32	89	93	91
	2	78	65	8	77	70	56
	Avg.	87	76	20	83	81	74
Height (cm)	1	102	56	98	184	139	154
	2	71	58	77	126	89	84
	Avg.	86	57	87	155	114	119
Height increment in the last year (cm)	1	10	9	12	25	17	28
	2	8	10	7	13	5	8
	Avg.	9	10	10	19	11	18
Relative height increment	1	0.11	0.21	0.16	0.16	0.14	0.25
	2	0.17	0.24	0.10	0.10	0.05	0.12
	Avg.	0.14	0.23	0.13	0.13	0.10	0.19
Stem diameter (mm)	1	13	10	13	24	30	21
	2	10	12	13	22	24	15
	Avg.	11	11	13	23	27	18
Vitality (mode)	1	3	2	1	1	2	1
	2	3	3	1	3	3	3
Quality (mode)	1	3	2	1	2	2	2
	2	3	3	2	3	3	3

of *Acer pseudoplatanus* (91% and 56% respectively). Seedlings of *Prunus avium* were the tallest (188 cm on average) and those of *Quercus petraea* (48 cm) were the shortest. All species but *Q. petraea* had greater average total heights on the more productive site. The initial height of the planted seedlings was different for each species – the tallest were *Acer pseudoplatanus* and *Prunus avium* seedlings, which were both taller than 110 cm on average, while the average height of *Quercus petraea* seedlings was only 25 cm. At planting, the height of *F. sylvatica*, *J. regia* and *C. australis* seedlings was between 60 and 90 cm (Gajšek et al., 2015). In the fourth growing season since planting, *Acer pseudoplatanus* had the largest height increments (28 cm on more productive site), but with the highest variability (Table 3). The results of the relative height increment analysis show that along with *Quercus petraea*, *Celtis australis* also had a better relative increment on the less productive site, while *Juglans regia* had especially small relative increments on the less productive site. Seedlings had a larger average stem diameter on the more productive site, except *Quercus petraea*. *Juglans regia* had the largest average stem diameter of 30 mm. *Juglans regia* and *Acer pseudoplatanus* exhibited the largest differences between sites (both 6 mm) (Table 3). Surprisingly, *Fagus sylvatica* seedlings were the most vital. With respect to quality, the results were very similar, with seedlings of *Fagus sylvatica* being the best quality. *Prunus avium* and *Acer pseudoplatanus* had good scores of vitality on the more productive site, while *Celtis australis* had the worst.

A significant association ($p < 0.001$) between survival rate and site was found for all species (Table 4). There was a significant effect of site on the vitality and quality of all species, except *Fagus sylvatica*.

Site also had a significant effect on the height and height increment for all species except *Quercus petraea* and *Fagus sylvatica* (Table 5). There were no significant differences in stem diameter between sites for *Fagus sylvatica* and *Prunus avium*. Within sites, we found significant differences in seedling height for *Quercus petraea*, *Juglans regia* and *Acer pseudoplatanus*.

4 DISCUSSION
4 RAZPRAVA

Valuable broadleaved trees are an increasingly important element of European forests (Spiecker et al., 2009). In many areas they have been removed in former times and replaced by other (mostly coniferous) species, resulting in non-site-adapted forests, reduced diversity and lower stand resilience. In light of climate change, conversions towards more diverse forests may result in increased forest resilience and reduced ecological risks.

The early growth of trees is influenced by many factors, from the quality of the seedling, planting method and environmental factors to the adaptation of the species and provenance to the chosen location (Close et al., 2005; Grossnickle, 2012; Smolnikar et al., 2019; De Lombaerde et al., 2020). While some of these factors

Table 4: Chi-Square test for survival rate, Mann-Whitney U test (between sites) and Kruskal- Wallis test (within sites) for vitality and quality

Preglednica 4: Stopnja preživetja - Hi-kvadrat test; vitalnost in kakovost - Mann-Whitneyev U test (med rastišči), Kruskal-Wallisov test (znotraj rastišč)

