THIRTY YEARS OF GROWTH OF WOODY PLANTS IN A BIOCORRIDOR ESTABLISHED ON AGRICULTURAL LAND: CASE STUDY FROM VRACOV (CZECH REPUBLIC)

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ABSTRACT

In the 1970s and 1980s, the concept of ecological networks was developed in the Czech Republic. The first biocorridors were established on arable land in the beginning of the 1990s. One of them was the Vracov biocorridor. This paper deals with the growth and development of trees on two permanent research plots in the period from 1993–2021. In the biocorridor, repeated inventories of woody plants and monitoring of biometrical parameters of trees and shrubs were carried out. The number of woody plants has been decreasing as the level of stand canopy has increased. Moreover, mean heights and diameters of skeleton (*Quercus robur, Tilia cordata*) and filling (*Acer campestre, Prunus avium*) trees and shrubs (*Cornus sanguinea*, *Ligustrum ovalifolium*) were compared. Under the given conditions, the growth of these tree species can be positively evaluated.

Keywords: Biocorridor, tree inventory, tree growth, game damage, TSES

INTRODUCTION

The concept of a territorial system of ecological stability (TSES) of the landscape was developed in the Czech Republic in the 1970s and 1980s in response to deepening problems in agricultural landscapes. The aim was to use elements of vegetation to reduce the negative impacts of human activity (e.g. declining biodiversity, increasing erosion, reducing soil retention capacity), enhance ecological stability and ultimately create a harmonious landscape (Buček *et al*. 2012; Mackovčin, 2000).

Such a landscape should have been characterised by more stable and appropriately distributed ecosystems in an intensively managed (used) landscape (Buček & Lacina, 1984). The basis of TSES are biocentres and biocorridors (Buček *et al*., 1995). Biocentres should enable the long-term survival of organisms in the landscape, while biocorridors should ensure their connectivity (Löw *et al*. 1995, Zimová *et al*., 2002, Bínová *et al*., 2017).

The idea of ecological networks is not specific to the Czech Republic and is being utilised elsewhere in the world (Jongman, 2008). However, the foreign approach is different from TSES. Abroad, biocorridors are mostly designed to connect reserves and national parks and ensure migration (Bennett, 2003; Bennett & Mulongoy, 2006; Fabos & Ahem, 1996, Hilty *et al*., 2006; Jongman & Pungetti, 2004). It is only in recent decades that the concept of green infrastructure has been developing (European Commission, 2022; Mell, 2017; Turner, 2006), which is closer to TSES. Both approaches not only address the connectivity of areas with higher biodiversity, but also ensure increased ecological stability.

TSES also has the advantage of being incorporated into national legislation as opposed to green infrastructure. The biocentre and biocorridor are defined by the implemented regulation of the Nature and Landscape Protection Act No. 395/1992 Gaz. The competence of individual authorities in relation to TSES are also defined. The implementation of TSES is considered to be in the public interest, as is the case with linear constructions.

The first biocorridors were established in the early 1990s in South Moravia. The first was the Vracov biocorridor, followed by the Radějov, Křižanovice, Medlovice and Stříbrnice biocorridors (all in 1990–1992). Subsequently, other compositional parts were established not only in Moravia but also in Bohemia. In the last two decades, the number of compositional parts of TSES has significantly increased due to the state's subsidy policy.

Despite the fact that the compositional parts have been established for thirty years and are still increasing significantly, there is not much information available on their development. One exception is the research carried out in 1993–1996 in the aforementioned Moravian biocorridors. The physico-chemical properties of soils, the development of biota and the growth of tree species were monitored. The research was subsequently continued in 2000–2001, and the results were handed over to the contracting authority without publication. The growth of woody plants was still irregularly monitored as part of students' final theses (Juhaňáková, 2003; Malý, 1997; Maršálová, 2003; Šincl, 2003). The results were sporadically published in scientific articles (Jelínek & Úradníček, 2010a; 2014; Úradníček, 2004) and occasionally presented at conferences (Jelínek & Úradníček, 2013, 2016; Úradníček, 2002; Úradníček & Jelínek, 2008; Úradníček & Selucký, 2007). Papers introducing the establishment of research plots in other compositional parts of TSES were also presented at conferences. Such research included the influence of the stand establishment method and transplant size on subsequent tree growth. The monitoring was carried out at the Valová and Klapý site (Dostálek *et al.*, 2007, 2009, 2014). Occasionally, other components of these biocorridors or other components of the TSES were monitored for students' final theses (Prokešová, 2019; Slach, 2014; Šimečková, 2010; Šťastová, 2012; Vašíček, 2015; Večeřa, 2014).

The aim of the paper is to evaluate the development of the woody component of the biocorridor in the early stages of development and in a longer time horizon (30 years) based on the evaluation of monitoring data from two permanent research plots of the Vracov biocorridor.

MATERIALS AND METHODS

Materials

The monitored biocorridor lies in South Moravia, Hodonin District, cadastral area of Vracov. It crosses the main road, Kyjov-Veselí nad Moravou, about 2 km NW of Vracov. The biocorridor was established in 1991. Its total length is 1890 m and the width is 15 m. It was established in an area free of autochthonous vegetation on arable land. Its target community should be of the forest environment character. In the outer rows, there were mainly shrubs with a mixture of *Prunus padus*. In the inner part of the biocorridor, there were various types of alternating shrubs and trees. When establishing the biocorridor, transplants 0.4–0.6 m high were used, with the exception of *Prunus avium* and *Tilia cordata*, where saplings about 2 m high were used. Plantings were fenced off after completion.

Autochthonous tree species should have been planted in the biocorridor, but this was not done. In PRP 1 and 2 were set out the following taxa: *Acer campestre*, *Carpinus betulus*, *Corylus avellana*, *Cornus sanguinea*, *Juglans regia*, *Ligustrum ovalifolium*, *Ligustrum vulgare*, *Lonicera korolkowii*, *Lonicera tatarica*, *Prunus avium*, *Populus tremula*, *Prunus padus*, *Prunus spinosa*, *Quercus robur*, *Rhamnus cathartica*, *Rosa multiflora*, *Sorbus aucuparia*, *Staphylea pinnata*, *Tilia cordata* and *Viburnum lantana*. The representation of individual species was not even.

In the biocorridor, two permanent research plots (PRP) were laid out, which were each 50 m long and 15 m wide. In each PRP, there are eight rows of trees at the mean distance of 2 m; plants spacing in the row is 1–1.6 m depending on the tree species.

In terms of the climate, the biocorridor is situated in the T4 region (Quit, 1971), which is the warmest region within the CR. The weather is remarkably warm and is slightly to moderately humid. The mean annual temperature in Bzenec is 9.0 °C (Culek *et al*., 2013). The mean annual precipitation is 547 mm (CHMI 2022).

The development of the selected tree species is shown in examples PRP 1 and PRP 2. PRP 1 was established at a distance of 80 m from the northern part of the biocorridor, which is at the sealed rural road. The plot size has a width 15 m and a length 50 m (0.08 ha). The altitude is 214–215 m. The topography is comprised of flat ground that is inclined 1° to SW. The soil type is Haplic Luvisols.

The PRP 2 is situated in the southern part of the northern section of the biocorridor and is intentionally laid out in the vicinity of the Kyjov-Vracov-Veseli nad Moravou main road, and it is 25 m north of the road specifically. The plot size has a width of 15 m and a length of 50 m (0.08 ha). The altitude is 199 m. The topography is comprised of flat ground without obvious ground unevenness. The soil type is Luvic Cambisols Protocalcic.

Biocorridor has been monitored from 1993 to the present (Koupilová, 2004; Malý, 1997; Novák, 2021; Procházka, 2015; Selucký, 2008; Šarapatka, 2001; Vetruba, 2003). It has the most data compared to other monitored biocorridors. The development of the number of tree species is shown in all data and growth in a seven-year period.

Methods

1) Tree inventory

a) Taxonomic classification was carried out on particular trees.

b) A complete list of determined trees was completed, including their quantitative proportions in 1993–2021.

c) A tree deployment plan was implemented for the expected long-term monitoring of trees.

