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## Conversion of old black pine stands using broadleaf tree species in the Slovenian Karst

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**Abstract:** The conversion of old black pine plantations into ecologically more stable broadleaf forests is an important goal in many Mediterranean countries. Six experimental plots split between more and less productive sites were established in the sub-Mediterranean climate zone of south-western Slovenia in an area of mostly pure black pine stands. In November 2012 they were planted with six native broadleaf species (*Celtis australis*, *Quercus petraea*, *Fagus sylvatica*, *Prunus avium*, *Juglans regia* and *Acer pseudoplatanus*). The test plantations were intended to become small initial nuclei from which the introduced broadleaf species could later spread naturally into the old and partly degraded pine plantations. Seedling condition was assessed one year after planting. Based on their high survival rates after the first growing season, all tested species except *F. sylvatica* showed promising potential for future conversion of old pine stands in the Slovenian Karst region. However, the results of one growing season only are insufficient to draw firm conclusions. Of all planted species *P. avium* had the highest survival rate (95%) and was least susceptible to poor field conditions. Without exception, all species showed lower survival rate on the less productive site. Unlike other species, *P. avium* and *J. regia* seedlings had considerable height increment, while *F. sylvatica* had the lowest. From the results we can assume that perhaps old pine stands in the area have already considerably improved soil conditions and thereby enabled the introduction of broadleaves.

**Additional key words:** planting broadleaves, forest conversion, survival rate, height increment, tree vigour

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### Introduction

The Slovenian Karst area was originally covered with deciduous forest; however, with growing demand for wood (especially construction timber, firewood and wood for Venetian and Austrian shipyards), the pressure on forests increased significantly, which led to their degradation. Grazing of sheep and goats resulted in even further damage to vegetation. In 1825 only 15% of the Karst was covered with

forest, while nowadays 65% of the area is forested (Kladnik 2011).

The traditional strategy for reforesting degraded lands in the Mediterranean was to first introduce a fast-growing pioneer species, usually a pine species, in order to stop further degradation and facilitate the introduction of either artificial or natural late-successional broadleaves. The success of forest plantations in the Mediterranean is often limited by poor soil conditions, more specifically low root support

capacity that reduces the amount of available water and nutrients. Consequently, soil preparation is often needed to increase soil depth and availability of water and nutrients.

Afforestation of the Karst region in south-western Slovenia began as early as 1859, when the first successful black pine (*Pinus nigra* Arnold) plantations were established under the guidance of Josip Koller (Kladnik et al. 2008). Black pine is irreplaceable in the processes of degraded site re-cultivation in the Croatian Mediterranean (Matić et al. 2011). Between 1850 and 1915, 10,842 ha of almost barren Karst was afforested in the area of present-day Slovenia. During World War I the afforestation almost stopped. In the period 1915–1945, only 850 ha was afforested and between 1945–1954 it increased again, to about 4000 ha (Gašperšič and Winkler 1986). Over time, Karst black pine plantations improved site conditions considerably. However, these large and homogeneous plantations (covering an area of 16,500 ha, see Diaci et al. 2014) are now increasingly threatened by pests, such as pine processionary (*Thaumetopoea pityocampa*), pine shoot moth (*Rhyacionia buoliana*), common pine sawfly (*Diprion pini*), and european pine sawfly (*Neodiprion sertifer*), and diseases, such as sphaeropsis blight (*Diplodia pinea*), *Cenangium ferruginosum*, and *Sydowia polyspora* (Jurc and Jurc 2014). Moreover, these networks of pine plantations interconnected through agricultural land have a high fire hazard and have facilitated the spread of large fires in the last decades. Due to improved soil conditions many black pine plantations are now being gradually 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, modern landscape and forest management, and the current social demands on forests, these species might not fully meet our expectations for timber quality, multi-purpose use, or succession direction and speed. Therefore, in addition to natural succession, a variety of possible approaches are being considered for gradually converting pine plantations and accelerating the development of stands with desired species structure. Broadleaf species are very suitable in sustainable and multi-purpose forest management as they significantly contribute to forest biodiversity, are less susceptible to fire risk and diseases, may play an important role in the upcoming climate changes and, according to some authors, are more popular than conifers from a recreational standpoint (Colson et al. 2010).