	Site	Survival rate		Vitality		Quality	
		p (within sites)[a]	*p* (between sites)[a]	*p* (within sites)[c]	*p* (between sites)[b]	*p* (within sites)[c]	*p* (between sites)[b]
Celtis australis	1	0.052	0.000	0.000	0.000	0.000	0.000
	2	0.964		0.011		0.071	
Quercus petraea	1	0.038	0.000	0.000	0.000	0.041	0.000
	2	0.003		0.000		0.000	
Fagus sylvatica	1	0.061	0.000	0.131	0.151	0.003	0.092
	2	0.000		0.990		0.329	
Prunus avium	1	0.005	0.001	0.034	0.000	0.089	0.000
	2	0.910		0.180		0.007	
Juglans regia	1	0.939	0.000	0.011	0.000	0.063	0.000
	2	0.000		0.796		0.777	
Acer pseudoplatanus	1	0.017	0.000	0.000	0.000	0.000	0.000
	2	0.000		0.309		0.490	

a - Chi-Square test; b - Mann-Whitney U test; c - Kruskal-Wallis test

Table 5: Nested analysis of variance for height, height increment and stem diameter (F - ratio)

Preglednica 5: Vgnezdena ANOVA za višino, višinski prirastek in premer mladik (F - vrednosti)

	Height		Height increment		Diameter	
	p (between sites)	p (within sites)	p (between sites)	p (within sites)	p (between sites)	p (within sites)
Celtis australis	114.629***	1.573 n.s.	5.385*	2.13 n.s.	57.026***	6.363***
Quercus petraea	0.713 n.s.	8.866***	1.958 n.s.	2.321 n.s.	10.928**	2.519*
Fagus sylvatica	4.449*	0.913 n.s.	3.037 n.s.	2.094 n.s.	0.100 n.s.	2.435 n.s.
Prunus avium	123.163***	0.676 n.s.	67.706***	1.401 n.s.	0.658 n.s.	1.811 n.s.
Juglans regia	132.856***	10.566***	142.608***	3.632**	82.461***	8.524***
Acer pseudoplatanus	153.246***	5.617***	92.514***	10.354***	74.700***	3.094*

n.s. not significant at $p > 0.05$; * $0.01 < p \leq 0.05$; ** $0.001 < p \leq 0.01$; *** $p \leq 0.001$

can be influenced by us, others cannot. The suitability of each species and the choice of the right provenance can be the key to planting success. The adequacy of both factors is reflected in vitality and growth rate. On the one hand, the seedling must form a strong root system that supplies it with sufficient nutrients in a competitive environment, and on the other hand, it must have sufficient height growth in order to compete for light. Monitoring the growth of young plants can therefore be a good indicator for the later success of a plant.

In our study, after four growing seasons, all species except *Fagus sylvatica* retained a high survival rate, with only a 10% decrease in average survival rate for all species from the first growing season (Gajšek et al., 2015). This indicates the high plasticity of the planted species. The first year is known to be decisive in the survival of seedlings (Maestre et al., 2003), but the following years indicate good rooting and long-term success. Seedlings from nurseries can also have less resistance to harsh conditions as the environment in nurseries ensures that seedlings are rich in nutrients and therefore have a good orientation for future growth. However, in more severe conditions these seedlings might therefore suffer more than those that were exposed to less favourable environmental conditions in the first years of growth.

The only species with low survival rate (20% in total) was *Fagus sylvatica*. Although seedlings of all species were exposed to direct sunlight radiation without tree cover, *Fagus sylvatica* was the most affected. *Fagus sylvatica* is a mesophilic species and recommended for planting in forest gaps and more humid areas (Johnson, 1997). At the juvenile stage, it is also especially vulnerable to limited water availability as it is not tolerant of strong and prolonged periods of drought that are common in the Karst. Also, seedlings of *Fagus sylvatica* were transplants (we define transplants as naturally regenerated seedlings that were transplanted into the research sites) and might have undergone some shock when transferred from a shaded environment to full sun.

Without exception, all species had a better survival rate on the more productive site, which indicates the better growing conditions on this site. According to Škrk (2018), the soil characteristics were slightly better on the more productive site with higher organic matter, potassium, calcium and magnesium. Although there were no significant differences between sites, they indicate better possible conditions on Site 1, which could be confirmed with more soil samples. Presumably, water quantity has the largest impact. The more productive site lies on flat terrain, with less water drainage. The less productive site is on a slope with stronger winds and a southwestern exposition. This leads to quicker water drainage and greater evapotranspiration, although the annual amount of precipitation in the area is relatively high (ARSO, 2021). It is also possible that solar radiation was slightly greater on the less productive site due to the southeastern exposition of the slope (Nevo et al., 1999), although differences in solar radiation were not measured in our research.