2) Game damage

At the beginning of each growing season, a visual inspection of all transplants and saplings in the PRP was carried out, and the number of individuals damaged by game (browsing and fraying) was determined. It was not distinguished whether the damage was caused by hares or roe deer.

3) Measuring the basic growth parameters in PRP 1 and PRP 2.

a) The tree height in cm up to the height of 10.5 m and over 10.5 m with a minimum accuracy of 0.1 m was measured. The peak of the green crown was also measured.

A folding height-measuring rod and a hypsometer Clinomaster or Nikon Forestry Pro were used.

b) The diameter at breast height (DBH) in mm of trees over 1.3 m tall or the root collar diameter (RCD) just above the ground were measured; the diameter was calculated from the stem perimeter. In multi-trunk individuals, the strongest trunk was measured.

c) The crown diameter was measured in two directions perpendicular to each other (in non-closed plantations from 1993–1996) when the crown width was in the belt direction (W1), where W2 is the perpendicular crown width.

4) Growing stock

Based on the mean heights and mean DBH, the volume of wood with a diameter > 7 cm with bark measured in m^3/ha was determined from the yield tables (Anonymous, 1990). The value is given for a full stock and a stand with 100 % cover of the species. The growing stock is used for comparison with other stands based on agricultural land.

These measurements were carried out at all woody plants in PRPs. Annual measurements were carried out from 1993–2003, with the exception of 1997. In the following years, the measurement interval lengthened. The development of woody plants in the biocorridor is shown in the example of trees such as *Quercus robur* (Pedunculate Oak) and *Tilia cordata* (small-leaved Linden) as skeleton tree species, *Acer campestre* (Field Maple) and *Prunus avium* (Mazzard/Wild cherry) and *Prunus padus* (Bird cherry) as filling species. This is further shown in two shrubs: *Cornus sanguinea* (Dogwood) and *Ligustrum ovalifolium* (California Privet).

Changes in the number of individuals in the two PRPs are demonstrated on all available data. The development of other monitored parameters on data from 1993, 2000, 2007, 2014 and 2021 (in seven-year periods).

Tree growth was evaluated by descriptive statistics (arithmetic mean, standard deviation) in Microsoft Excel 2019. The significance of the differences between particular species within a PRP and between the two PRPs were tested by analysis of variance (ANOVA) at a level of significance a=0.05. Multiple subsequent comparisons were made via the Tukey HSD method. These methods of statistical evaluation were applied using R software (R Core Team 2021) and R studio (RStudio Team 2020). Boxplots were created using R package "ggplot2" (Wickham 2016).

The mean annual increment was determined when evaluating the growth of trees in the PRPs. In this paper we use the term increment to refer to the mean annual increment unless a different one is specified.

RESULTS

Tree inventory

PRP 1

During each inventory, the number of individuals of each species was determined in the PRP. At the beginning (1993) of surveillance, there were 343 individuals of 19 species. Of these, 160 (47 %) were trees and 183 (53 %) were shrubs. The total number gradually decreased to 133 in 2021 (i.e., 39 % of the original quantity). Of those, 71 were trees (53 %) and 82 were shrubs (47 %). A gradual decrease in the number of individuals was observed in all species. By 2003 it had decreased by 10 %, which is 36 individuals in 10 years. Over the next four years, it decreased by another 18 individuals. This was a total decrease of 54 individuals since the beginning of monitoring, from 1993–2007. Over the next 14 years, from 2007–2021, the number of woody plants decreased by 156 individuals (by 54 %). In 2021, and only 12 taxa (Table 1) were detected in the PRP, which is seven fewer than at the beginning. Disappeared species represented less than four individuals in 1993. The ratio between the number of trees and shrubs did not change significantly throughout the entire period of observation.

At the beginning of the monitoring, the most abundant species was *Ligustrum ovalifolium*, with 106 individuals. During the reporting period, their number fell by 64 % to 38. Other shrubs had a smaller representation. With the exception of *Cornus sanguinea*, these were units of individuals. There were originally 44 *C. sanguinea* individuals in the PRP. Their numbers fell by 70 % to 13. During the period of observation, four shrub species disappeared.

The most numerous tree (*Acer campestre*) was initially represented by 44 individuals. Their number dropped by 38 % to 31. The reduction was more pronounced for other trees, including *Quercus robur*, which decreased by 64 %; *Prunus avium*, which decreased by 68 %; and *Prunus padus*, which decreased by 63 %. The largest relative decrease was observed in *Tilia cordata*. Of the original seven individuals, only two survived, which is a decrease of 71 % (Table 1). During the monitoring period, three species of trees disappeared, which were represented by one individual each at the beginning.

Table 1: Number of woody plants in PRP 1

<table>
<tr><th>species / year</th><th>1993</th><th>1994</th><th>1995</th><th>1996</th><th>1998</th><th>1999</th><th>2000</th><th>2001</th><th>2002</th><th>2003</th><th>2007</th><th>2014</th><th>2021</th></tr>
<tr><td>Acer campestre</td><td>44</td><td>44</td><td>44</td><td>42</td><td>41</td><td>37</td><td>36</td><td>34</td><td>31</td><td>31</td><td>31</td><td>31</td><td>31</td></tr>
<tr><td>Carpinus betulus</td><td>1</td><td>1</td><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Cornus sanguinea</td><td>44</td><td>44</td><td>44</td><td>43</td><td>43</td><td>44</td><td>44</td><td>43</td><td>43</td><td>43</td><td>43</td><td>38</td><td>13</td></tr>
<tr><td>Corylus avellana</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>5</td><td>5</td><td>4</td><td>3</td><td>3</td></tr>
<tr><td>Juglans regia</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Ligustrum ovalifolium</td><td>106</td><td>106</td><td>106</td><td>106</td><td>104</td><td>104</td><td>104</td><td>103</td><td>103</td><td>103</td><td>96</td><td>89</td><td>38</td></tr>
<tr><td>Ligustrum vulgare</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>1</td><td></td><td></td><td></td></tr>
<tr><td>Lonicera korolkowii</td><td>1</td><td>1</td><td>1</td><td>1</td><td rowspan="2">6</td><td rowspan="2">7</td><td rowspan="2">7</td><td rowspan="2">7</td><td rowspan="2">6</td><td rowspan="2">6</td><td rowspan="2">6</td><td rowspan="2">6</td><td></td></tr>
<tr><td>Lonicera tatarica</td><td>5</td><td>5</td><td>5</td><td>6</td><td>4</td></tr>
<tr><td>Populus tremula</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td></td><td></td><td></td></tr>
<tr><td>Prunus avium</td><td>32</td><td>31</td><td>31</td><td>30</td><td>30</td><td>30</td><td>30</td><td>30</td><td>30</td><td>30</td><td>29</td><td>27</td><td>11</td></tr>
<tr><td>Prunus padus</td><td>35</td><td>35</td><td>35</td><td>35</td><td>35</td><td>34</td><td>35</td><td>35</td><td>35</td><td>35</td><td>31</td><td>24</td><td>13</td></tr>
<tr><td>Prunus spinosa</td><td>3</td><td>3</td><td>3</td><td>3</td><td>2</td><td>2</td><td>2</td><td></td><td>5</td><td>5</td><td>4</td><td>2</td><td>1</td></tr>
<tr><td>Quercus robur</td><td>39</td><td>38</td><td>38</td><td>37</td><td>37</td><td>36</td><td>35</td><td>34</td><td>34</td><td>34</td><td>33</td><td>21</td><td>14</td></tr>
<tr><td>Rhamnus cathartica</td><td>5</td><td>5</td><td>5</td><td>5</td><td>6</td><td>6</td><td>4</td><td>5</td><td>5</td><td>5</td><td>5</td><td>2</td><td>1</td></tr>
<tr><td>Rosa multiflora</td><td>4</td><td>4</td><td>4</td><td>4</td><td>2</td><td>2</td><td>2</td><td></td><td>4</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Staphylea pinnata</td><td>4</td><td>4</td><td>4</td><td>3</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td></td><td></td><td></td></tr>
<tr><td>Tilia cordata</td><td>7</td><td>7</td><td>7</td><td>7</td><td>7</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td><td>2</td></tr>
<tr><td>Viburnum lantana</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td><td>2</td><td>2</td><td>3</td><td>3</td><td>3</td><td>3</td><td>2</td><td>2</td></tr>
<tr><td>Total number</td><td>343</td><td>341</td><td>341</td><td>335</td><td>327</td><td>319</td><td>316</td><td>308</td><td>312</td><td>307</td><td>289</td><td>249</td><td>133</td></tr>
</table>

