Occurrence and use of tree species in the Hardtwald forest stands close to the city of Karlsruhe compared to the early 19th century

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Research

Abstract

Background: Forest use in Central Europe has changed significantly in the last centuries. This is particularly the case near settlements, where, apart from wood production, forest use has changed from agricultural use to recreational use. The aim of the study was to compare the differences in tree species composition resulting from the changes in forest use in an urban forest close to the city of Karlsruhe, Germany. Additionally, this study aims to summarize changes in the usage of frequently occurring tree species. Furthermore, the extent to which the use of the species mentioned in the book compares with other regions in the world was examined.

Methods: Historic information on tree species occurrence and usage was derived from C. C. Gmelin's "Nothülfe gegen Mangel aus Mißwachs" (Emergency Relief Against Deficiencies in Growth), an ethnobotanical work from 1817 and herbarium specimens. Information on recent species composition and usage was assessed in field surveys, and a literature survey.. For ethnobotanically useful species historical and recent occurrences and usage were compared and discussed .

Results: Our results indicate a decline in ethnobotanically useful tree species in the last two centuries. Most prominently species from the Rosaceae and other tree species used due to their fruits were absent in the current survey. This indicates a changed species composition compared to 1817 within the Hardwald forest. The change in the species composition can be attributed primarily to the shift in forest use compared to earlier times, as well as to the different environmental conditions. A decline in stone fruit species and an increase in "future tree species" can be observed, as these are better adapted to the changed conditions.

Conclusions: The use of the Hardwald forest has changed from a commercial forest with livestock farming to a local recreation area according to PEFC standards. It can be determined that 52.17% of the species in other areas are still used according to the possibilities presented in Gmelin's book.

Keywords: 19th century ethnobotany, vegetation. change, usage change,, Germany, Baden-Württemberg, Karlsruhe

Background

Forest use in central Europe has changed in the last centuries. However, only few studies exist that study the effects of this change in forest use on the occurrence of tree species.

One method to analyze historical species occurrences is the analysis of herbarium specimens. Research with herbarium materials is relevant in various fields of the natural sciences. From phenology, land use and restoration ecology (Landshut and Schäfer, 2017) to biochemistry (Yoshida et al., 2013) and data on climate change (Lang et al., 2018), herbaria play a major scientific role in various fields. The Senkenberg Museum's herbarium data on algae are currently of great importance for the bioeconomy for the production of petroleum and kerosene (University of Göttingen, 2024). The 2021 newspaper article by Harris, Mulligan, and Brummit presents a six-step method "that enables the use of herbaria data to create a spatial model of functional diversity metrics at the continental scale" (Harris et al., 2021). The article highlights the importance of herbaria for observing plant traits over time in different areas. Furthermore, herbarium specimens often represent to only available source of information about historical species occurrences and therefore have frequently been used to study vegetation change (cite)Herbarium specimens also make a crucial contribution to this work, creating a reconstruction of the forest stand in the Hardtwald forest near Karlsruhe around 1817 and demonstrating the difference to today's species occurrence.

Not only forest use, but also the usage of individual plant species has changed in the course of the time… Old books provide knowledge on historical use of plants. Here we use C. C. Gmelin's "Nothülfe gegen Mangel aus Mißwachs" The title of this book could be translated in today's language as "What to do in the event of severe crop failures?" Carl Christian Gmelin (1762-1837) published his guide at a time when the still young Grand Duchy of Baden was struggling with particularly serious social, economic, ecological, and political conflicts, after the preceding Napoleonic Wars, with their huge loss of human life and the destruction of rural livelihoods, the economic consequences of the Continental Blockade against the British Empire, and the tremendous food shortages due to the weather-related crop failures in 1816 and 1817, as direct effect caused by the Tambora volcanic eruption in Indonesia in 1815.

The aim of our study was to compare and evaluate the historical and recent occurrence and use of tree species in the Hardtwald, close the city Karlsruhe. The analysis was based on the hypothesis that the peri urban forests, close to Karlsruhe, have undergone fundamental changes due to different forest use. We use Information from C. C. Gmelin's "Nothülfe gegen Mangel aus Mißwachs" (Emergency Relief Against Deficiencies in Growth) of 1817 and herbarium specimens to reconstruct historical species composition. Information on current species composition was derived from field sampling. with the current forest stands of the Hardtwald Forest, south of the Adenauerring in Karlsruhe, near the Karlsruhe Institute of Technology and the castle park.

Materials and Methods

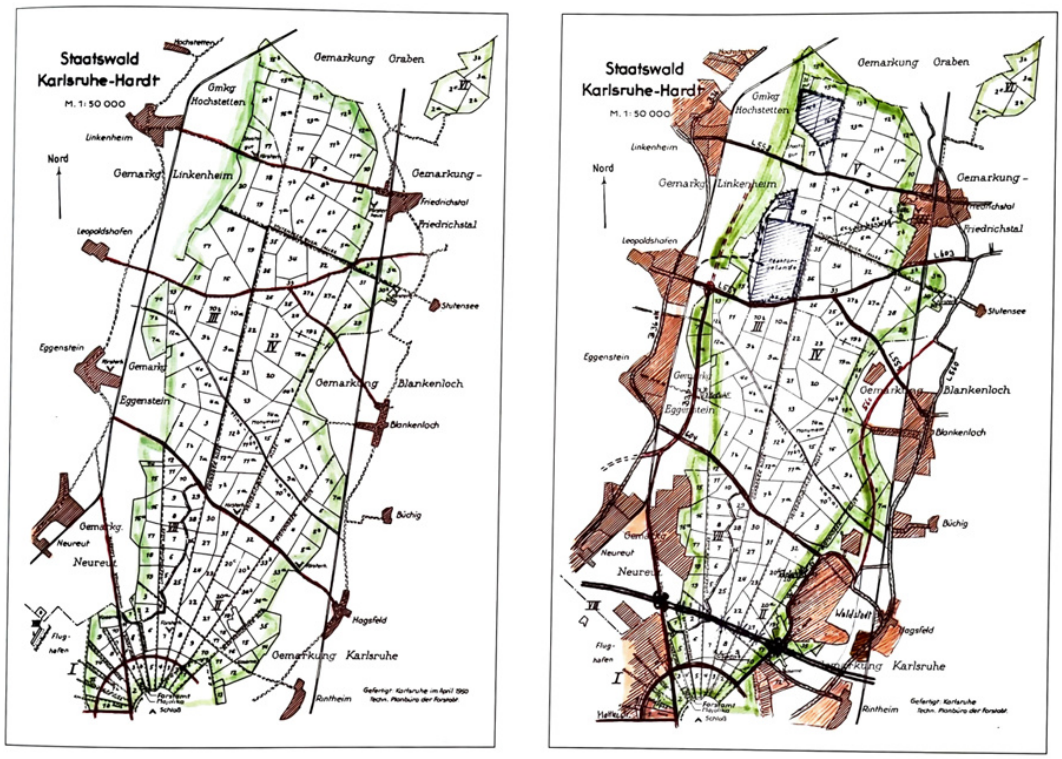
Study area

The area today

The Hardtwald is located in the Upper Rhine Valley, close to Karlsruhe, Germany. Today, the area is considered a landscape conservation zone and part of the Natura 2000 protected area network (Karlsruhe, 2024b and LUBW, 2024a, 3:19 p.m.). The Hardtwald forest in the north of Karlsruhe is characterized by an oak-beech forest (LUBW, 2024b and Karlsruhe, 2024b). Rare beetles can also be found there, especially in the pheasant garden, such as the great longhorn beetle (Karlsruhe, 2024b). Since 2021, the area has been a PEFC-certified local recreation area (Karlsruhe, 2024a). The study area is characterized by a temperate oceanic climate with a mean annual temperature of 11ºC and mean annual precipitation of 780mm (Figure 4). Historical climate data shows a 10-year average temperature gradient of 1.1 K from 1811 to 2000 (climate diagrams, 2010) (Figure 5).

The soils in the Hardtwald forest in the north of Karlsruhe are characterized by terra fusca / brown earth and a partially podzolic brown earth, i.e., sandy, dry, acidic, and nutrient-poor (LGRB, 2024 and Blum, 2004, p. 38f.). The groundwater table is several meters deep, making it difficult for plants to reach the water with their roots (Blum, 2004, p. 38f.) (Fig. 1,2). Figure 3 on the left shows a soil profile of the study area at a scale of 1:10,000 (LGRB, 2024). The colors displayed there represent, on the one hand, dark brown, a cambisol, partly terra fusca cambisol, and gleyic cambisol from river and meltwater gravel. On the other hand, light brown represents a cambisol with some podzolization from fluvial sands (LGRB, 2024 and Blum, 2004, p. 38f.). Figure 3 on the right, at a scale of 1:50,000 (LGRB, 2024), shows a geological map of the study area. The light blue color symbolizes Quaternary freshwater deposits (Fig. 3). The fertility of a cambisol as an arable or forest soil depends on its parent rock and therefore varies across a wide spectrum. Deep and loamy cambisols can store a lot of water for plants,

while shallow, sandy, or stony ones can store only a little" (Lfu Bayern, 2024). The Hardtwald forest and the study area are located in the Upper Rhine Graben. The geology is partly characterized by Quaternary freshwater deposits from the Upper to Middle Jurassic. A rock layer from the Northern Black Forest Gneiss Group is also present. (LGRB, 2024). We used the parts of the Hardtwald (48.9956° N, 9.3287° E) closest to the city center as study area.