Taller seedlings are usually recommended for sites with little environmental stress but potential excessive competition (Grossnickle, 2012). In our study seedlings of *Prunus avium* and *Acer pseudoplatanus* were the tallest at planting and remained so after four years, which can be an advantage with respect to competition but also a disadvantage with respect to water stress. The height increments from the last growing season were greater on both sites compared to the first year after planting (Gajšek et al., 2015) in all species except *Juglans regia*, which suggests good rooting of seedlings. However, many terminal shoots of *Juglans regia* seedlings were damaged due to late frost. *Quer-*

cus petraea was the only species with greater heights and stem diameters on the less productive site and also had significantly greater height increments compared to the first growing season on both sites. A larger stem diameter in general suggests sturdiness, resilience to drought and a good-sized root system (Grossnickle, 2012), and this may indicate that drier site conditions have generally not been as decisive for the growth of *Quercus petraea* as for other species. However, its seedlings were the shortest at planting and therefore had lower growth requirements (e.g. for water), which was an advantage compared to the other planted tree species and resulted in easier adaptation to the new environment. *Celtis australis* also had a greater relative height increment on the less productive site, which also indicates less sensitivity to the conditions in the area. The better growing conditions on Site 1 overall had a decisive impact on seedling vitality and quality, as a significant association between site and vitality and quality was found for all species, except *Fagus sylvatica*. In general, the vitality and quality of all seedlings (except *Fagus sylvatica*) were far from excellent, indicating that the conditions in this area are not ideal for the species planted, but can still allow realistically good growth. Surprisingly, the few remaining seedlings of *Fagus sylvatica* that survived for four years were vital and of good quality. This shows that surviving individuals actually grew well. We can assume that the initial quality of seedlings has a large impact on the success of the species after planting. Furthermore, those which were planted on particularly good microlocations with deeper soil presumably had good rooting and consequently better access to micronutrients and water. Soils in the Karst differ greatly in the horizontal (rockiness) and vertical (depth) direction. Seedlings that were planted in locations with deeper soil grew taller and were more vital. However, this effect did not have a significant impact on the differences between tree species due to the large number of planted seedlings and randomized order of planted seedlings on each plot.

4.1 Individual species performance

4.1 Uspešnost posameznih vrst

Among all the planted species in our research, *Celtis australis* had the best results in many measured parameters, indicating lower susceptibility to drier conditions. However, good survival in the first years does not necessarily indicate successful growth in the future. In a similar study (Topić, 1997), all planted seedlings of *Celtis australis* (bareroot) died in 33 years of research. It is expected that in the future the roots will probably expand and reach deeper ground, which will result in better vitality. Some seedlings in our research had especially large heights and increments, indicating that they were probably planted in deep soil. It was the only species in our research that was container bred. Some studies confirm the increased survival of container-grown seedlings due to lower plant water stress compared to bareroot seedlings (Grossnickle, 2012). In general, *Celtis australis* is known to be adapted to drought and resistant to diseases (Brus, 2012); therefore, it might also exhibit good survival rate in the future and might prove to be a suitable species for planting in the Karst and in the context of climate change.

Quercus petraea also showed good resistance to drier conditions. It did not achieve large heights or height increments, but it is typical for *Quercus* to grow slower in first years and then more quickly (Topić, 1997; Dey et al., 2012). This represents promising potential for its success. In the Karst it is often one of the dominant species, and it is also promising in gradual conversion by means of natural regeneration (Diaci et al., 2019). We expect that in the long term *Quercus petraea* might be the most successful of all of the planted species, although perhaps not the best quality. In European forests, *Quercus petraea* might be less affected in the context of climate change compared to some other species (Pretzsch et al., 2013; Walentowski et al., 2017) and will probably expand its distribution range in the future (Sáenz-Romero et al., 2017).

Fagus sylvatica had highest mortality; therefore, its suitability for black pine conversions in the Karst is questionable. Microlocation conditions proved to be very important for its good growth. Introducing *Fagus sylvatica* in the Karst is possible on specific locations where conditions are more humid and the soils deeper (e.g., karst dolines with deeper soils and higher soil moisture). Climate change will probably have a negative impact on beech growth at marginal sites of its distribution area (Hogg et al., 2005; Jump et al., 2006; Peñuelas et al., 2007) but a positive impact at higher altitudes. The total growing stock may decrease on sites with low water availability (Prislan et al., 2019). However, good vitality and quality of the surviving *Fagus sylvatica* seedlings might indicate better potential than that shown in this experiment so far.