During the monitoring period, the numbers of some shrub species fluctuated, meaning the number of individuals decreased and then increased. Some transplants had been bitten down to the soil surface by game or had dried up. It was therefore not possible to measure them, and it was not clear at the time whether they would regenerate. After they regenerated, they were measured again. *Rosa multiflora* was purposefully removed in the biocorridor. Its numbers fluctuated during the monitoring as it sprouted again or expanded back to the PRP. In some shrub species, there were more individuals in the PRP than in 1993. This was the result of counting shoots or seedlings. *Rosa multiflora*, *Cornus sanguinea*, *Viburnum lantana* and *Ligustrum ovalifolium* were spread by root suckers, starting around 1994. *Sambucus nigra* is an abundant self-seeding species. Seedlings of *Prunus avium* were first observed in 1995. Since about 2005, seedlings of *Acer campestre*, *Tilia cordata* and *Prunus padus* have sporadically appeared in the PRP.

In the part of the biocorridor where PRP 1 is defined, there is a sparse stand of tree species (Fig. 1). Despite the loss of individuals and changes in the structure of the stand, there is still a stable stand of trees in the PRP, which is able to fulfil its necessary functions.

Fig. 1: View of thinned stand in PRP 1

PRP 2

At the first inventory, there were 323 individuals of 15 species in the PRP. Of this number, 165 were trees (51 %) and 158 were shrubs (49 %). The number of tree species gradually decreased to 143 by 2021 (44 % decrease). Of these, 111 were trees (78 %) and 32 were shrubs (22 %). The total number of individuals declined gradually until 1998. During the winter of 1998–1999, a large number of *Ligustrum ovalifolium* died (49 %). Another significant drop in numbers followed between 2003–2007, from 233 to 176 (24 % decrease).

The cause was a thickening crown cover and shading of shrubs and the smaller *A. campestre*. In 2007, there were 46 % fewer woody plants than in 1993. In the second half of monitoring (2007–2021), the number decreased by 33 individuals (29 %). The cause of the decrease in the number of individuals was the continued dying of shaded individuals and the felling of several oaks (four individuals). At the beginning, the representation of trees and shrubs was balanced, while at the last inventory, trees were predominant. Almost all the bushes grown inside the stand had died.

Table 2: Number of woody plants in PRP 2

species / year	1993	1994	1995	1996	1998	1999	2000	2001	2002	2003	2007	2014	2021
Acer campestre	45	45	45	45	45	41	39	39	37	35	21	21	21
Corylus avellana	7	7	7	7	5	6	6	6	6	6	6	6	5
Cornus sanguinea	38	38	38	38	38	38	38	40	43	42	29	28	22
Ligustrum ovalifolium	93	92	91	88	82	42	39	34	33	21	3	3	0
Lonicera tatarica	3	3	3	2	3	3	3	3	3	3	0		
Populus tremula	1	1	1	1	1	1	1	1	1	1	1	1	0
Prunus avium	41	41	41	41	41	40	39	39	38	38	38	36	34
Prunus padus	31	31	31	31	31	31	31	31	31	31	28	28	28
Prunus spinosa	3	3	3	3	3	3	3	3	3	3	3	0	
Quercus robur	38	38	37	37	36	35	35	35	34	34	33	24	21
Rhamnus cathartica	3	3	3	3	3	3	3	3	3	2	0		
Rosa multiflora	3	3						4	3	2	0		
Sorbus aucuparia	1	1	1	1	1	1	1	1	1	1	0		
Tilia cordata	8	8	8	8	8	8	8	8	8	8	8	7	7
Viburnum lantana	8	8	7	6	8	7	6	5	6	6	6	6	5
Total number	323	322	316	311	305	259	252	252	250	233	176	160	143

In the winter of 2014–2015, trees in the outer rows were cut, which resulted in the lightening of the stand. It was caused by *Sambucus nigra* (not monitored) growing here. With the gradual restoration of the canopy closure, its number decreased.

In 2021, there were eight species in PRP, which is seven fewer than at the beginning of the monitoring. These included species that were represented by fewer than three at the beginning (Table 2). The most abundant species was *Ligustrum ovalifolium* with 93 individuals in 1993. The species was last detected in 2014 with three individuals. The second most abundant shrub was *Cornus sanguinea* with 38 individuals in 1993. Its number had declined to 22 by 2021 (42 % decrease). Over the monitoring period, the number of shrub species had declined from eight to three.

The most numerous species of tree was *Acer campestre*, which was represented by 45 individuals. Its number fell to 21 individuals by 2021, (53 % decrease). For other trees, the decrease in number was smaller. *Q. robur* decreased by 45 % (17 pcs), *P. avium* by 17 % (7 pcs), *P. padus* by 10% (3 pcs) and *T. cordata* by 13 % (1 pcs). Of the arboreal species, only *Sorbus aucuparia* (one species) had been lost.

Several years after the biocorridor was established, *Rosa multiflora* was destroyed. It was not present from 1995–2000 in the PRP, but it subsequently re-established itself. Its complete eradication occurred after 2003 (Table 2).

As in PRP 1, *R. multiflora*, *C. sanguinea*, *V. lantana* and *L. ovalifolium* spread by root suckers. Most of them, however, died with the thickening of the canopy. Seedlings of *P. avium* were first observed in 1996. Since about 2005, seedlings of *A. campestre*, *T. cordata* and *P. padus* have also appeared in the PRP.

The stand in PRP 2 consists mainly of trees (Fig. 2). Most of the bushes in the inner part of the stand have died. The stand is stable and performs the required functions.

Fig. 2: Prosperous closed stand in PRP 2

Game damage

PRP 1

Plantings in the biocorridor have been fenced off since the beginning. Nevertheless, they have been damaged by browsing and fraying. Browsing damage was not significant initially, affecting only 41 individuals (12 %) in 1993 and six individuals (2 %) in 1994. In 1995, 103 individuals (30 %) were damaged by browsing and in 1996 as many as 266 individuals (79 %).

The greatest browsing damage was on *Cornus sanguinea*. In 1993, 23 bushes (52 %) were damaged, in 1994 only one bush was damaged and in 1995 and 1996 all bushes were damaged. Of all the trees, *Quercus robur* was the most damaged by browsing. In 1993, seven individuals (18 %) were damaged, in 1994, none were damaged, in 1995, 13 individuals (34 %) were damaged and in 1996, 10 individuals (27 %) were damaged. 38 individuals (86 %) of *Acer campestre*, 100 individuals (94 %) of *Ligustrum vulgare*, 17 individuals (57 %) of *Prunus avium* and 22 individuals (63 %) of *Prunus padus* were damaged by browsing in 1996, when the damage was greatest (Table 3).

Damage from fraying was less than that from browsing. Due to the saplings used, *Prunus avium* and *Tilia cordata* were damaged. In 1993, 17 *P. avium* (53 %) and two *Tilia cordata* (29 %) individuals were damaged. In subsequent years, the fraying damage was less (Table 3).

In the following years, the fraying was sporadic and was no longer monitored. Occasionally, woody plants were damaged by fraying, especially *Acer campestre*.