▸ SIEDLUNGSENTWICKLUNG IM BEREICH DES HARDTWALDS UM 1950

▸ SIEDLUNGSENTWICKLUNG IM BEREICH DES HARDTWALDS UM 1980

Figure 1. Development of the area around the Hardtwald, Source: Blum, 2004, p. 15

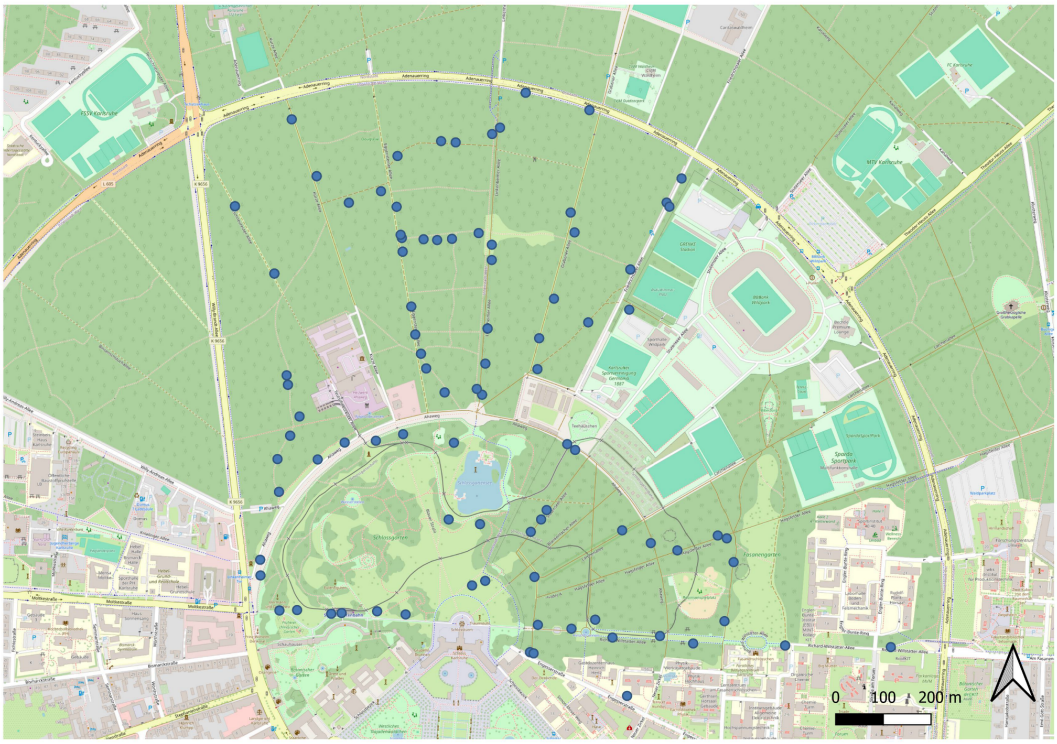


Figure 2. All data points recorded in the study area

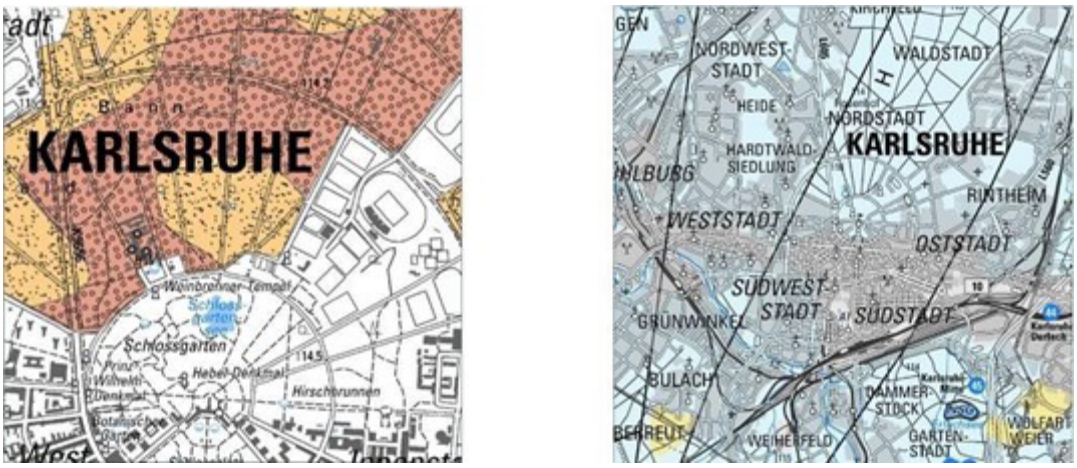


Figure 3. Soil and geology of the study area, left: soil, scale 1:10,000; right: geology, scale 1:50,000; Source: LGRB

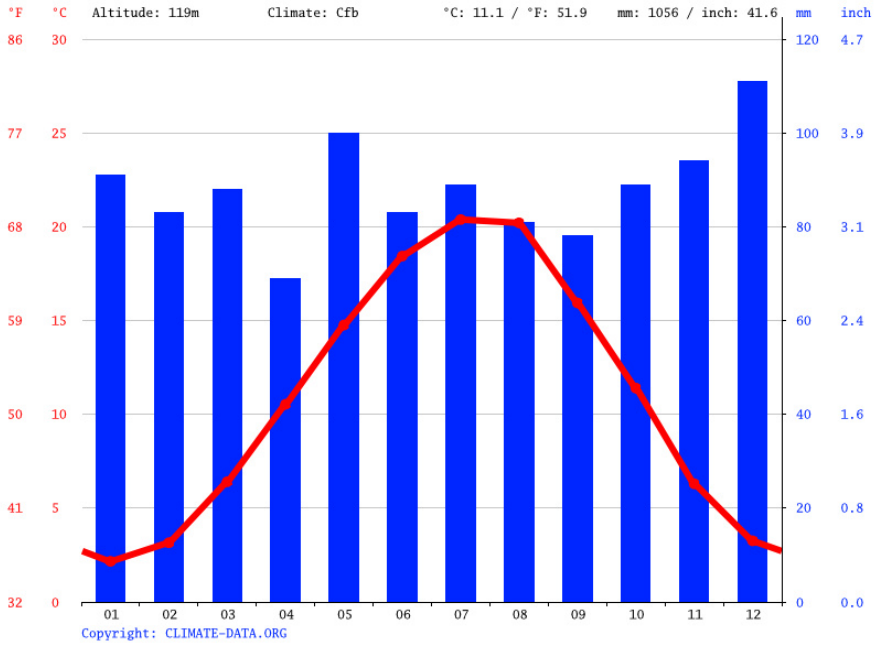


Figure 4. Köppen climate diagram (ClimaData, as of August 7, 2024, 2:37 p.m.)

10-jähr. Mittel:	Jan	Feb	Mrz	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	Jahr
1801-1810 [°C]	0.5	2.3	5.0	9.5	15.7	17.7	19.9	19.7	15.4	10.2	5.2	2.5	10.3
1811-1820 [°C]	-0.3	3.3	5.9	11.0	15.3	17.4	18.7	18.3	15.5	10.4	4.8	1.2	10.1
1821-1830 [°C]	-0.6	2.1	6.8	11.6	15.7	18.4	20.4	19.5	16.3	10.9	6.0	3.3	10.9
1831-1840 [°C]	0.3	2.9	5.5	9.6	15.2	18.8	19.9	19.3	15.7	10.8	5.6	2.2	10.5
1841-1850 [°C]	-0.1	2.7	5.8	10.8	15.6	18.7	19.6	19.1	15.6	10.7	6.1	1.9	10.6
1851-1860 [°C]	1.6	1.4	4.9	9.6	13.7	18.4	19.5	19.4	15.0	10.7	3.7	1.3	9.9
1861-1870 [°C]	0.5	3.2	5.0	10.7	15.0	17.6	19.4	18.2	15.3	9.8	4.9	1.1	10.1
1871-1880 [°C]	0.7	2.4	5.7	9.9	12.8	17.4	19.3	18.6	14.8	9.4	4.6	0.5	9.7
1881-1890 [°C]	0.4	1.9	4.8	9.4	14.3	17.6	19.0	17.8	14.2	8.7	5.5	1.2	9.5
1891-1900 [°C]	-0.1	2.4	5.5	10.0	13.6	17.7	19.1	18.5	14.9	9.8	5.3	1.7	9.9
1901-1910 [°C]	0.7	2.1	5.6	9.5	14.0	17.5	19.0	18.0	14.2	10.0	4.5	2.3	9.8
1911-1920 [°C]	1.8	2.7	6.4	9.4	15.1	17.2	18.5	18.0	14.3	8.9	4.8	3.6	10.1
1921-1930 [°C]	2.1	2.6	6.0	9.7	14.5	17.2	19.7	18.0	15.1	10.5	5.0	2.0	10.2
1931-1940 [°C]	1.7	2.1	5.8	9.7	14.4	18.1	19.3	18.7	15.2	9.6	6.0	0.8	10.1
1941-1950 [°C]	0.0	1.5	5.6	10.6	14.2	17.4	19.7	19.0	15.4	10.1	4.8	1.4	10.0
1951-1960 [°C]	1.1	1.4	6.1	9.7	14.3	17.5	19.4	18.2	15.0	9.7	5.2	3.0	10.1
1961-1970 [°C]	0.6	2.4	5.2	10.4	14.1	17.8	19.2	18.2	15.5	10.7	5.4	0.9	10.1
1971-1980 [°C]	1.6	3.3	6.4	9.4	14.2	17.4	19.3	18.8	15.0	9.6	5.3	2.7	10.3
1981-1990 [°C]	1.5	1.8	6.5	9.9	14.6	17.3	20.2	19.5	15.7	11.0	5.2	3.1	10.5
1991-2000 [°C]	2.6	3.5	7.5	10.9	15.4	18.3	20.7	20.7	15.7	10.5	5.7	3.2	11.2

Figure 5. Overview of the historical 10-year average in Karlsruhe (climate diagrams, 2010).