In Europe, since the early 1990s broadleaf plantations have been promoted financially as multifunctional forests for biodiversity, timber production and recreation, while conifers had been predominately used until then (Brunet 2007). As a result, EU af-

forestation incentives (EEC 2080/92) have yielded more than 0.5 million ha of newly established broadleaved forest across Western Europe (Report to... 1997). In the USA, the demand for hardwood seedlings is increasing (Jacobs et al. 2004), and, moreover, some studies have shown that the public mainly prefers broadleaves over conifers, mostly for their appearance (O'Leary et al. 2000).

There is a noticeable lack of studies regarding using broadleaves for forest conversion in the Mediterranean and in karst areas in particular. Quantified survival rates for various planted broadleaf species are particularly rare. Because of the lack of studies on this subject, it is essential to obtain local experience and knowledge based on which the successful conversion of existing black pine plantations would be feasible. Since the conversion of such large areas is an expensive measure, a detailed assessment of various possible tree species and their starting success is crucial. The introduction of desired broadleaves can be achieved either by direct planting of seedlings over large areas, or preferably, due to lower costs, through establishing small initial nuclei from which the introduced tree species can spread naturally into old and partly degraded pine stands over time. To the best of our knowledge this idea has not yet been tested in any other research in this way. Selected broadleaf species must be suitable both for establishing plantations as well as for forming future immigration nuclei while at the same time ensuring the multifunctional role of the forest. Most newly planted trees are subject to stress-related problems due to serious root loss when dug at the nursery. This condition, commonly known as transplant shock, results in increased vulnerability to drought, insects and diseases. To a greater or lesser degree, transplant shock lasts until the natural balance between the root system and the top or crown of the transplanted tree is restored. Of those newly planted trees that do not survive, most die during this root-establishment period. The survival of seedlings in the first year after planting is crucial when establishing forest plantations (Maestre et al. 2003), with the first summer being the most important period in terms of survival (Ceacero et al. 2012).

The goal of our study was to examine the suitability of various broadleaf tree species for the purpose of conversion of old black pine stands in the Slovenian Karst by assessing seedling survival rate, height increment and vigour after the first growing season.

## Materials and Methods

### Study area

In 2012 six experimental plots, each 50 × 100 m in size, were established within old black pine stands

Table 1. Main characteristics of the experimental plots

Plot No.	Coordinates	Site	Site Index ( $SI_{100}$ )	Altitude (m)	Inclination (°)	Rockiness (%)
1	45°41'17.05"N 13°58'49.31"E	1	21	441	0–5	5
2	45°41'13.66"N 13°58'57.74"E					
3	45°41'16.86"N 13°58'56.65"E					
4	45°42'08.79"N 13°59'31.70"E	2	18	541–642	15	10
5	45°42'11.62"N 13°59'31.83"E					
6	45°42'15.16"N 13°59'25.44"E					

in the Slovenian Karst near the town of Divača in the sub-Mediterranean climate zone. The prevailing potential vegetation on all plots was the forest association *Seslerio–Ostryetum* and the altitude ranged between 400 and 650 m. All plots were located on limestone bedrock with rendzina soil. The mean air temperature in 2013 was 12.2°C, while the mean maximum temperature was 17.6°C. Total annual precipitation amounted to 1492 mm and the total solar radiation was 2159.7 hours. The summer of 2013 was extremely hot, and in some places, new temper-

ature records were reached. In the area of our study, the average maximum temperature for July and August 2013 was 30.3°C while it was only 26°C in 2014 (ARSO, 2014). On the first three plots, which were located on flat terrain, growing conditions were considerably better than those on the second three plots (see Site Index – Table 1), which were located on a slope and at higher altitude. 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) (Table 1, Fig. 1).