Table 3: Number of woody plants damaged by game in PRP 1

species / year	1993		1994		1995		1996	
	browsing	fraying	browsing	fraying	browsing	fraying	browsing	fraying
Acer campestre	1	2	1	3	22	1	38	
Prunus avium	1	17	1	8	4	2	17	5
Carpinus betulus					1			
Corylus avellana	5		1		6		6	
Cornus sanguinea	23		1		44		43	
Juglans regia		1						2
Ligustrum ovalifolium	1		1				100	
Ligustrum vulgare					2		2	
Lonicera korolkowii								
Lonicera tatarica							2	1
Populus tremula	1			1				
Prunus padus							22	
Prunus spinose	1	1			2		2	
Quercus robur	7	2		3	13	4	10	
Rhamnus cathartica					1		5	
Rosa multiflora							8	
Staphylea pinnata	1		1		4	1	3	1
Tilia cordata		2			4		5	
Viburnum lantana							2	
Total number	41	25	6	15	103	8	265	9

PRP 2

No damage was detected in PRP in 1993 and 1994. In 1995, 42 of the transplants (14 %) were damaged by browsing. In 1996, browsing was more frequent, with 108 damaged individuals (35 %). The most damaged species was *Cornus sanguinea*. In 1995, 31 shrubs (82 %) were damaged and in 1996, 35 shrubs (92 %) were damaged. The most damaged tree was *Acer campestre*. In 1995, seven transplants (16 %) were damaged and in 1996, 28 transplants (62 %) were damaged. Fraying damage was sporadic in PRP 2 (Table 4).

As in PRP 1, browsing was sporadic and no longer monitored in the following years. There was occasional damage to woody plants by fraying, especially *Acer campestre*.

Table 4: Number of woody plants damage by game in PRP 2

species / year	1993		1994		1995		1996	
	browsing	fraying	browsing	fraying	browsing	fraying	browsing	fraying
Acer campestre					7		28	
Prunus avium							6	
Corylus avellana					1		2	
Cornus sanguinea					31		35	
Ligustrum ovalifolium					2		14	1
Ligustrum vulgare								
Populus tremula								
Prunus padus							3	
Prunus spinose					1		3	
Quercus robur						1	6	2
Rhamnus cathartica							3	
Rosa multiflora								
Sorbus aucuparia								
Tilia cordata							6	
Viburnum lantana							2	1
Total number	0	0	0	0	42	1	108	4

Evaluation of growth parameters

<u>Height</u>

PRP 1

The main skeleton species, *Quercus robur*, reached a mean height of 133 cm in 1993. The heights of the individuals had a large range (Fig. 3), because some transplants were damaged by game.

After the fence was repaired, the situation improved and the *Q. robur* grew well. The mean height of *Q. robur* was 595 cm in 2000, 805 cm in 2007, 986 cm in 2014 and 1059 cm in 2021 (Fig. 3). The tallest *Q. robur* measured 270 cm in 1993 and 720 cm seven years later. At the last measurement in 2021, the tallest tree reached 12.9 m. The increase of *Q. robur* was at an increment of 33.1 cm/year (the largest of the trees).

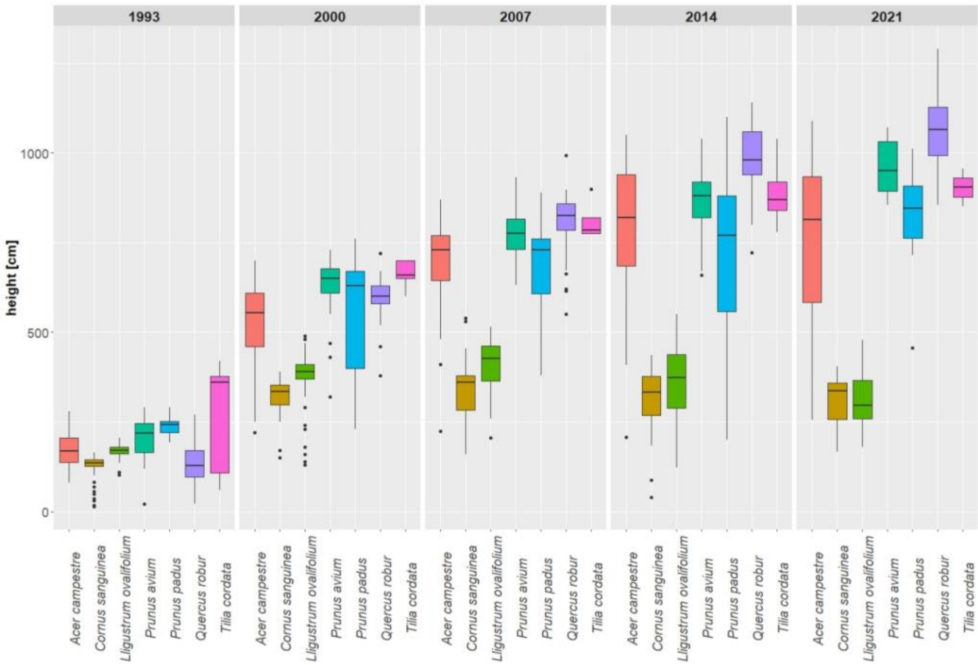
Tilia cordata, second skeleton species, was planted out as a sapling with a trained crown. Despite the fact that some of the individuals were damaged by game, in 1993 it had a mean height of 259 cm. During the first years it grew slower than *Q. robur*. It had a mean height of 662 cm in 2000, about 70 cm more than *Q. robur* (the difference was not significant). In 2007, it had a mean height of 810 cm, the same as *Q. robur*. In the following years, it lagged slightly behind *Q. robur*; in 2014 it measured at 890 cm, and in 2021, it measured at 904 cm (oak 1059 cm). This difference was due to the death of the highest *T. cordata*.

The most abundant filling species at the beginning was *Acer campestre*. Despite the initial damage by game, it grew well. At the beginning it had a mean height of 173 cm. In the following years, the mean height gradually increased to 521 cm in 2000, 687 cm in 2007, 795 cm in 2014 and finally to 758 cm in 2021. Poorly growing and fraying individuals were represented throughout the observation period. Between 2014–2021, the effects of several years of drought (crown dieback) were evident. As a result, the mean height decreased up until 2021.

Prunus avium, the second filling species, was planted out as a sapling with a trained crown. In 1993, it had a mean height of 207 cm and grew similarly to *T. cordata*. In the following years, the mean height gradually increased to 628 cm in 2000, 770 cm in 2007, 872 cm in 2014 and 961 cm 2021. The tallest *P. avium* tree had a height of 1070 cm in 2021.

Prunus padus is one of the abundant species. Despite being planted in a drier habitat, it grew well. At the beginning of the monitoring, it had a mean height of 239 cm. Its growth was similar to that of *Acer campestre*; it had a height of 549 cm in 2000 and 684 cm in 2007. In the winter of 2013–2014, *P. padus* were cut back, but most of them started to grow back in the spring. In 2014, the mean height was 182 cm and by 2021 it had increased to 833 cm (Fig. 3).

Fig. 3: Height of woody plants in PRP 1



The mean height of the shrub species *Ligustrum ovalifolium* and *Cornus sanguinea* in 1993 was similar to that of trees: 169 cm and 122 cm. The largest mean height was in 2007, which measured at 408 and 340 cm. In the following years, the number of individuals decreased, and the surviving ones shrivelled. In 2021, their mean height was 310 and 309 cm (Fig. 3).

The differences in the mean heights of the monitored tree species in 1993 were, with some exceptions, significant. A significant difference was not demonstrated between *Prunus avium–Prunus padus–Tilia cordata*, *Quercus robur–Cornus sanguinea* and *Ligustrum ovalifolium–Acer campestre*. In 2021, there was no longer a significant difference in the mean heights of the bushes. There was no significant difference between the mean heights of the tree species *Prunus avium–Quercus robur–Tilia cordata*.

As mentioned above, *Prunus avium* and *Tilia cordata* saplings were taller than those of other trees. In 1993, both species had a mean height over 200 cm. In contrast, the mean height of *Acer campestre* was 177 cm and *Quercus robur* was only 133 cm (the difference is significant). In 2000, the mean height of *Q. robur* approached that of *T. cordata* and *P. avium.* In 2007, the mean height of these species was almost the same. From 2008, *Q. robur* had a greater mean height than *T. cordata* and *P. avium*.