History of the Hardtwald Forest

In 1715, Karlsruhe Palace and the adjacent town were founded by Margrave Karl-Wilhelm. Part of the complex were individual large enclosures stretching across the Hardtwald from Karlsruhe to Graben-Neudorf. Before 1915, this game park was only accessible on special occasions, such as timber auctions or in times of need to collect leaves and litter for the animals (Blum, 2004, p. 14).

After the revolution of 1918, the major "extension" began: many areas were cleared for agricultural purposes, but the continuous forest structure was largely preserved until World War II. After that, the city and surrounding villages continued to expand, at the expense of the forest (Blum, 2004, p. 15 f.).

In the 1930s, the then forester implemented the Philippian wedge cut. This regeneration program, geared to the typical wind direction of the Hardtwald, included the reforestation of young trees in the lee of older and larger trees to protect them from stronger winds (Blum, 2004, p. 18). In 1956, the Hardtwald became a research location, as construction of the Karlsruhe Research Center began that year" (mein KA, 2019). Today, the former research center forms part of the KIT's North Campus.

In the past, domestic animals were allowed to "graze in the Hardtwald forest and prevented the regeneration of the tree layer by grazing; fallen leaves, ground plants, and mosses were gathered together and used as bedding in the stables" (Blum, 2004, p. 52), which led to soil depletion.

Pheasant Garden

The Pheasant Garden, located close to the city of Karlsruhe and represents the eastern part of the palace gardens and borders the Wildparkstadion and the Hardtwald (Karlsruhe, 2024). In 1714, the hunting lodge was built on the "Bocksblöße" (Bocks Blöße) next to the palace park. This laid the foundation for the first peasantry. The pheasant garden encompassed 108 hectares and was built west of the future palace. By 1750, it was home to 500 pheasants and 15 peacocks (Blum, 2004, p. 20 ff.).

Over the years, however, the pheasant garden shrank due to the construction and expansion of the Dragoon Barracks in 1803 and the construction of the Technical University in 1836. From 1868 to 1873, the barracks were further expanded, and schools were built on the site, all at the expense of the garden (Blum, 2004, p. 24). Today, the State Forestry Office in Karlsruhe manages the pheasant garden park. The forestry school in the pheasant garden has become an educational center of the Baden-Württemberg State Forestry Administration with a wide range of responsibilities. (Blum, 2004, p. 26). Furthermore, it now represents one of the main thoroughfares for pedestrians, cyclists, and visitors of all kinds, and is a popular green oasis in the heart of the city.

Parts of the Hardtwald are designated as protected area under the EU's Habitats Directive (FFH). The forest plays an important role as a fresh air corridor, for the inner-city and the water supply of Karlsruhe. The forest stands are regularly managed: old trees are replaced by young ones, while others are removed to avoid limiting the light resources for the young trees. (Blum, 2004, p. 26 ff.)

Data Collection

The selection of species was limited to woody species of the Rosaceae, Sapindaceae, Oleaceae, and Fagaceae families. The selection of species did not follow a specific pattern; instead, all tree species discussed in Gmelin's work were filtered and examined. Various sources were used to collect the data. Herbarium specimens were sorted and evaluated as the first source. The sorting was based on the specimen's location. Karlsruhe, the Stadtgarten, and Hardtwald forest, as well as all available years, were of particular interest. In addition, the interactive distribution map of the Flora of Baden-Württemberg from the Natural History Museum in Stuttgart was used, and the corresponding quadrant (6196) was analyzed (Baden-Württemberg, 2024b). The appropriate quadrant was determined using a coordinate finder (Baden-Württemberg, 2024a). To obtain the distribution map data, the respective Latin species name was entered into the search bar and the corresponding quadrants were selected. The displayed data was then imported into an Excel list and graphically displayed using QGIS. More information can be found in the section on analysis with QGIS. The subsequent survey took place over three days (April 11, 12, and 16, 2024) and included mapping the species to be studied. For this purpose, a map of the area was inspected and printed, and a list of the tree species to be studied was created. In the field, the focus was on recording and numbering the species and entering them into the list along with their coordinates. This data was later transferred and analyzed using the Excel Data Analysis add-on (Figs. 2, 3). This was followed by the creation of a histogram of the average number of specimens, the abundance. Each tree mapped in the field was also recorded. The mapped points were graphically represented using

QGIS 3.36.1. The route extended exclusively along the paths. It started in the Pheasant Garden, continued southwest through the palace park, and from there along the paths in a linear fashion eastward until reaching the Wildparkstadion.

Literature Research

Finally, a literature search was conducted on the species studied. For this purpose, Google Scholar and the series "Ethnobotany of Mountain Regions" of the Caucasus, Central Asia and Altai, the Himalayas, Eastern Europe, and Uzbekistan were consulted. The historical data comes from the 1817 work "Nothülfe gegen Mangel aus Mißwachs" by C.C. Gmelin. This is a description of plants as a possible food source. In addition, the 2008 book "Erlebnis Hardtwald: Der Traum in Grün" by Patricia Blum was used as a source for information about the Hardtwald.

Data Evaluation

The Excel analysis is based on the average number of plants, abundance, and the environment. An abundance of 5 indicates a high density (more than 6 individuals), and an abundance of 1 indicates a single tree. 0 indicates the absence of the species, 2 represents two individuals, 3 represents three or more, and 4 represents a group of 5 to 6 individuals. The values were assigned based on the number of individuals and their frequency in their environment. Version 3.36.1 was used for the QGIS analysis. The analysis of the field data in QGIS is based on the distribution of species in the study area. First, an OSM map was integrated and a .txt file was created for each species, which were then also imported and displayed individually.

To evaluate the distribution map in QGIS, the quadrants of Baden-Württemberg were first loaded as a shape file along with an OSM map. The required quadrants were then colored one after the other as polygons and could thus be addressed as needed.

Results and Discussion

Inspired by the ethnobotanical work of C. C. Gmelin, the occurrence and use of ethnobotanically useful species are compared with the early 19th century. At the same time, a comparison of their use with the type of use in other regions of the world is sought.

Assessed species

1. *Acer platanoides* L. (Sapindaceae)
2. *Acer pseudoplantanus* L. (Sapindaceae)
3. *Aesculus hippocastanum* L. (Sapindaceae)
4. *Castanea sativa* Mill. (Fagaceae)
5. *Crataegus laevigata* Gand. (Rosaceae)
6. *Crataegus monogyna* Jacq. (Rosaceae)
7. *Cydonia oblonga* Mill. (Rosaceae)
8. *Fagus sylvatica* L. (Rosaceae)
9. *Fraxinus excelsior* L. (Oleaceae)
10. *Malus domestica* (Suckow)Borkh. (Rosaceae)
11. *Mespillus germanica* (L.) Kuntze (Rosaceae)
12. *Prunus avium* (L.) L. (Rosaceae)
13. *Prunus cerasus* L. (Rosaceae)
14. *Prunus domestica* L. (Rosaceae)
15. *Prunus insititia* (L.) Bonnier und Layens (Rosaceae)
16. *Prunus serotina* L. (Rosaceae)
17. *Prunus spinosa* L. (Rosaceae)
18. *Pyrus communis* L. (Rosaceae)
19. *Quercus robur* L. (Fagaceae)
20. *Sorbus aria* M.Roem (Rosaceae)
21. *Sorbus aucuparia* L. (Rosaceae)
22. *Sorbus domestica* Spach (Rosaceae)
23. *Sorbus torminalis* (Gand.) Sennikov und Kurtto (Rosaceae)

While all species were common in the 18. and 19. centuries, presently only nine species were found in the area, all of them forest species common in the region. In striking contrast, many species, especially Rosaceae that formerly were widely used for food purposes, have completely disappeared from the Hardtwald forest (Table 1).