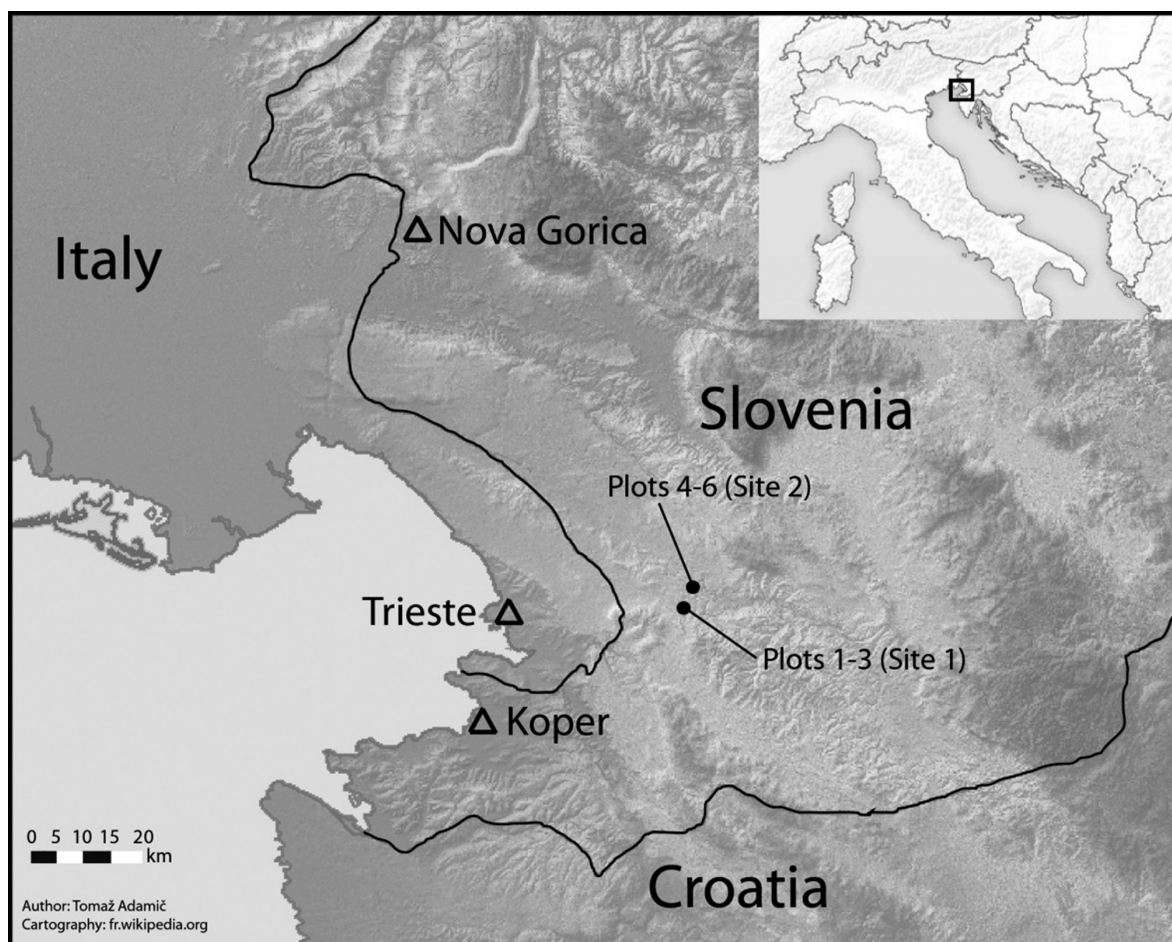


Fig. 1. Locations of the studied plots

## Methodology

On all research plots, old black pines were first cut down, followed by site preparation consisting of the removal of some bigger stumps and the removal of excess vegetation. Finally, a 45 × 80 m metal mesh fence was installed on each plot. Six broadleaf tree species were included in the trial: 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.). With the aim of testing a variety of ecologically diverse species, the six selected species intentionally cover a somewhat wider ecological range of broadleaves and not only thermophilic species, which would be the most obvious choice. *C. australis* seedlings were container bred, seedlings of *F. sylvatica* came from natural regeneration and were further bred in a nursery, while seedlings of all other species were bare rooted. Seedlings of *A. pseudoplatanus* and *P. avium* were both taller than 110 cm on average. *F. sylvatica*, *J. regia* and *C. australis* seedling height was between 60 and 90 cm, while *Q. petraea* seedlings were around 25 cm in height.