Prunus avium had good growth, which indicates its high plasticity. However, it is typical for *Prunus avium* to grow faster in juvenile stages and then slow down (Kotar and Maučič, 2000; Welk et al., 2016). In the Karst there are favourable conditions for *Prunus avium,* as it prefers warm sites with an adequate amount of low winter temperatures. It can also tolerate summer droughts which are typical for the Karst; in longer dry periods it reduces foliage quantity, so xylem rings are narrower in those years (Kotar and Maučič, 2000). Thus, it will probably also exhibit high survival rate in the future and will positively contribute to karst forests.

Juglans regia exhibited profoundly lower survival and growth at the less productive site. Summer drought in the Karst might affect its growth, as it has high water requirements (Gauthier and Jacobs, 2011; Jerszurki et al., 2017; Pelleri et al., 2020). The results suggest that conversion of old *Pinus nigra* forests with *Juglans regia* will be efficient, especially on less dry sites and areas where late frost is less likely to occur (avoiding karst sinkholes and bottoms of the dolines). Thus, favourable site conditions (deep soils) as well as the need to apply correct planting designs and correct management systems need to be considered (Pelleri et al., 2020). Due to its shade intolerance, it should be planted at a very wide spacing (Clark et al., 2008). Regarding its sensitivity to frost, predicted changes in climate towards higher annual temperatures and milder winters might have a positive impact, while a decline in the amount of precipitation might have a negative impact (Dankers and Hiederer, 2008; Fischer and Schär, 2010).

Acer pseudoplatanus retained the largest heights among all planted species. It also had larger height increments compared to those measured after first growing season (Gajšek et al., 2015), which indicates good rooting. This species requires good conditions. It is sensitive to drought, and therefore it is not surprising that it exhibited the largest differences in measured parameters between the more and less productive sites among all planted species. Water conditions are especially crucial within the first years for the successful establishment of seedlings (Weber and Bahr, 2000). Sunburn damage and die-off in young *Acer pseudoplatanus* can occur under prolonged hot and dry conditions (Schneidewind, 2004). When planting, it should be selected for less dry sites. In southern Europe, its productivity will probably decline due to its sensitivity to drought.

5 CONCLUSIONS
5 ZAKLJUČKI

The results of the measured parameters after the fourth growing season compared to those after the first growing season did not deteriorate significantly. All planted species except *Fagus sylvatica* retained a high survival rate, especially *Celtis australis*. *Prunus avium* was the most successful species overall, while *Fagus sylvatica* was the least successful. *Quercus petraea* showed high resistance to dry conditions and is likely to be the most successful in conversion due to its growth characteristics. *Acer pseudoplatanus* was the most susceptible to poor site conditions. Therefore, the overall results show the promising potential of all planted species except *Fagus sylvatica* for the conversion of old pine plantations in the Karst region and also for the future of the observed tree species in the context of climate change. When planting, microsite conditions need to be considered. In order to be able to make even more reliable predictions about how a particular tree species will behave in the long term, measurements should be repeated regularly in the future.

6 SUMMARY
6 POVZETEK

Klimatske spremembe s sabo prinašajo spremenjene temperaturne in padavinske režime ter pogostejše vremenske ekstreme. Podnebne razmere, ki danes prevladujejo v srednji Evropi, naj bi bile v prihodnosti podobne tistim, ki so trenutno značilne za južno Evropo. Spremembe se dogajajo hitro in treba je raziskati, ali bodo prevladujoče drevesne vrste preživele tudi bolj zaostrene razmere.