Table 1. Results of the survey

Species present		**Species absent**	
Acer platanoides		*Castanea sativa*	
43	3,36	0	0
Acer pseudoplatanus		*Cydonia oblonga*	
14	3,21	0	0
Aesculus hippocastanum		*Fraxinus excelsior*	
14	1,57	0	0
Crataegus laevigata		*Malus domestica*	
1	1	0	0
Crataegus monogyna		*Mespilus germanica*	
4	1,5	0	0
Fagus sylvatica		*Prunus cerasus*	
8	1,75	0	0
Prunus avium		*Prunus domestica*	
10	1,8	0	0
Prunus serotina		*Prunus insititia*	
12	2	0	0
Quercus robur		*Prunus spinosa*	
4	1	0	0
		Pyrus communis	
		0	0
		Sorbus aria	
		0	0
		Sorbus aucuparia	
Total: 9		0	0
		Sorbus domestica	
		0	0
		Sorbus torminalis	
		0	0
		Total: 14	

Left: Number of specimens found in the field; Right: Abundance of specimens in the field

Similarly, most species that were widely used in the 18. and 19 centuries had completely lost their use in current times, even if the species were still present in forest stands, indicating a profound loss of traditional uses (Table 2).

Table 2. Comparison of current occurrence and current use based on historical models

Occurrence but no use	**Occurrence and use**	**No occurrence but previous use**	**No occurrence no use**
Acer platanoides	*Prunus avium*	*Cydonia oblonga*	*Castanea sativa*
Acer pseudoplatanus		*Fraxinus excelsior*	*Prunus domestica*
Aesculus hippocastanum		*Malus domestica*	
Crataegus laevigata		*Mespilus germanica*	
Crataegus monogyna		*Prunus cerasus*	
Fagus sylvatica		*Prunus insititia*	
Prunus seotina		*Prunus spinosa*	
Quercus robur		*Pyrus communis*	
		Sorbus aria	
		Sorbus aucuparia	
		Sorbus domestica	
		Sorbus torminalis	
Total: 8 / 34,78%	**Total: 1 / 4,35%**	**Total: 12 / 52,17%**	**Total: 2 / 8,70%**

While traditional use of tree species - apart from timber production – has mostly disappeared in Karlsruhe , we can still trace the use of such species to other parts of Europe (Table 3).

Table 3. Comparison of occurrence and use in other areas (Historical use: The species is still used in the areas under consideration according to the use listed in Gmelin's work)

Species was historically used in another area	Species not historically used in other areas
Aesculus hippocastanum	*Acer platanoides*
Fagus sylvatica	*Acer pseudoplatanus*
Fraxinus excelsior	*Castanea sativa*
Malus domestica	*Crataegus laevigata*
Prunus avium	*Crataegus monogyna*
Prunus cerasus	*Cydonia oblonga*
Prunus domestica	*Mespilus germanica*
Prunus insititia	*Quercus robur*
Prunus serotina	*Sorbus aria*
Prunus spinosa	*Sorbus domestica*
Pyrus communis	*Sorbus torminalis*
Sorbus aucuparia	
Total: 12 / 52,17%	**Total: 11 / 47,83%**

Some representative species

***Acer platanoides* L.**

Acer platanoides (Fig. 5) is a widely distributed species in the region and often planted as alley tree. General data are given in Table 4.

Figure 5. Herbarium specimen of A*. platanoides*

Table 4. Overview of *Acer platanoides*

Latin Name	***Acer platanoides* L.**
German Name	Spitzahorn
Family	Sapindaceae
Synonym	-
Topographic map quadrant	6916/1; 6916/2; 6916/3; 6916/4 (Stand:2023/2023/2019/2023)
Specimens found	43
Abundance	3,63
Herbarium vouchers	**17**
Past use	The leaves were used in dried form as winter fodder for cattle and sheep, young leaves were used for salads. (Gmelin, 1817, p. 138)
Present use	Timber cultivation for tools and bows (Göttingen, 2024); roads and shade trees (Caudullo and Rigo, 2016)
Use in other regions	Azerbaijan: The tree is used to treat liver and kidney problems and to treat purulent wounds. The leaves can also be used as a dye for wool. The wood is suitable for carpentry and woodturning, as well as for furniture and musical instrument making. Georgia: The flowers are used for tea. Adjara: The tree is used for chariot construction. (Mehdiyeva et al., pp. 77-84)

The distribution area of *Acer platanoides* extended originally across the entire Hardtwald forest and the adjacent areas. This was also reflected in newly collected survey data, where the species could be found throughout the entire area and was evenly distributed (Figure 6).

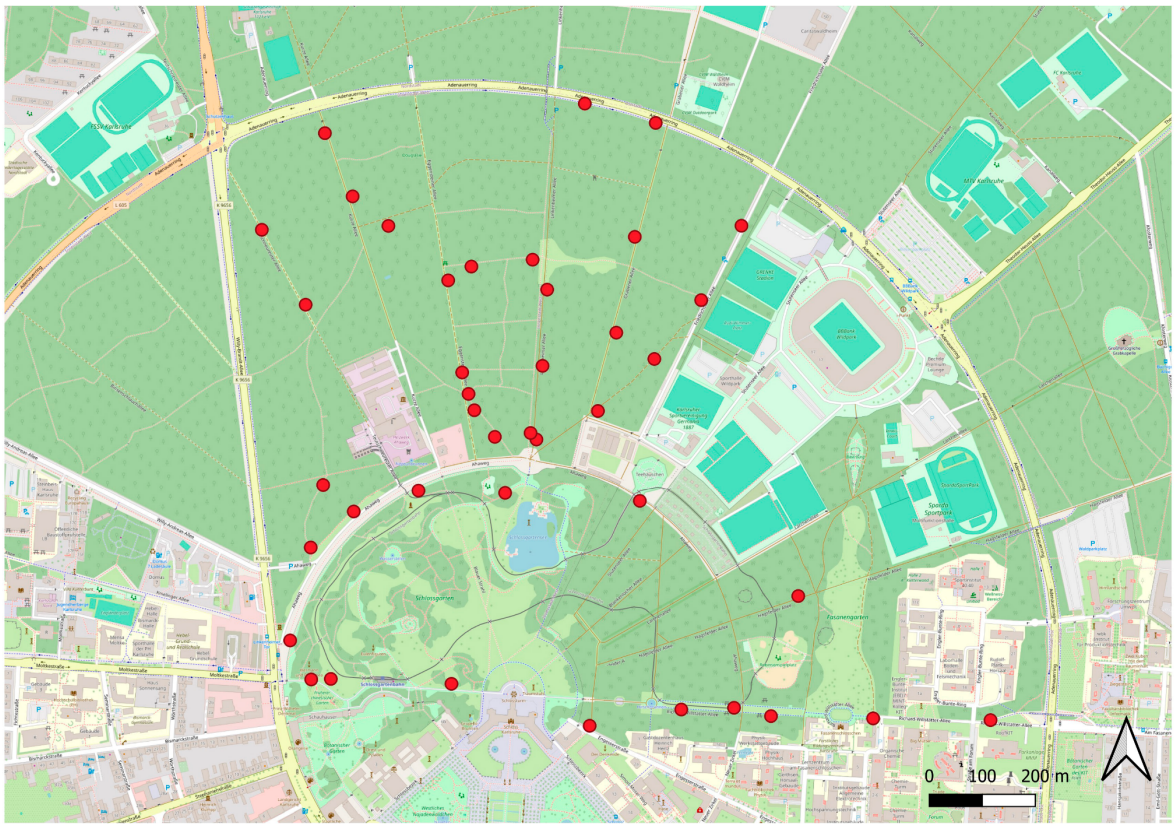


Figure 6. Distribution of *A. platanoides* in the study area

Acer platanoides prefers gravelly to clayey soils with a moderate nutrient content. A high humus content is also gratefully accepted. Calcareous soil variations are also accepted by the Norway maple (Schröder, 2024). This corresponds to the soil types found in the study area. It occurs there both in the more acidic podzolic cambisol and in the clay-rich terra fusca building soil (Figure 3). Thus, optimal conditions prevail, which is reflected in the species occurrence. As can be seen from the abundance distribution in Figure 7, the tree often occurs in the company of its own kind. However, this is not evident from the abundance. Figure 8 shows that specimens of *A. platanoides* were collected every 40 years. This suggests that this species has been present in our study area since at least 1850, the first herbarium specimen found. The species appears to be particularly common during Kneucker's collecting period around 1930. The analyzed quadrant 6916/1 and the current findings also show that the species has a constant occurrence.