Planting was carried out in November 2012. Seedlings were planted into manually dug holes at 2 m intervals. Each of the six species was planted in five successive lines with 14–17 seedlings per individual line. The position of the individual species within the plot was randomized. On average, 478 seedlings of each species were planted in all six plots (approximately 80/plot). An unplanted strip of land was left on every plot for control. In October 2013, after the end of the first growing season, a survey of seedling condition was performed. The height and the height increment of seedlings were measured. We determined the seedling's survival (0 dead, 1 alive) and calculated the survival rate (given as percentage) for each species. For vigour assessment a 3-level scale was used (1 – good vigour; 2 – medium vigour; and 3 – low vigour). When determining the differences in height increment of the seedlings and association

between survival rate, vigour and plots and sites, we used the terms “within site” and “between sites”. The term “within site” was used when analysing the differences within the first or second group of plots while the term “between sites” was used when analysing the differences between the two groups of plots. In order to determine whether shading from the surrounding remaining old pine trees had any influence on survival rate of seedlings, every plot was divided into four rectangular strips of equal width so that the first quarter was always located at the northern part of each plot, the fourth quarter at the southern part, while the second and third quarter were in between the two.

## Statistics

Differences in the annual height increment of seedlings among individual plots and between sites were tested with the Kruskal-Wallis and Mann-Whitney U-test respectively. The Chi-Square test was used to test the association between survival rate and vigour of seedlings on one hand and plots and sites on the other. The Chi-Square test was also used to determine the relationship between shading of the surrounding old trees and survival rate of seedlings. All tests were performed with IBM® SPSS® Statistics.

## Results

The species with the highest survival rate after the first growing season was *P. avium* (95%), followed by *J. regia* (92%) and *C. australis* (91%), while *F. sylvatica* had by far the lowest survival rate of all planted species (44%) (Table 2). All species without exception showed lower survival rate on the less productive site, with *P. avium* showing the smallest difference in survival rate between the two sites and *A. pseudoplatanus* the largest. The survival rate of *P. avium* also had the smallest coefficient of variation (2.9%) of all the species (Table 2). Considering the harsh conditions (extremely hot summer in 2013), the survival rate of

Table 2. Summary table of main studied parameters for all species on both sites

	Site	<i>Celtis australis</i>	<i>Quercus petraea</i>	<i>Fagus sylvatica</i>	<i>Prunus avium</i>	<i>Juglans regia</i>	<i>Acer pseudoplatanus</i>
Survival rate (%)	1	99	94	55	97	97	93
	2	84	71	32	93	88	63
	$\bar{x}$	91	83	44	95	92	78
CV (%)		10.9	16.3	42.2	2.9	8.2	27.4
	1	6	5	2	14	22	4
	2	5	4	3	13	19	5
Height increment (cm)	$\bar{x}$	5.5	4.5	2.5	13.5	20.5	4.5
	1	Medium	Good	Low	Good	Good	Medium
	2	Medium	Medium	Low	Medium	Medium	Medium

<sup>1</sup> mode of vigour

Table 3. Chi-Square test of survival rate and vigour along with Kruskal-Wallis and Mann-Whitney U-test of increment for all species on both sites

	Site	Survival rate		Vigour		Increment	
		P (within sites)	P (between sites)	P (within sites)	P (between sites)	P (within sites)	P (between sites)
<i>Celtis australis</i>	1	0.048	0.000	0.391	0.000	0.059	0.171
	2	0.010		0.003		0.089	
<i>Quercus petraea</i>	1	0.586	0.000	0.337	0.000	0.454	0.650
	2	0.080		0.414		0.232	
<i>Fagus sylvatica</i>	1	0.125	0.000	0.411	0.453	0.008	0.000
	2	0.000		0.133		0.726	
<i>Prunus avium</i>	1	0.405	0.273	0.065	0.000	0.036	0.814
	2	0.419		0.000		0.000	
<i>Juglans regia</i>	1	0.601	0.000	0.032	0.000	0.623	0.000
	2	0.007		0.002		0.318	
<i>Acer pseudoplatanus</i>	1	0.033	0.000	0.737	0.000	0.094	0.047
	2	0.000		0.793		0.394	

*P. avium*, *J. regia* and *C. australis* after the first growing season can be rated as high, that of *Q. petraea* and *A. pseudoplatanus* as moderate, and that of *F. sylvatica* as low.

Of all studied species, *F. sylvatica* had the smallest annual height increment (2.5 cm on average), while *J. regia* had the largest, which was quite considerable (20.5 cm on average). The differences in increment for *J. regia* and *P. avium* between the more and less productive site were not particularly large. The vigour of *Q. petraea*, *P. avium* and *J. regia* noticeably deteriorated when comparing the more productive to less productive site, whereas the other species largely retained the same vigour between the two sites (Table 2).