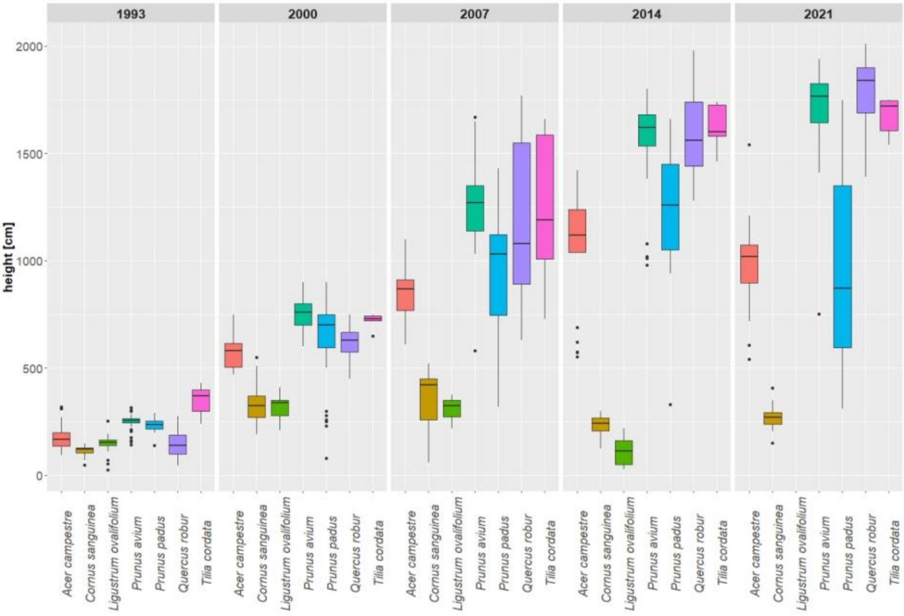
According to the yield tables used in forestry (Anonymous, 1990), *P. avium*, *Q. robur* and *T. cordata* have a yield class of 5. Interestingly, the yield class has gradually decreased. In 2007, its yield class was 3, and it was 4 in 2014. *A. campestre* has a yield class of 6, though its yield class was 3 in 2007 and 4 in 2014. The growing stock with bark was 65 m^3/ha for *A. campestre*, 100 m^3/ha for *P. avium*, 120 m^3/ha for *Q. robur* and 90 m^3/ha fir *T. cordata* in 2021.

PRP 2

The most abundant skeletal tree, *Quercus robur*, had a mean height of 145 cm in 1993. Its damage from game was less than in PRP 1, so heights had less variability (Fig. 4). In the following period, the transplants grew well, and *Q. robur* reached mean heights of 617 cm (2000), 1198 cm (2007), 1580 cm (2014) and 1787 cm (2021). At the last measurement, the tallest *Q. robur* was 2010 cm tall. The increase was at an increment of 58.6 cm (the highest among the trees, like PRP 1).

Tilia cordata, the second skeletal tree, was planted out as a sapling with a trained crown and had a mean height of 346 cm in 1993. In the following years, it grew less than *Q. robur* and the mean height was similar to *Q. robur*: 724 cm in 2000, 1229 cm in 2007 and 1630 cm in 2014. In 2021, it already had about one meter less mean height than *Q. robur*, with a mean height of 1673 cm. The tallest *T. cordata* was 1750 cm tall.

Fig. 4: Height of woody plants in PRP 2



The most abundant filling tree, *Prunus avium*, which was also planted out as a sapling with a trained crown, had a mean height of 249 cm in 1993. In the following years it grew similarly to *Q. robur*. Its mean height was 758 cm in 2000, 1260 cm in 2007, 1556 cm in 2014 and 1706 cm in 2021. In 2021, the tallest individual was 1940 cm tall. The increase of *P. avium* was at increments of 52 cm.

Acer campestre, the second abundant filling tree, reached the mean height of 173 cm in 1993. This was a little more than *Q. robur* (no significant differences). Its growth was slower than that of skeletal trees and reached a mean height of 578 cm in 2000, 844 cm in 2007, 1054 cm in 2014 and 990 cm in 2021. The mean heights of *Prunus padus* were slightly greater before 2014, when they were cut back. After cutting, they regenerated well and in 2021 they had the same mean height as *A. campestre* (Fig. 4).

The mean height of the two most abundant shrub species, *Ligustrum ovalifolium* and *Cornus sanguinea,* was similar to trees in 1993, measuring at 150 cm and 116 cm, respectively. The largest mean height was in 2007, at 307 and 334 cm. Subsequently, their representation decreased, and the surviving bushes dried up. In 2021, the mean height of *C. sanguinea* was 271 cm (Fig. 4), and *L. ovalifolium* was no longer represented in the PRP.

In 1993, the differences in mean height were not significant between *Prunus avium–Prunus padus, Quercus robur–Acer campestre* and *Cornus sanguinea–Corylus avellana–Ligustrum ovalifolium*. In 2021, there was no longer a significant difference in the mean heights of the bushes. There was no significant difference in the mean heights for the tree species *Prunus avium, Quercus robur* and *Tilia cordata,* or *Prunus padus* and *Acer campestre*.

In 1993, the mean height of *Tilia cordata* saplings was more than twice as great as that of *Q. robur.* The difference in height between *Q. robur* and *P. avium* was smaller (Fig. 4), and the difference between heights was significant in both cases. By the year 2000, the difference in mean heights for these species had decreased and only *Q. robur* and *P. avium* had a significant difference. The mean heights were already similar and had no significant difference in the following years.

According to the yield tables (Anonymous, 1990), *P. avium*, *Q. robur* and *T. cordata* have a yield class of +1. As at PRP 1, the yield class has gradually declined, albeit only by one notch. *A. campestre* has a yield class of 5 (a decrease of three notches since 2007). The growing stock with bark of *A. campestre* was 100 m^3/ha, *P. avium* was 230 m^3/ha, *Q. robur* was 220 m^3/ha and *T. cordata* was 230 m^3/ha in 2021.

Diameter at breast height (DBH)

PRP 1

The largest mean DBH at the beginning of monitoring was *Tilia* cordata, measuring at 32 mm. Other trees had a mean DBH that was smaller (Fig. 5), such as *Acer campestre* at 11 mm, *Quercus robur* at 9 mm, *Prunus avium* and *Prunus padus* at 15 mm (the difference is insignificant for *Prunus padus–Acer campestre*, *Prunus padus–Prunus avium, Quercus robur–Acer campestre* and *Prunus avium–Acer campestre* at p=0.05041). With the exception of *P. padus*, individuals lower than 1.3 m were also represented where the diameter of the root neck (DRC) was measured. The mean DRC was 24 mm for *T. cordata*, 23 mm for *A. campestre*, and 18 mm for *Q. robur* and *P. avium*. *T. cordata* also had the highest mean DBH in 2000 and 2007, measured at 113 and 134 mm, respectively. *P. avium* had almost the same mean DBH (102 and 125 mm). In 2014, the mean DBH of both species was the same, with *T. cordata* at 146 mm and *P. avium* at 147 mm. In 2021, *P. avium* had the highest mean DBH, which measured at 181 mm. *T. cordata*'s DBH was only 148 mm (only two individuals survived). Throughout the monitoring period, the differences between the DBH of these species were insignificant.