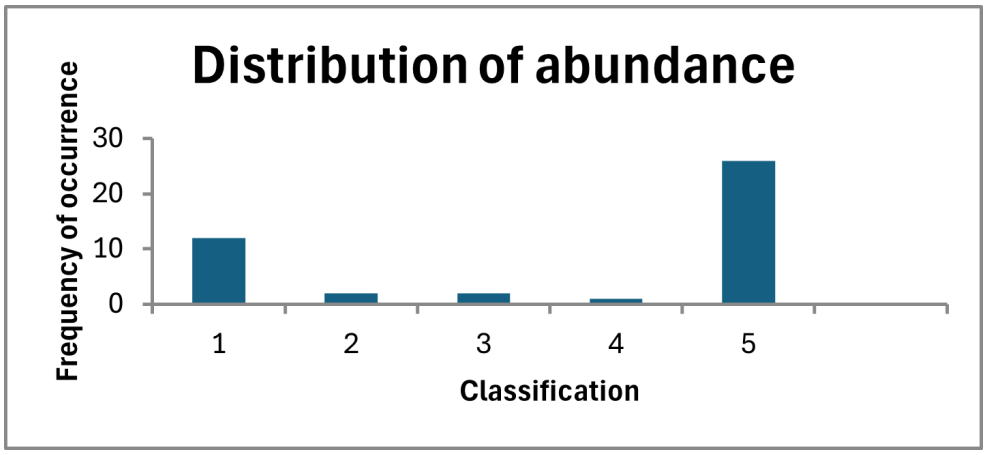


Figure 7. Abundance distribution of *A. platanoides*

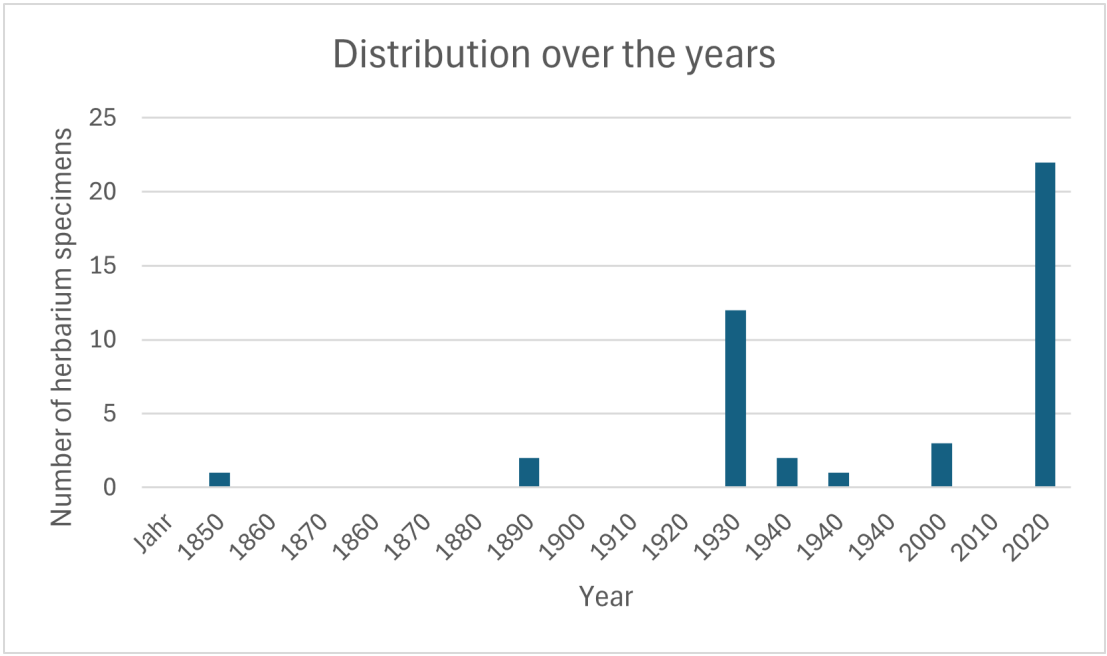


Figure 8. Distribution of specimens over the years of *A. platanoides*

From the available data, it can be deduced that the species has been present in the study area since around 1850 and is now used as a street and shade tree. Even today, the tree is still used for salads, but the flowers, not the young leaves, are used (Greiner, 2022). In Georgia, the flowers are also used, but for brewing tea. Furthermore, it can be deduced that the species has a relatively constant occurrence and use, both in Gmelin's time around 1830, when it was "frequently planted in pleasure grounds" (Gmelin, 1817, No. 138), and in 1850, when it can still be found in the palace gardens. Finally, it can be stated that the tree is still used and popularly planted today in a modified form, following its historical model.

***Fraxinus excelsior* L.**

Fraxinus excelsior (Fig. 9) was originally widely distributed in more humid areas in the region but suffered precipitous decline over the last decade due to Emerald ash borer (*Agrilus planipennis*). General data are given in Table 5.

Figure 9.Herbarium specimen of *Fraxinus excelsior*, Gmelin 181

Table 5. Overview of *Fraxinus excelsior*

Latin Name	***Fraxinus excelsior* L.**
German Name	Gemeine Esche
Family	Oleaceae
Synonym	-
Topographic map quadrant	6916/1; 6916/2; 6916/3, 6916/4 (Stand:2023/2022/2011/2023)
Specimens found	0
Abundance	0
Herbarium vouchers	5
Past use	The fresh and dried leaves are suitable as forage for goats, sheep, and cattle. The wood is suitable for turning and carpentry work as well as for wine barrels (Gmelin, 1817, p 139)

Present use	The wood is used for tool handles as well as for furniture and flooring. The leaves are used as animal feed in winter. In addition, the bark can be used to tan calf leather. The species is also used as street tree. (Beck et al., 2016)
Use in other regions	Urals and North Caucasus: The boiled leaves are used to heal wounds, treat diarrhea, and other illnesses. Central Asia: It is used as a hemostatic agent. The leaves and fruits are pickled and eaten. The wood is used as a building material in construction and shipbuilding. It can also be used for musical instruments and as animal feed. The species serves as an ornamental plant, and dyes can be extracted from it. (Sher et al., 2021)

The distribution area of *Fraxinus excelsior* originally extended across the study area and the adjacent areas. However, no individual specimens were found during the field survey. This could be due to the widespread ash dieback of 2022, which also affected parks and street trees (Kowalski et al., 2010). The soil conditions are also unsuitable, as the species prefers alkaline (R7) and nitrogen-rich (N7) soils (Müller et al., 2021 p. 677 and Kraft, 2021 p. 30), and the study area tends to have more acidic soils (Figure 3). As shown in Figure 10, it has been found in the present day, as well as in the 1800s. It is possible that the trees listed in the 2020s have since succumbed to the disease and are therefore no longer found in the study area.

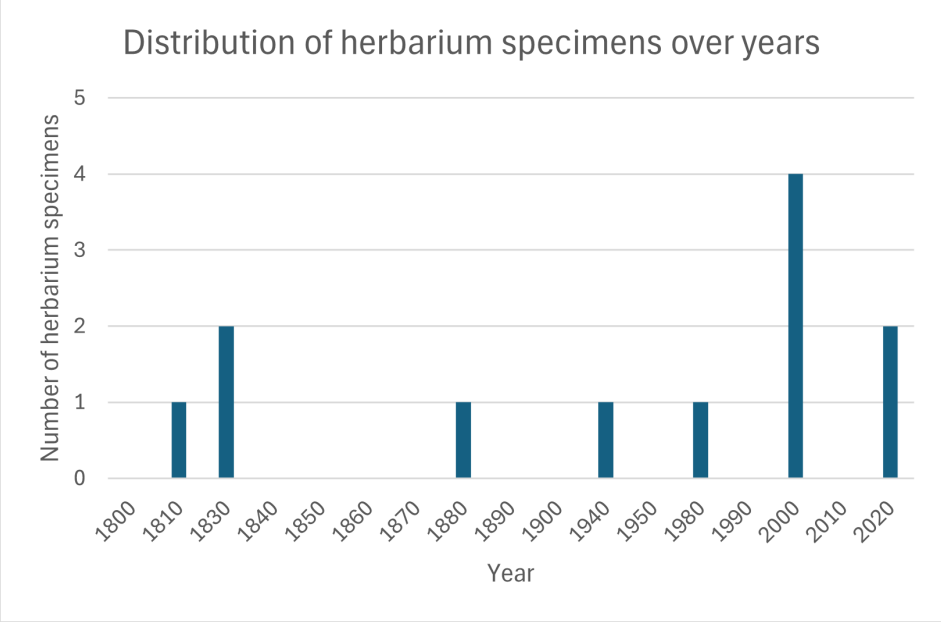


Figure 10. Distribution of specimens over the years of *F. excelsior*

The wood was used both in the past and today as a material for furniture and other objects. The leaves are also still used as fodder. However, its medicinal use for gastrointestinal complaints is not yet widespread and appears to be limited to the Urals and the North Caucasus. Its use as an ornamental and street tree also overlaps with other regions of the world.

***Prunus serotina* L.**

Prunus serotina (Fig. 11) was originally widely distributed in region. General data are given in Table 6.

The occurrence of the species can be verified from the 1800s onwards through herbarium specimens and in the 2020s through finds. It is striking that there is a lack of occurrence after the 1940s (Figure 12).

The herbarium specimens identified demonstrate a fairly constant occurrence of the species in the study area since the 1800s, with a temporal gap between the 1950s and the 2010s. Figure 13 shows that the species occurs primarily in the center of the study area. According to the soil distribution map (Figure 3), this area is primarily a partially podzolic cambisol, which has an acidic character and thus precisely meets the needs (Müller et al., 2021 p. 432 and Kraft, 2021 p. 41) of the species (WUH, 2015). The surrounding area is dominated by terra fusca soil, a very clayey soil type. This does not correspond to the species' suitable conditions (WUH, 2024Twelve individuals with an abundance distribution of 2 (Figure 14) were identified during the field survey, thus indicating a low occurrence in group stands.