We found significant association ( $p < 0.001$ ) between survival rate and site for all species except *P. avium* (Table 3). For species *C. australis*, *F. sylvatica*, *J. regia* and *A. pseudoplatanus*, significant association was found between their survival rate and plot. For *C. australis* and *A. pseudoplatanus* significant association was found between survival rate and all plots, while for *F. sylvatica* and *J. regia* it was found only for the less productive site. Regarding survival rate, *P. avium* noticeably stood out with no association either

with plots or sites. Likewise, no such relationship was found between plots and survival rate of *Q. petraea*, though it was found ( $p < 0.001$ ) between the sites and its survival rate (Table 3).

Significant association ( $p < 0.001$ ) between the seedling vigour and sites was found for all species except *F. sylvatica*, as its survival was poor on both sites (Table 2). Significant relationship between the vigour of the seedlings and plots was found for *J. regia*, while for *C. australis* and *P. avium* this relationship was confirmed only in the case of the less productive site. As regards both survival rate and vigour, *Q. petraea* behaved in the same way: significant association ( $p < 0.001$ ) between site and survival rate/vigour, while a relationship between plot and survival rate/vigour was not confirmed (Table 3).

We found significant differences in seedling height increment among plots within the more productive site for *F. sylvatica* and among all plots on both sites for *P. avium*. Between the sites, significant differences in seedling height increment were found for *F. sylvatica*, *J. regia* and *A. pseudoplatanus*, while for *Q. petraea*, we did not find any differences (Table 3).

Table 4 shows the results of species' survival rate after dividing each plot by quarters as to determine

Table 4. Average survival rate and Chi-Square test of survival rate divided by quarters (1st quarter – northern part of each plot, 4th quarter – southern part) for all species on both sites

	Site 1 (Plots 1–3)					Site 2 (Plots 4–6)				
	Survival rate (%)				P	Survival rate (%)				P
	1	2	3	4		1	2	3	4	
<i>Celtis australis</i>	100	100	100	95	0.028	82	83	92	78	0.223
<i>Quercus petraea</i>	95	90	100	92	0.095	72	73	57	83	0.016
<i>Fagus sylvatica</i>	40	57	60	65	0.039	47	25	30	26	0.038
<i>Prunus avium</i>	93	93	100	100	0.041	92	98	90	93	0.290
<i>Juglans regia</i>	98	98	97	97	0.885	90	85	88	86	0.854
<i>Acer pseudoplatanus</i>	92	93	98	90	0.281	58	77	60	57	0.085

whether shading of surrounding old pine trees had any influence on seedling survival rate. The shading from old pines was presumably more noticeable on the southern quarter (4) of each plot and less noticeable on the remaining three quarters. We found that such was the case with *F. sylvatica* (shade-loving plant), whose survival rate was lowest at the northern quarter (1) and then gradually improved before becoming highest at the southern quarter (4), where shading was presumably most noticeable (Table 4). The survival rate distribution of *F. sylvatica* was almost the opposite on the less productive site, with the highest survival rate found on the northern quarter (1). The association between survival rate and plot quarters on the more productive site was significant for *F. sylvatica*. On the same site (Site 1), survival rate of other species did not vary much from one quarter to another; however, this relationship was also significant for *C. australis* and *P. avium*. Even though the distribution of survival rate for most species was more uneven and without any noticeable trend on the less productive site (Site 2), significant association was found for *Q. petraea* and *F. sylvatica*.

## Discussion

When establishing forest plantations, the survival of seedlings in the first year after planting and in the few successive years is crucial. In our experiment, after the first growing season and considering the harsh conditions of the area under analysis, the results showed moderate to high survival rate for most of the tested species, which could possibly indicate that the species used are promising for the purpose of converting old pine stands in the Slovenian Karst. The introduction of broadleaves into pine plantations should not begin until the soil conditions have already been considerably improved by conifers, which seems to be an unavoidable succession step in the restoration of degraded karst land, which is in line with the findings of Matić et al. (2011). However, *F. sylvatica* is an exception due to its insufficient survival rate. The poor results of this species are difficult to interpret. They might be attributed to the species' low resistance to summer water stress, especially in a summer as extreme as that of 2013, as well as to the generally poor quality of its seedlings and the fact that they came from natural regeneration and may have undergone some shock when transferred from a shaded environment to full sun. This is in line with findings of Tabari et al. (2005) who found that *Fagus orientalis* seedlings from natural regeneration that grew under the canopy until transplanting had growth difficulties under direct light that manifested in decreased shoot growth with increasing gap size. Johnson et al. (1997) stated that the growth of container bred *F. sylvatica*