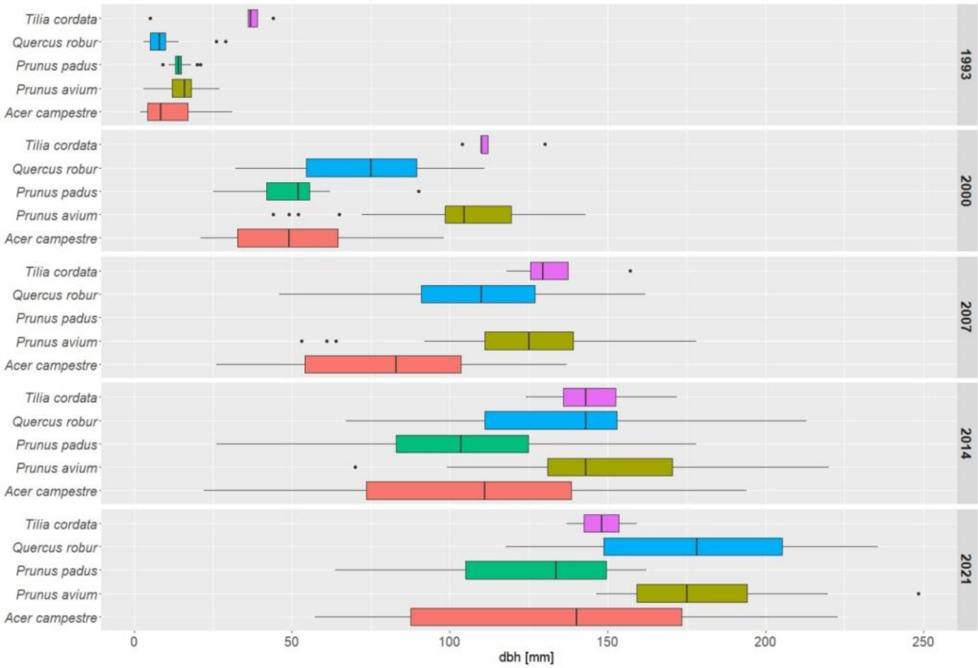
The mean DBH of *Q. robur* in 2000 (still a significant difference), 2007 and 2014 was smaller than that *T. cordata* and *P. avium*, measuring at 73, 107 and 136 mm, respectively. In 2021, despite the decline of individuals, *Q. robur* was the second strongest tree with a mean

DBH of 178 mm. This shows that *T. cordata* has not been able to maintain the lead it had at the start as a sapling, unlike *P. avium*.

In the two filling species, *A. campestre* and *P. padus*, the mean DBH was similar the whole time (Fig. 5), and there was an insignificant difference between them.

The strongest tree was *P. avium* with a DBH of 248 mm, and the second strongest was *Q. robur* with a DBH of 236 mm. The strongest *A. campestre* had a DBH of 223 mm, while the *T. cordata* only had a DBH of 159 mm. The largest increment was in *P. avium* at 5.9 mm, followed by *A. campestre* at 4.5 mm.

Fig. 5: Diameter at breast height of woody plants in PRP 1



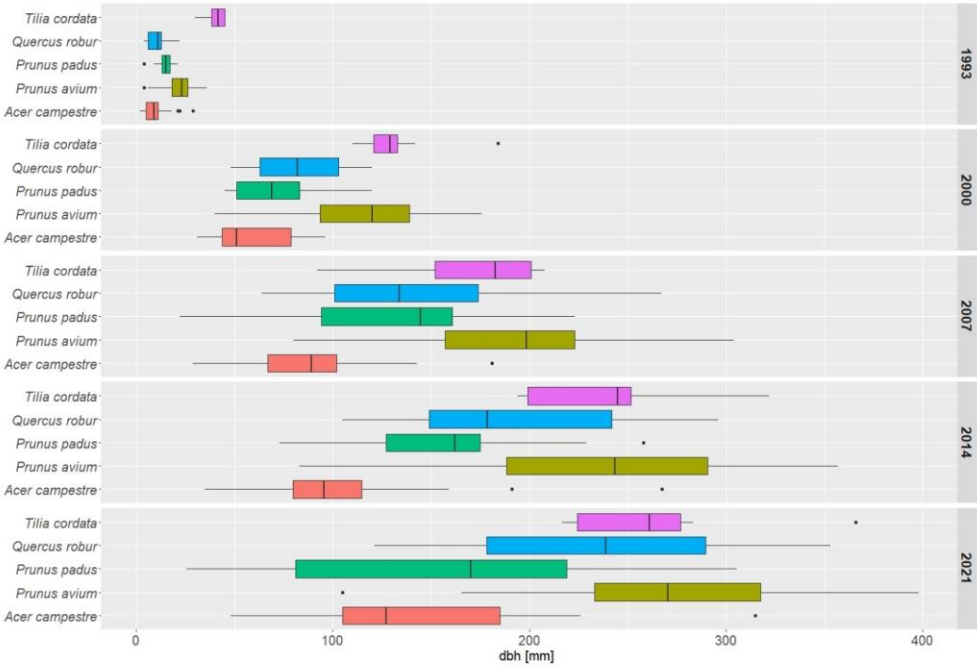
PRP 2

At the beginning of the monitoring, *T. cordata* had the largest mean DBH, which was 40 mm. The other skeletal tree species had smaller measurements for their mean DBH as well as other tree species. *Q. robur* had a DBH of 10 mm, *A. campestre* was 9 mm, *P. avium* was 22 mm and *P. padus* was 15 mm. With the exception of *Prunus padus–Quercus robur* and *Quercus robur–Acer campestre*, the differences were significant. Some individuals of *Q. robur* and *A. campestre* were smaller than 1.3 m. Their mean DRC was 22 and 26 mm, respectively. *T. cordata* had the highest mean DBH in 2000 at 133 mm. Subsequently, *P. avium* reached similar mean DBH values (Fig. 6). At the last measurement, *P. avium* and *T. cordata* had the mean DBH of 264 mm and 271 mm, respectively. Throughout the monitoring period, the difference in the mean DBH of *T. cordata* and *P. avium* was insignificant. *P. avium* was the species with the highest growth rate, at an increment of 8.9 mm.

The mean DBH of *Q. robur* was initially smaller, at just 26 mm in 2000, but gradually the *T. cordata* and *P. avium* grew. Since 2007, the difference in the mean DBH of *T. cordata* and *Q. robur* has been insignificant, and since 2014, the difference in the mean DBH was also insignificant between *Q. robur* and *P. avium*. In 2021, the mean DBH of *Q. robur* was only 32 mm less than that of *T. cordata*. The strongest *Q. robur* had a DBH of 353 mm.

A. campestre and *P. padus* had a smaller mean DBH throughout the entire monitoring period. In 2000, they had roughly the same DBH, while in 2007 and 2014, *A. campestre* had a mean DBH about a third less than *P. padus*. In the winter of 2014–2015, several *P. padus* individuals were cut. They subsequently regrew and in 2021 had the same mean as *A. campestre* (Fig. 6). With the exception of 1993, the differences in DBH were insignificant.

Fig. 6: Diameter at breast height of woody plants in PRP 2



<u>Crown diameter</u>

PRP 1

One of the monitored parameters was the size of the crown. The most abundant tree species in PRP 1 (*A. campestre*) achieved the mean crown diameter of 126×139 cm in 1993, 189×214 cm in 1994, 226×254 cm in 1995 and 237×254 cm in 1996. *P. avium* had the most similar crown size of the trees. *Q. robur*, on the other hand, had a mean crown diameter of only 46×52 cm in 1993, which was a consequence of game browsing. In the following years, the crowns of *Q. robur* were not damaged and grew to 115×118 cm in 1994, 142×178 cm in 1995 and 167×193 cm in 1996. The situation was similar for *T. cordata*, which had a mean crown diameter of 77×74 cm in 1993 and 340×400 cm in 1996 (Table 5).

Of the shrub species, *Lonicera korolkowii* and *Rosa multiflora* had the largest mean crown diameters in 1993, which measured at 280×220 cm and 255×274 cm, respectively. For the most abundant shrub species, *Ligustrum ovalifolium*, the mean crown diameter developed to 101×107 cm in 1993, 141×163 cm in 1994, 182×217 cm in 1995 and 188×234 cm in 1996. In the following years, a canopy developed and the crowns' growth in width was greatly reduced. The mean crown diameter stagnated or decreased. Therefore, this parameter was not monitored further. After 2014, there was a significant die-off of woody plants and increase in damage from drought. The canopy has thinned considerably, so this process continues.