Figure 11. Herbarium specimen of *Prunus serotina,* Gmelin, May 24, 1814

Table 6. Overview of *Prunus serotina*

	***Prunus serotina* L.**
German Name	Virginische Traubenkirsche
Family	Rosaceae
Synonym	Prunus virginiana
Topographic map quadrant	-
Specimens found	12
Abundance	2
Herbarium vouchers	12
Past use	The ripe fruits are processed into cherry spirit. The wood is used for turning and carpentry. (Gmelin, 1817, No. 57)
Present use	The fruits serve as a food source for wildlife (Marquis, 1990). The species can be used in food, pharmaceutical, and cosmetic products (Telichowska et al., 2020).

Use in other regions	Southern Appalachians: The bark of young trees is used as a cough suppressant, tonic, and sedative. The fruits are also used to make jelly and wine. Rum or brandy can also be flavored. (Marquis, 1990)

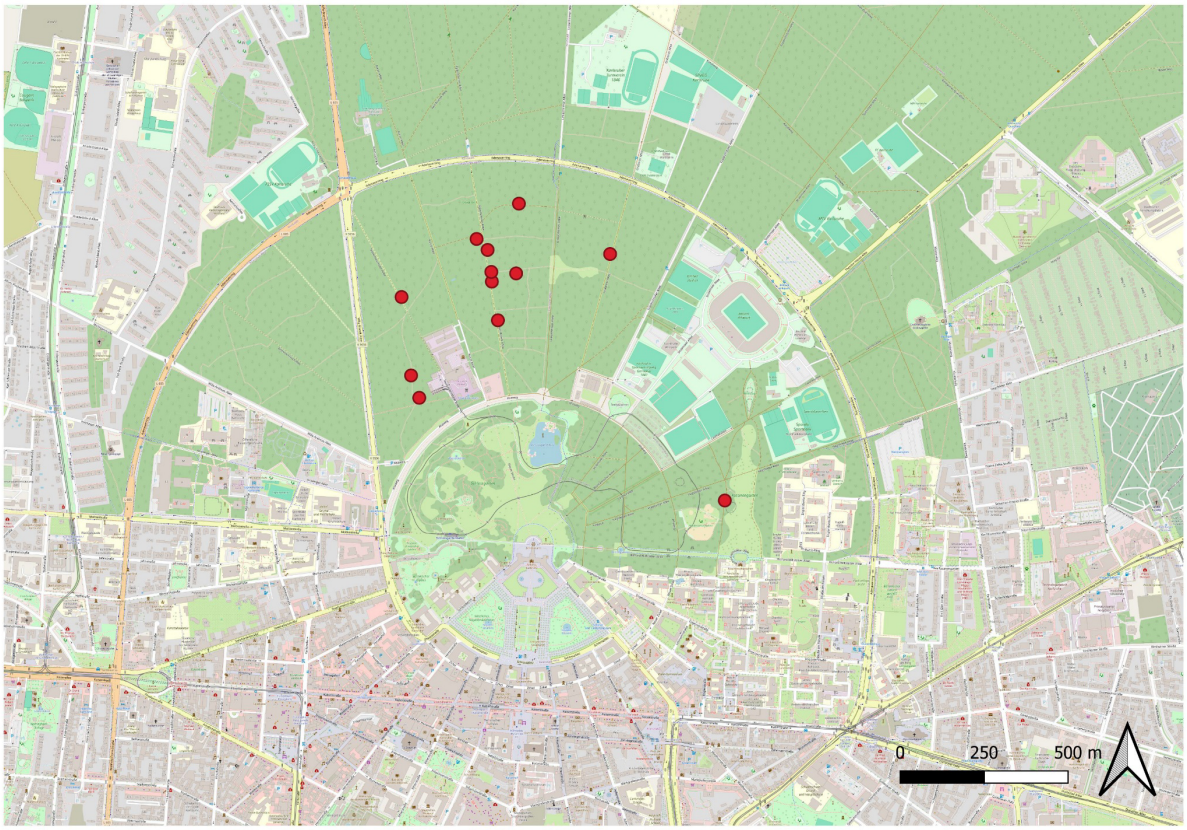


Figure 12. Distribution of *Prunus serotina* in the study area

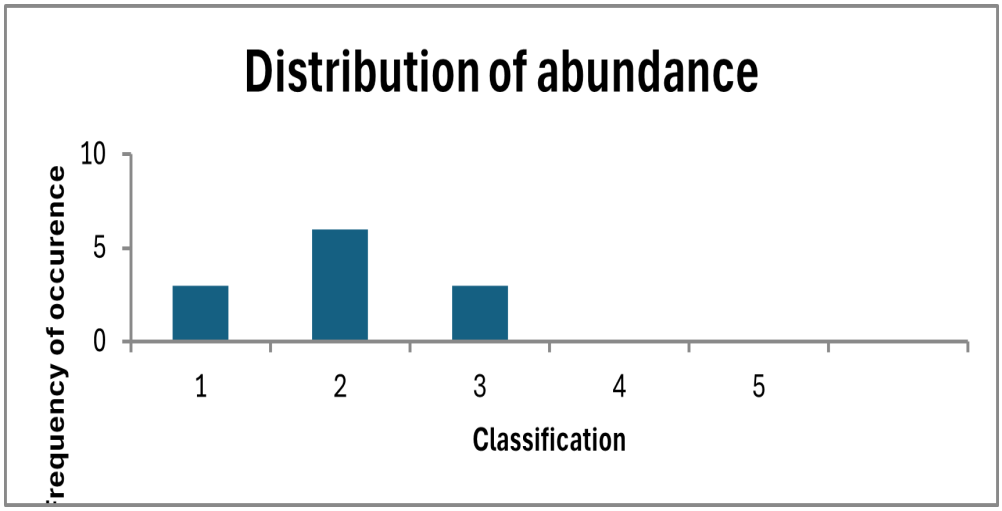


Figure 13. Abundance distribution of *P. serotina*

In the past, the fruits were processed into church spirit. This is still used today in the southern Appalachians. There, the bark of young trees is also used for medicinal purposes (Marquis, 1990). The medicinal benefits have also been recognized in our latitudes and are also used in cosmetics (Telichowska et al., 2020).

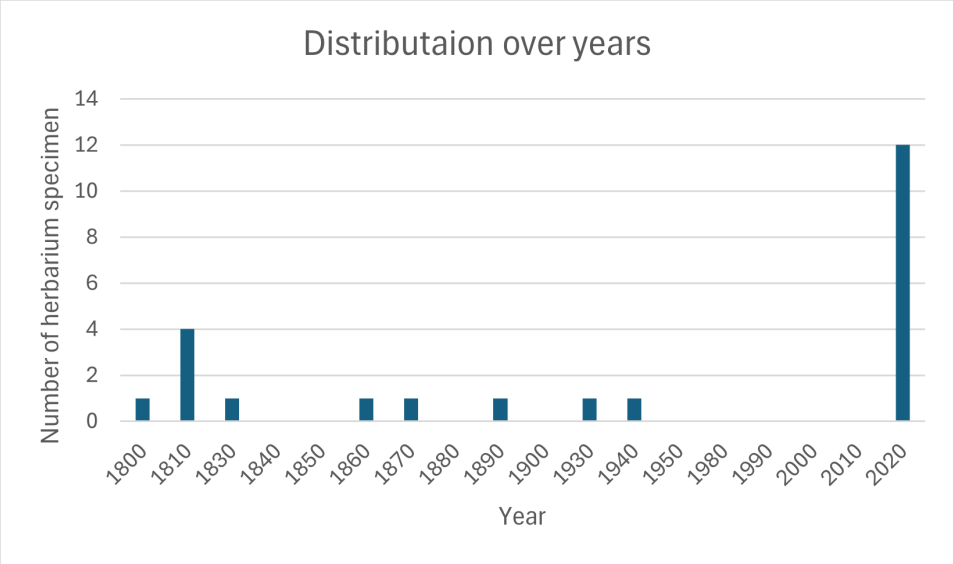


Figure 14. Distribution of specimens over the years of *P. serotina*

An overview historic and present uses of all species is given in Table 7. A complete overview on herbarium vouchers is featured in Table 8, and a comparison of available vouchers to present day mapping and collections is given in Table 9.

Discussion

How has the occurrence of tree species from Gmelin's "Emergency Relief" changed from 1817 to today?

Currently, only 39.13% (Table 4) of the tree species described in Gmelin's work can still be found in the palace gardens. Thus, 60.87% (Table 4), or well over half, have disappeared from the park or were never resident there. This is to be considered under the assumption that all species described in the work were present there. However, several individuals of the genera Tilia and Carpinus were found in various stages of development during the inspection. The percentage of species present and not serving a historical purpose according to Gmelin's work is 34.78% (Table 5). The percentage of species that also occur and still serve a historical purpose today is 4.35% (Table 5). However, the proportion of species that do not occur and provide a benefit is 52.17% (Table 5), thus representing the highest value. Species that do not occur and do not provide a benefit, in contrast, account for only 8.70% (Table 5). It is therefore clearly evident that species that are still used according to historical models are less common in the study area than those that are no longer used according to historical models. Most obvious species from the family Rosaceae, that are predominantly used as fruit trees are missing today. The observed shift in tree species composition can mainly be attributed to changes in forest use. Since 2020 the castle park has met the PEFC standards for a recreational forest. (PEFC Deutschland e.V., 2024 and Karlsruhe, 2024). This includes both the adaptation of the forests and the operational structures and processes to sustainably provide the desired ecosystem services (BMEL, 2021, p. 71). The desired ecosystem service here corresponds to the preservation of the palace gardens as a recreational area and the function of Karlsruhe's green lung (KIT, 2019). According to the city of Karlsruhe, 800-1,000 new trees are planted annually, including an increasing number of so-called future tree species. The trend of the changing tree species composition, away from traditional species such as beech, and sessile oak (FVA, 2017) and toward future tree species (GBA and Karlsruhe, 2024), also plays a role. This is most evident in the absence of Fraxinus excelsior in the recent survey, as this species is no longer expected to find suitable environmental conditions in the study area. Today, the most widely distributed tree species are the genera Acer, *Carpinus*, *Quercus*, *Tilia*, and *Prunus* (GBA and Karlsruhe, 2024). This is supported by the species found and the increased occurrence of the genera *Tilia* and *Carpinus*. These future tree species are better adapted to the climatic conditions (GBA and Karlsruhe, 2024).