Kras je območje na jugozahodu Slovenije, za katerega je značilno submediteransko podnebje z višjimi temperaturami in s pogostimi poletnimi sušami. Prav zato je primeren za poskuse, ki upoštevajo razmere, ki bodo predvidoma vladale v širšem delu države v prihodnosti. Trenutno je Kras v velikem deležu pokrit z borovimi gozdovi, ki so rezultat obsežnega pogozdovanja s črnim borom na koncu 19. in v začetku 20. stoletja. V današnjem času so ti gozdovi dotrajani, slabo se pomlajujejo, ogrožajo jih škodljivci, velika je tudi njihova požarna ogroženost. Napočil je čas, da v te gozdove uvedemo tudi druge drevesne vrste. Čeprav se nekatere vrste, kot so mali jesen, črni gaber in puhasti hrast, že samoniklo vraščajo, bi si želeli tudi nekaj ekonomsko zanimivejših drevesnih vrst. Da bi ugotovili, kakšen bo uspeh nekaterih izbranih, v Sloveniji pogostih drevesnih vrst v bolj sušnih razmerah, ki so napovedane za prihodnost in kakšna je njihova primernost za premeno borovih gozdov na Krasu, je bil leta 2012 zasnovan poskus v bližini Divače. Na dveh rastiščih in skupno šestih ploskvah so bili posajeni navadni koprivovec (*Celtis australis* L.), graden (*Quercus petraea* (Matt.) Liebl.), navadna bukev (*Fagus sylvatica* L.), divja češnja (*Prunus avium* L.), navadni oreh (*Juglans regia* L.) ter gorski javor (*Acer pseudoplatanus* L.). Tri ploskve so bile na ravnini (rastišče 1), druge tri pa na pobočju z naklonom 15 ° (rastišče 2). Prve meritve so bile opravljene po prvi rastni sezoni leta 2013,

ponovljene in razširjene pa so bile leta 2017 po štirih rastnih sezonah. Merjeni so bili naslednji parametri: višina sadik, višinski prirastek, premer debla 5 cm nad tlemi; ocenjeni parametri pa so bili: preživetje, vitalnost in kakovost.

Ugotovili smo velik, 70-odstotni delež preživetja vseh posajenih sadik. Vse so dosegale višji delež preživetja na rastišču v ravnini v primerjavi z rastiščem na pobočju, kar je najverjetneje posledica večjega nagiba terena, ki povzroči hitrejše odtekanje vode, ter večje vetrovnosti, ki še pospešuje izsuševanje.

Z velikimi prirastki in visokim deležem preživetja se je kot uspešna izkazala divja češnja, ki pa predvsem na slabšem rastišču ni dosegla dobre vitalnosti in kakovosti. Izkazala se je kot odporna na sušne razmere. Čeprav ne bo dosegala najboljše kakovosti, jo je v kraških gozdovih kot plodonosno drevesno vrsto smiselno saditi. Prav tako je imel velik delež preživetja navadni koprivovec, kar potrjuje njegovo odpornost na sušne razmere in posledično primernost za sajenje na rastiščih, ki so prizadeta s poletno sušo. Višinski prirastki so v veliki meri odvisni od mikrolokacije, na kateri je bila zasajena sadika. Na globljih tleh so bile dosežene višine precej večje. Čeprav je graden dosegel nizke višine na obeh rastiščih, je bil v primerjavi z drugimi vrstami precej uspešen tudi na slabšem rastišču, kar kaže na njegovo odpornost. Kot že naravno zelo pogosta vrsta v kraških gozdovih je velik potencial v prihajajočih podnebnih spremembah. Navadni oreh je zelo občutljiv za jesenske in predvsem spomladanske pozebe, kar se je izkazalo tudi v naši raziskavi, vendar to ni bistveno vplivalo na njegovo preživetje. Višje letne in predvsem zimske temperature so zanj ugodne, kljub temu pa potrebuje zadostno količino padavin. Gorski javor je bil izmed vseh izbranih vrst v poskusu najbolj občutljiv za (mikro)lokalne razmere, zelo sušna rastišča mu ne ustrezajo. Kot najmanj primerna pa se je izkazala navadna bukev, saj je večina sadik zaradi pomanjkanja vode odmrla. Sadike bukve so bile na ploskvah izpostavljene direktni sončni svetlobi, kar bukvi kot sencozdržni vrsti ne ustreza. Zato bi jo morali v kraških gozdovih vnašati v majhne vrzeli oziroma najprej osnovati sestoje različnih vrst listavcev in šele nato vanje vnesti bukev. V predvidenih podnebnih spremembah se bo njen delež predvsem v nižinah lahko zmanjšal.

Vse drevesne vrste, z izjemo navadne bukve, so se tako izkazale kot primerne za uporabo tako pri premeni borovih gozdov kot tudi v luči podnebnih sprememb. Za oblikovanje še trdnejših napovedi je treba v prihodnosti meritve ponoviti.

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