Table 5: Mean crown diameter of woody plants in PRP 1 (cm)

species / year	1993		1996		1999	
	width 1	width 2	width 1	width 2	width 1	width 2
Acer campestre	126	139	237	254	193	245
Carpinus betulus	23	15				
Corylus avellana	35	27	103	86	105	159
Cornus sanguinea	100	103	160	203	151	195
Juglans regia	6	7	91	89	30	90
Ligustrum ovalifolium	101	107	188	234	126	159
Ligustrum vulgare	38	56	124	137		
Lonicera korolkowii	280	220	260	310		
Lonicera tatarica	190	201	237	223		
Prunus avium	118	117	250	266	196	236
Populus tremula	56	30	265	240	230	250
Prunus padus	167	170	245	296	225	248
Prunus spinosa	28	37	104	108	190	305
Quercus robur	46	52	167	193	230	259
Rhamnus cathartica	118	136	191	265	183	227
Rosa multiflora	255	274			180	160
Staphylea pinnata	22	26	30	35	166	206
Tilia cordata	77	74	137	145	340	400
Viburnum lantana	103	103	187	210	185	246

PRP 2

The mean crown diameter of each species has increased dynamically since the beginning. *Q. robur* had a mean crown diameter of 90×95 cm in 1993. This was the smallest crown projection among the trees. Within three years, its mean crown had more than doubled to 232×212 cm. Other trees had larger crowns at the beginning, such as *T. cordata* at 141×138 cm, *P. avium* at 146×162 cm, *A. campestre* at 142×150 cm and *P. padus* at 166×174 cm. The crowns of these species increased in size, but less than those of *Q. robur* (about 1.8 times). The filling species, *A. campestre* and *P. avium*, had approximately the same mean crown diameter as the skeletal species (Table 6).

The mean crown diameters of *C. sanguinea* and *L. ovalifolium* in 1993 were similar to *Q. robur*, measuring at 99×104 cm and 89×91 cm, respectively. The crown enlargement of these species was similar to that of the trees. In 1996, *C. sanguinea* and *L. ovalifolium* had a mean crown diameter of 177×204 cm and 150×193 cm, respectively. The crowns had thus increased by a factor of about 1.9 compared to their size in 1993.

As in PRP 1, the canopy gradually built up and the crown projection did not increase further. The shaded parts of the crown began to die back due to insufficient light. Shrubs developed asymmetrical crowns and shrub mortality increased with increasing shading (see above).

Table 6: Mean crown diameter of woody plants in PRP 2 (cm)

species / year	1993		1996		1999	
	width 1	width 2	width 1	width 2	width 1	width 2
Acer campestre	142	150	236	273	229	247
Corylus avellana	83	83	158	220	205	283
Cornus sanguinea	99	104	177	204	156	212
Ligustrum ovalifolium	89	91	150	193	289	111
Lonicera tatarica	155	158	302	262	208	198
Prunus avium	146	162	244	300	210	240
Populus tremula	52	34	235	235	270	330
Prunus padus	166	174	252	328	214	269
Prunus spinose	117	118	233	222	106	180
Quercus robur	90	95	232	212	208	239
Rhamnus cathartica	82	80	148	170	164	212
Rosa multiflora	317	317			128	132
Sorbus aucuparia	105	130	140	165	200	230
Tilia cordata	141	138	245	251	340	383
Viburnum lantana	54	53	130	124	156	158

DISCUSSION

The biocorridor was established as a dense stand of trees. The number of individuals gradually decreased in both PRPs, but at a different rate. In PRP 1 it was gradual until 2014 and covered all represented taxa. After that, the number of individuals of most taxa decreased sharply (by 46 %). The cause was most likely several years of drought. On the other hand, there was a large decrease in numbers in PRP 2 in the winter of 1998–1999, when the number of individuals of *L. ovalifolium* decreased by 49 %. In other years, the decline was gradual and affected all species represented. The gradual decrease in the number of individuals was caused by a canopy closure. The number of individuals in the PRP has not been significantly affected by the dry period as the soil has more favourable moisture conditions. The effect of stand density on survival rates and growth of trees has been documented by many authors (Kerr, 2003; Kuehne *et al.*, 2013; Saha *et al.,* 2012).

A comparable loss of individuals was found in the Radějov (Jelínek & Úradníček, 2014) and other biocorridors (Jelínek, 2011). Dostálek *et al.* (2007) found slightly higher seedling mortality rates for several taxa at the Valová site. The highest mortality rate was observed for *Quercus robur* (54 %), *Carpinus betulus* (51 %) and *Tilia cordata* (33 %). The mortality rate of oak was possibly increased by using small transplants (0.2–0.4 m). However, transplants of the same size were also used for *Prunus avium*, but the survival rate was higher (80 %). A gradual decline in the number of *Q. robur* individuals on forested arable land was also found by Valkonen (2008). Over five years, the number of individuals declined by 25 %.

Higher mortality of plantings on former agricultural land was also reported by Don *et al*. (2007). In the stands they studied, mortality was measured at 0–8 % for *Acer campestre*, 3–51 % for *Carpinus betulus*, 32–58 % for *Prunus avium*, 19–61 % for *Quercus petraea* and 0–40 % for *Tilia cordata*. For the other species represented, it ranged from 0 % (*Fraxinus excelsior*) to 100 % (*Pinus silvestris*). Dostálek (2005) observed stands of similar species composition. After three years, mortality rates were 67 % for *Betula pendula*, 46 % for *Carpinus betulus,* 46 % for small transplants (0.2–0.4 m) and 27 % higher transplants (1.4–1.8 m) of *Quercus robur* and 27% for small transplants (0.2–0.4 m) and 28 % higher transplants (1.4–1.8 m) of for *Tilia cordata*. For the other species monitored, it was within 10 % (i.e. *Acer campestre*, *Prunus avium*, *Prunus padus*, *Cornus sanguinea*, *Euonymus europaea*, *Ligustrum vulgare*).

It is evident from the above that the survival rate is highly variable. It is dependent on many factors, such as weather (precipitation, temperature), damage by game and competition between tree species, and it can vary from one to tens of per cents (Cicek *et al*., 2010; Erkan *et al.*, 2017; Granger & Buckley, 2021; Repáč & Belko, 2020).

As in the forest, plantations on agricultural land are damaged by browsing and fraying. The degree of damage caused by game depends on many factors, such as the density of game populations (Bleier *et al*., 2012; Ward *et al*., 2008), the distance between agricultural and forest areas (DeVault *et al*., 2007), the field size and surrounding land cover types (Dudderar *et al*., 1989), the palatability of plants (Gill, 1992; Milne-Rostkowska *et al*., 2020, Ward *et al*., 2008) and the topographic factors (habitat structure) (Cai *et al*., 2008).

Fencing is the most common method of protecting plantings when establishing biocorridors. This was used in the Vracov biocorridor. The fencing was regularly inspected and maintained in good condition. Nevertheless, damage by game has occurred in the plantations, the degree of which varied from year to year. In 1993 and 1994, it was only found in PRP 1 (up to 12 %). In 1995 and 1996, the browsing was found in both PRPs, but there was a large difference between areas. While 79 % of the transplants were damaged in PRP 1, only 35 % were damaged in PRP 2. This difference may be due to the proximity to a frequently used road. As has been documented by many authors, traffic noise and other disturbances have an effect on mammal population densities and thus on the damage they cause (Joly *et al.*, 2006; Milne-Rostkowska *et al*., 2020; Rytwinski & Fahrig, 2012; Shannon *et al*., 2014).

Damage in the Vracov biocorridor was considerably less compared to unfenced biocorridors. In the Radějov biocorridor, about 60 % of transplants were damaged in 1993 and 85 % a year later in 1994. In 1996, 97 % of plantings were damaged by browsing (Jelínek & Úradníček, 2016). A similar situation was found in the biocorridor in Medlovice and in Stříbrnice, where the browsing reached 69 % and 92 %, respectively (Úradníček, 2006).

From the above, it is clear that fencing of plantations on agricultural land has a significant impact on their subsequent growth. The same conclusion was reached by Hjelm *et al*. (2018) as well as Sweeney & Dow (2019). This corresponds with findings in reforestation (Ammer, 1996; Bergquist *et al*., 2009; Bugalho *et al.*, 2013; Kriebitzsch, 2000; Kuiters & Slim, 2002; Taylor *et al*., 2006).