Table 7. Overview of uses of all species examined

Latin Name	German Name	Family	Field survey	Abundance	Herbarium vouchers	Distribution map	Past use	Present use	Use in other regions
Acer platanoides L.	Spitzahorn	Sapindaceae	43	3,63	17	5	Winter feed for animals, salads (Gmelin, 1817)	Tools, street and shade tree (Georg-August-University Göttingen, 2024 and Caudullo et al., 2016)	Azerbaijan: The tree is used to treat liver and kidney problems and to treat purulent wounds. The leaves can also be used as a dye for wool. The wood is suitable for carpentry and woodturning, as well as for furniture and musical instrument making. Georgia: The flowers are used for tea. Adjara: The tree is used for chariot construction. (Mehdiyeva et al. 2017)
Acer pseudoplatanus L.	Bergahorn	Spaindaceae	14	3,21	5	7	Winter animal feed, vinegar, brandy, beer brewing (Gmelin 1817)	Timber industry, musical instruments (LWF, 2009)	Azerbaijan: medicinal use, timber industry; Georgia: tea (Mehdiyeva et al., 2017)
Aesculus hippocastanum L.	Rosskastanie	Spaindaceae	14	1,57	2	0	Animal feed, brandy (Gmelin, 1817)	Tea, chestnut flour for laundry cleaning (Vogel, 2024)	Himalayas: Veterinary medicine, timber industry, animal nutrition (Paudel et al., 2021)

Castanea sativa Mill.	Edelkastanie	Fagaceae	0	0	8	2	Firewood, tanning, dyeing, bedding for animals (Gmelin, 1817)	Timber industry, gluten-free bread (LWF, 2009)	Azerbaijan: medical use (Mehdiyeva et al., 2017)
Crataegus laevigata Gand.	Gemeiner Weißdorn	Rosaceae	1	1	4	0	Animal feed, honey, timber construction (Gmelin, 1817)	Medicinal use (Elsadig Karar et al., 2016 and Cui et al., 2024)	Azerbaijan: medical use (Mehdiyeva et al., 2017) Armenia: medical use; Georgia: medical use (Batsatsashvili et al., 2017)
Crataegus monogyna Jacq.	Eingriffeliger Weißdorn	Rosaceae	4	1,5	9	7	Animal feed, honey, wood processing (Gmelin, 1817)	Medicinal use (Martinelli et al., 2021)	Central Asia: Medical use (Bussmann et al., 2020)
Cydonia oblonga Mill.	Quitte	Rosaceae	0	0	0	0	Brandy, vinegar, pastries (Gmelin, 1817)	Timber industry, food, medicinal use (Sajid et al., 2015)	Medical use Central Asia: Medical use (Bussmann et al., 2020); Caucasus: Medical use; Central Asia: Medical use; Iran: Medical use (Bussmann et al., 2019)"
Fagus sylvatica L.	Rotbuche	Fagaceae	8	1,75	14	3	Animal feed, fuel oil, oil, food (Gmelin, 1817)	Timber industry and woodworking, musical instruments, fuel (Durrant et al., 2016)	Azerbaijan: medicinal use, food, animal feed, wood processing; Georgia: medicinal use, food, fuel, wood industry (Batsatsashvili et al., 2017)

Fraxinus excelsior L.	Gemeine Esche	Oleaceae	0	0	5	7	Animal feed, woodwork (Gmelin, 1817)	Timber industry, animal feed, tanning, street tree (Beck et al., 2016)	Urals/North Caucasus: medicinal use; Central Asia: medicinal use, food, timber industry, musical instruments, animal feed, ornamental plant, dyes (Sher et al., 2021)
Malus domestica (Suckow) Borkh.	Apfel	Rosaceae	0	0	0	0	Vinegar, spirits, animal feed, food, medicinal use (Gmelin, 1817 and Patocka et al., 2020)	Food, medicinal use (Patel et al., 2012)	Food (Bussmann et al., 2020)
Mespilus germanica (L.) Kuntze	Mispel	Rosaceae	0	0	3	0	Food, brandy, wine (Gmelin, 1817)	Food, waste industry, medicinal use (Nistor et al., 2024)	Iran: Research on medical use (Shariatifar et al., 2011)
Prunus avium (L.) L.	Vogelkirsche	Rosaceae	10	1,8	4	7	Food, alcohol, rubber, medicinal use (Gmelin, 1817)	Wood processing, animal feed, landscape tree (Welk et al., 2016)	Caucasus: medicinal use, alcohol, timber industry, veterinary medicine (Bussmann et al., 2020)
Prunus cerasus L.	Sauerkirsche	Rosaceae	0	0	2	0	Food, juice, wine, brandy (Gmelin, 1817)	Vinegar (Özen et al., 2020)	Alcohol, juice/nectar (Bussmann et al., 2020 and Toydemir et al., 2013)
Prunus domestica L.	Pflaume	Rosaceae	0	0	4	1	Food, alcohol, oil (Gmelin, 1817)	Research, medical use (Sultana et al., 2020)	Caucasus: Food, alcohol (Bussmann et al., 2020)
Prunus insititia (L.) Bonnier & Layens	Kriech-Pflaume	Rosaceae	0	0	0	0	Food, alcohol, timber industry (Gmelin, 1817)	Food, alcohol (Rogmans, 2024)	

Prunus serotina L.	Virginische Traubenkirsche	Rosaceae	12	2	12	0	Alcohol, timber industry (Gmelin, 1817) industry (Gmelin, 1817)	Food, alcohol, medicinal use, ornamental tree (Popescu et al., 2016)	Southern Appalachians: medicinal use, food, wine (Marquis, 1990)
Prunus spinosa L.	Schlehdorn	Rosaceae	0	0	2	5	Alcohol, food (Gmelin, 1817)	Food, alcohol, medicinal use, ornamental tree (Popescu et al., 2016)	England: alcohol; Armenia: medicinal use, food, alcohol, tea, wood processing; Azerbaijan: medicinal use, food, alcohol, dye solution; Georgia: medicinal use, food, alcohol (Gmelin, 1817 and Batsatsashvili et al., 2017)
Pyrus communis L.	Kultur-Birne	Rosaceae	0	0	1	0	Vinegar, brandy, oil. Animal feed, timber industry (Gmelin 1817)	Medicinal use (Hong et al., 2021)	Georgia: medicinal use; Azerbaijan: medicinal use; Caucasus: tea, alcohol, food, timber industry, animal feed (Abbasi et al., 2021)
Quercus robur L.	Stieleiche	Rosaceae	4	1	23	6	Animal feed, food (Gmelin, 1817)	Timber industry, fuel, street and park tree, animal feed (Eaton et al., 2016)	-
Sorbus aria M.Roem	Echte Mehlbeere	Rosaceae	0	0	0	0	Food, spirits, timber industry, street tree (Gmelin, 1817)	Garden tree, timber industry (Welk et al., 2016)	-

Sorbus aucuparia L.	Vogelbeere	Rosaceae	0	0	0	1	Animal feed, spirits, vinegar/citric acid, plant and street tree, medicinal use, alcohol, food (Gmelin, 1817 and Räty et al., 2016)	Landscape tree, Wood industry, dyeing (Räty et al., 2016)	Eastern Europe: medicinal use, timber industry, dyeing; Azerbaijan: medicinal use, tanning; Caucasus: alcohol, tea/coffee, fuel; Urals: veterinary medicine (Bussmann et al., 2020); Urals: veterinary medicine (Bussmann et al., 2020)
Sorbus domestica Spach.	Speierling	Rosaceae	0	0	0	0	Food, vinegar, alcohol (Gmelin, 1817)	Wood industry, food, medicinal use (Welk et al., 2016)	-
Sorbus torminalis (Gand.) Sennikov und Kurtto	Elsbeere	Rosaceae	0	0	0	0	Food, spirits, vinegar, timber industry (Gmelin, 1817)	Wood industry (Welk et al., 2016)	Georgia: medicinal use, tea (Batsatsashvili et al., 2017)

Table 8. Who collected what and when?