seedlings was better in small gaps than in the understory or clearings. According to Jarčuška (2009), the growth of *F. sylvatica* in natural regeneration mostly depends on belowground resources in the first year. The poor quality of its seedlings might have also been the cause for much of the seedling mortality. According to Grossnickle (2012), factors affecting seedling physiological quality, such as stress resistance and nutritional status, bear a major influence on survival. Regarding the quality of the soil on the other hand, Don et al. (2007) could not find any correlation between soil quality and seedling establishment success or survival rate for *F. sylvatica* or *Q. petraea*. Comparing our species' survival rates to those from other studies that dealt with some of the same species, we see that *P. avium* seedlings in our study had a survival rate of 95% after the first growing season, while in a study from Turkey seedling survival rate was 77% after the second growing season (Esen et al. 2012). A study from Germany also cites low survival rates for *F. sylvatica* (from 21%) in the first three years after planting (Don et al. 2007). For *Q. petraea* the same study cites a survival rate between 39 and 81%, while it amounted to 83% in our study. The survival rates of *C. australis* from our study and the study of Topić (1997) were almost the same (91% and 92.5%, respectively) after the first year since planting.

Unfavourable field conditions at the less productive site are the likely reason for the lower survival rates of the seedlings growing there. The terrain is considerably steeper with more rocky ground and a shallower soil layer. It is less protected from surrounding old black pine stands and thus more exposed to winds and more prone to sunburn. The survival rates between the two sites varied significantly from one species to another. *P. avium* was the least susceptible to poor field conditions. This might indicate its somewhat higher ecological amplitude, especially when compared to *A. pseudoplatanus*, which had the largest drop in survival rate from the more to less productive site. However, these differences may also be in part a result of differences in seedling quality between species and could diminish in the coming years.

The considerably larger height increment of *P. avium* and *J. regia* seedlings compared to that of all other species is also likely a result of better quality seedlings, which were sturdy and well-rooted at the time of planting. The height of seedlings at the time of planting did not seem to be relevant; for instance, despite the fact that seedlings of *A. pseudoplatanus* were among the tallest, their increment after first year was quite small.

The exception and higher ecological amplitude of *P. avium* was once again proven in statistical analysis of association between survival rate and plots/sites as no such relationship was found for this species. Determining the reasons why *P. avium* performed so well

in all conditions would necessarily require further research. After *F. sylvatica* (with its exceptionally poor results), *A. pseudoplatanus* seedling survival rate had the greatest variability, which makes the species seem rather susceptible to small-scale, local micro conditions. Seedlings of *Q. petraea* behaved more uniformly within each of the two sites regarding both survival rate and vigour, but differed between the sites.

We also tested whether shading from the surrounding old pine trees had any influence on the survival rate of the seedlings in the first year. Some studies show that *F. sylvatica* seedlings have high probability of survival not only at low but also at high levels of light (Kunstler et al. 2005). According to Ammer (2002), *F. sylvatica* shows a strong decrease in growth with decreasing light quantity, but although it has a high survival rate under low light, it also has a low growth rate under high light (Petritan et al. 2007). Our results showed no clear shading effect from the surrounding trees on seedling survival rate, not even at the more productive site where the terrain is flat and the surrounding trees are taller. We assume that this impact will probably be seen in the coming years.

In conclusion, based on their high survival rates after the first growing season, all tested species (*P. avium*, *J. regia* and *C. australis* in particular) except *F. sylvatica* showed promising potential for use in future direct or indirect conversion of old pine stands in the Karst region. However, the results after the first growing season are insufficient to draw firm conclusions. Of all planted species *P. avium* had the highest survival rate and was least susceptible to poor field conditions. Without exception, all species showed lower survival rate on the less productive site. Unlike other species, *P. avium* and *J. regia* seedlings had considerable height increment, while *F. sylvatica* had the lowest. We can assume that perhaps old pine stands in the area already considerably improved soil conditions and thereby enabled the introduction of broadleaves.

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