The fencing of plantings also reduced damage to trees by fraying. Also, for this damage there was a difference between PRPs, with PRP 1 sustaining more damage. More individuals were damaged in 1993 (7 %) and 1994 (4 %). In PRP 2 only 1 % were damaged in 1994. In unfenced planting in the Radějov biocorridor, 8 % of individuals were damaged by fraying (Jelínek & Úradníček, 2016).

Among woody plants, *Cornus sanguinea* was the species most damaged by browsing in the Vracov biocorridor. For other woody plants, damage varied from year to year. *Quercus robur* was damaged to a lesser extent throughout the measurement period. In some years, especially 1996, *Acer campestre* (which was also damaged in 1995), *Ligustrum ovalifolium*, *Tilia cordata* and *Prunus avium* were damaged to a high degree. *Prunus avium* was damaged mainly by fraying. That different tree species are damaged to different degrees was documented from both biocorridors and forest cultures (Ameztegui & Coll, 2015; Bergquist *et al*., 2009; Boulanger *et al*., 2009; Kupferschmid, 2018; Szwagrzyk *et al*., 2020). Jelínek & Úradníček (2016) found that in the studied biocorridors, *Acer* spp. were the most damaged, followed by *Fraxinus excelsior* and *Carpinus betulus*, *Tilia cordata* and *Quercus* spp. Among shrubs, *Cornus sanguinea*, *Euonymus europaea* and *Ligustrum vulgare* were the most damaged.

Damage of woody plants may be compounded by increased nitrogen content in the sprouts (due to its high content in the soil) and lower monoterpene content, as such plants are preferred by herbivores (Champagne *et al.*, 2021, Löyttyniemi, 1985; Ball *et al.*, 2000). In addition, the new sprouts (which replaced the browsed ones) had higher nitrogen and phosphorus contents compared to the common ones, which increased their attractiveness (Löyttyniemi, 1985; Edenius *et al.*, 1993). Higher damage in previously browsing individuals has been demonstrated by a number of other authors (Duncan *et al.*, 1998; Bergquist *et al*., 2003; Senn & Suter, 2003; Pépin *et al*., 2006).

In some biocorridors, a plastic shelter was used for the protection of transplants against game. One example is the Křižanovice biocorridor, where the game damage was between 7 % and 51 % (Jelínek & Úradníček, 2016).

In addition to ungulate game, plantations can also be significantly damaged by hares and rodents (Crosby & Self, 2016). In the Vracov biocorridor, the browsing of roe deer and hares was not distinguished. In other TSES composition parts, it has been detected in fenced plantations in the range of 11–61 % (Jelínek & Úradníček, 2016). The cause was the use of mesh with large open areas. Incidences of rodent damage to transplants in the TSES were not reported in the literature, nor was this damage observed in the Vracov biocorridor.

If we compare growth in the two PRPs, it is clear that the trees grew better in PRP 2 throughout the monitoring period. With the exception of *P. avium*, the difference in tree height between the PRPs was not significant in 1993. There was no significant difference between the heights of *Prunus padus* in 2021 due to their cutting. The differences in growth between PRPs are due to better soil conditions and water availability. For *Q. robur*, *T. cordata* and *P. avium*, the difference in mean height is 7.28, 7.69 and 7.45 m respectively. The difference in mean height of *A. campestre* a *P. padus* is smaller, 2.32 and 1.33 m.

The DBH differences among PRPs were significant in 1993 only for *P. avium*, which also had significant differences for height. In contrast to height, the DBH differences remained in 2021. The smallest DBH difference was for *A. campestre* (11 mm) and the largest was for *T. cordata* (116 mm).

There are also large differences between the growing stock with bark in the PRPs. The largest difference is for *T. cordata* (90 vs. 230 m^3/ha). The stock in PRP 1 is determined by the parameters of two individuals and cannot be considered too precise. On the other hand, for *P. avium* and *Q. robur,* the difference is also large in correspondence to differences in yield class: 100 vs. 230 m^3/ha and 120 vs. 220 m^3/ha. In the case of *A. campestre,* which grows in the understory, the difference in stock is much smaller, at 65 vs. 100 m^3/ha.

There is not much information on the growth of trees on former agricultural land. Cukor et al. (2022) monitored stands of *Q. robur* and *T. cordata* on former farmland in cooler and wetter territory. In the fourteen-year-old stand, *Q. robur* had a mean height of 6.9 m (worse growth compared to PRP 1) and a DBH of 84 mm. *T. cordata* had a mean height of 10.9 m (better growth compared to PRP 1) and a DBH of 93 mm (even in PRP 1, these species had a larger mean DBH). The stand volume (volume of solid wood with a diameter > 7 cm without bark) of *Q. robur* was 33.8 m^3/ha and T. cordata 145 m^3/ha. *Q. robur* had higher stand volume in both PRPs. T. cordata, on the other hand, had a smaller stand volume in PRP 2 (130 m^3/ha).

The dominant *Q. robur* in a mixed thirty-three-year-old stand in Denmark had a mean height of 14.4 m. All conifers in the same stand had a greater mean height (Callesen *et al.*, 2006). This is a smaller mean height than PRP 2. In fifteen-year-old stands in Lithuania, the mean height of *Prunus avium* was 5.5–7.8 m, *Quercus robur* 2.6–6 m a *Tilia cordata* 3.3–8.8 m. DBH was 5.2–11.4 cm, 2.8–6.6 cm and 4–11.8 cm (Daugaviete *et al.*, 2015). Tree growth was dependent on habitat conditions and was worse than in the Vracov biocorridor.

Prunus avium in mixed stands on former arable land had a mean height of 1.1–1.3 m at the age of four years, 3.7–4.5 m at the age of ten years and 5–5.8 m at the age of thirteen years (Bartoš *et al.*, 2015). The lower mean height compared to PRP 1 was due to competition from other tree species.

Agricultural land was also afforested with other tree species. For example, Cukor *et al*. (2017) evaluated tree growth in an approximately sixty-year-old stand dominated by *Alnus incana*, *Betula pendula*, *Fraxinus excelsior*, *Larix decidua* and *Picea abies*. The mean height of the stands was 13–30 m, the mean DBH was 17–43 cm and the stand volume was 313–678 m^3/ha. In stands of the same age, *Alnus glutinosa* had a mean height of 16–23 m and a DBH of 22–29 cm and *Alnus incana* had the mean height of 17–20 m, a DBH 29–32 cm (Vacek *et al.*, 2016). *Fagus sylvatica* had a mean height of 22.1 m and a mean DBH of 21.8 cm in a fifty-year-old stand (Štefančík, 2019). Species other than those on PRPs have been dealt with in the Czech Republic, such as in Bartoš *et al*. (2006), Bartoš & Kacálek (2011), Cukor *et al*. (2019), Jan *et al*. (2017) and Podrázský *et al*. (2011).

Two sizes of transplants were used in the establishment of the Vracov biocorridor. Saplings with trained crowns had a larger mean height at the beginning (significant difference), but the height difference gradually decreased. After about eight years, the heights equalised, and the differences were not statistically significant. This shows that the use of saplings with trained crowns is not justified in terms of the long-term development of the stand. This was confirmed in other biocorridors (Jelínek & Úradníček, 2010b), and the same conclusion was reached by Dostálek *et al*. (2009, 2014).

CONCLUSION

Based on the results obtained, it can be concluded that all the tree species used in the establishment of the biocorridor have proved their worth. Their growth can be assessed positively. Since there is not enough data in the literature on the growth of the studied species under similar conditions on agricultural land, it is practically impossible to compare the results obtained. Therefore, the obtained results can be evaluated as basic for further research and used as material for possible comparisons in the future. Without evaluating the growth of woody species in other biocorridors, it is not possible to generalise the results.

Further research needs to focus on answering several important questions. For now, it is unclear how much stress is caused by recurrent droughts and how it will affect woody plants vigour and growth in the future. It is also unclear how the vigour of woody plants in the biocorridor will be affected by fungal pathogens. These disturb roots and conductive tissues, which may significantly exacerbate the effects of water scarcity. It is, therefore, necessary to continue the research and the further assessment the development of the woody plants carried out interdisciplinary.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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