Number of records													
	1780-1810	**1811-1840**	**1841-1870**	**1871-1900**	**1901-1930**	**1901-1931**	**1901-1932**	**1901-1933**	**1931-1960**	**1961-1990**	**1991-2010**	**2011-2024**	**Total**
Benzinger			**1**										**1**
Prunus serotina			1										1
Bonnet				**2**									**2**
Prunus serotina				2									2
Döll			**8**										**8**
Acer platanoides			1										1
Castanea sativa			1										1
Fagus sylvatica			2										2
Quercus robur			4										4
Frick									**1**				**1**
Acer platanoides									1				1
Gmelin	**7**	**29**	**1**										**37**
Acer pseudoplatanus	1												1
Aesculus hippocastanum		2											2
Castanea sativa		3											3
Crataegus laevigata		2											2
Crataegus monogyna		5											5
Fagus sylvatica	1												1
Fraxinus excelsior		3											3
Prunus cerasus	1	1											2
Prunus domestica		2											2
Prunus serotina	1	5											6
Prunus spinosa		1	1										2
Pyrus communis		1											1
Quercus robur	3	4											7
Hruby									**2**				**2**
Fagus sylvatica									1				1
Prunus serotina									1				1
Jauch									**1**				**1**

Quercus robur									1				1
Kleinsteuber										**3**	**8**	**3**	**14**
Crataegus monogyna										1	1	1	3
Mespilus germanica											3		3
Prunus avium											1	2	3
Prunus serotina											2		2
Sorbus aria										1			1
Sorbus aucuparia										1			1
Sorbus torminalis											1		1
Kneucker				**10**	**1**	**1**	**1**	**1**	**40**				**54**
Acer platanoides				1					13				14
Acer pseudoplatanus									3				3
Castanea sativa					1		1		2				4
Crataegus laevigata									1				1
Crataegus monogyna									1				1
Fagus sylvatica				2				1	8				11
Fraxinus excelsior				1					1				2
Prunus avium				1									1
Prunus cerasus				1									1
Prunus domestica									2				2
Prunus serotina				2					2				4
Prunus spinosa									1				1
Quercus robur				2		1			6				9
Oberdorfer									**1**				**1**
Pyrus communis									1				1
Ruh				**2**									**2**
Acer platanoides				1									1
Acer pseudoplatanus				1									1
Teufel									**1**				**1**
Crataegus laevigata									1				1
Vernier		**2**											**2**
Quercus robur		2											2
Total	**7**	**31**	**10**	**14**	**1**	**1**	**1**	**1**	**46**	**3**	**8**	**3**	**126**

Table 9. What was collected and when?

Occurrence in time period	1780-1810	1811-1840	1841-1870	1871-1900	1901-1930	1931-1960	1961-1990	1991-2010	2011-2024	Total
Acer platanoides			**2**	**4**		**28**	**5**	**71**	**60**	**170**
Field survey									42	42
Herbarium vouchers			2	4		28				34
Distribution map							5	71	18	94
Acer pseudoplantanus	**2**			**2**		**6**	**4**	**45**	**28**	**87**
Field survey									14	14
Herbarium vouchers	2			2		6				10
Distribution map							4	45	14	63
Aesculus hippocastanum		**4**					**3**	**19**	**19**	**45**
Field survey									14	14
Herbarium vouchers		4								4
Distribution map							3	19	5	27
Castanea sativa		**6**	**2**		**4**	**4**	**3**	**9**	**1**	**29**
Herbarium vouchers		6	2		4	4				16
Distribution map							3	9	1	13
Sorbus domestica				**1**						**1**
Distribution map				1						1
Crataegus laevigata		**4**				**4**			**1**	**9**
Field survey									1	1
Herbarium vouchers		4				4				8
Crataegus monogyna		**10**				**2**	**9**	**22**	**16**	**59**
Field survey									4	4
Herbarium vouchers		10				2	2	2	2	18
Distribution map							7	20	10	37
Fagus sylvatica	**2**		**4**	**4**	**2**	**18**	**4**	**13**	**14**	**61**
Field survey									8	8
Herbarium vouchers	2		4	4	2	18				30
Distribution map							4	13	6	23

Fraxinus excelsior		**6**		**2**		**2**	**4**	**32**	**7**	**53**
Herbarium vouchers		6		2		2				10
Distribution map							4	32	7	43
Malus domestica								**6**	**1**	**7**
Distribution map								6	1	7
Mespilus germanica				**1**				**6**		**7**
Herbarium vouchers								6		6
Distribution map				1						1
Prunus avium				**2**			**3**	**38**	**24**	**67**
Field survey									10	10
Herbarium vouchers				2				2	4	8
Distribution map							3	36	10	49
Prunus cerasus	**2**	**2**		**2**				**2**		**8**
Herbarium vouchers	2	2		2						6
Distribution map								2		2
Prunus domestica		**4**				**4**		**3**		**11**
Herbarium vouchers		4				4				8
Distribution map								3		3
Prunus serotina	**2**	**10**	**2**	**8**		**6**		**4**	**12**	**44**
Field survey									12	12
Herbarium vouchers	2	10	2	8		6		4		32
Prunus spinosa		**4**				**2**	**3**	**23**	**2**	**34**
Herbarium vouchers		4				2				6
Distribution map							3	23	2	28
Pyrus communis		**2**				**2**				**4**
Herbarium vouchers		2				2				4
Quercus robur	**6**	**12**	**8**	**4**	**2**	**14**	**4**	**32**	**15**	**97**
Field survey									4	4
Herbarium vouchers	6	12	8	4	2	14				46
Distribution map							4	32	11	47

Sorbus aria							**2**	**1**		**3**
Herbarium vouchers							2			2
Distribution map								1		1
Sorbus aucuparia							**5**	**12**	**3**	**20**
Herbarium vouchers							2			2
Distribution map							3	12	3	18
Sorbus torminalis								**2**		**2**
Herbarium vouchers								2		2
Total	**14**	**64**	**18**	**30**	**8**	**92**	**49**	**340**	**203**	**818**

How has the use of the species still found today changed?

The species still found today were formerly used primarily as forage, which is now being replaced by modern forage sources. Some of them also fulfill a medical function that they did not previously fulfill. It is striking that some of the species used as food in the past, are now used medicinally (*Crataegus leavigata, Crataegus monogyna, Prunus serotina*). These are primarily effective in the cardiovascular system and metabolism. They also exhibit antimicrobial and antitumor effects. Today, the species still found today are used to shape the park and are part of Karlsruhe's Green Lung (KIT, 2019).

How has the use of the Hardtwald changed?

The Hardtwald forest, with its palace park and pheasant garden, remains dedicated to recreation, however, the area may be accessed by anyone at any time of year and is no longer a privilege reserved for the prince (Blum, 2004). It was previously used primarily for animal husbandry and, in part, for the production of animal feed. Today, the palace park is one of the main traffic arteries for pedestrians, cyclists, and visitors of all kinds. It is considered the green lung of Karlsruhe and, as a source of fresh air, contributes to the city's climate (KIT, 2019 and Karlsruhe, 2024). The purpose of animal husbandry is no longer fulfilled, as no animals are kept there, with the exception of ducks, and only sustainable forestry is practiced (see question 7.1). The pheasant garden, along with the meadow at the pheasant garden, is dedicated to local recreation (Karlsruhe City Guide, 2024).

Are tree species still used in other regions today according to historical models?

The percentage of species still used in other regions according to historical models is 52.17% (Table 6), thus accounting for half of all species. It is striking that Table 5 and Table 6 differ only in that three species (*Prunus avium*, *Castanea sativa*, and *Prunus domestica*) are classified in the other column, Occurrence and Use. It is evident that, in other regions, species of the genus Prunus are primarily used in the categories of food, medicine, and timber. It is also noticeable that, above all, obviously useful fruits are still used as in earlier times. In contrast, *Cydonia oblonga*, which also has an obviously useful fruit, is no longer used according to historical models. One reason for this could be the sour taste of the fruit. On the other hand, many of the species no longer used in a historical context are described in Gmelin's work as sweet and palatable. No obvious reason for the classification of the species can be identified. Further studies are needed regarding their cultivation and economic yield, as well as their cultural value.

Conclusions

This study demonstrates that the species composition and use within the study area in the Hardtwald forest have changed compared to the past in terms of species occurrence, and that use has changed to a local recreation area for everyone. The changed situation, from impoverished soil due to the removal of leaf litter in winter in earlier times to partially remaining litter today, creates different basic conditions for species. The soil can build up a humus layer through litter turnover and thus accommodates far more living organisms than in earlier times. The increase in nutrients due to the resulting humus-rich topsoil in the soil and regular irrigation by the city create new opportunities for other species to establish or be established, and a reorientation of vegetation and fauna is possible, leading to new biodiversity.

If one considers the climatic classification data presented in the subsection "Climate," it becomes clear that the climate experienced a decrease of -0.6°C between 1811 and 1900. From 1900 to 2000, an increase of 1.3°C was observed. A further classification for the years 2000 to 2008 results in a decrease of -0.7°C. To examine this from an ecological perspective, a closer look at the sequence of data is recommended (see appendix). This shows that the number of collected data, both herbarium specimens and the distribution map, increased sharply between the intervals 1901-1930 and 1961-1990, but also decreased sharply. This also applies to the intervals 1780-1810 and 1841-1870. The peaks in the diagram for Table 12 of herbarium data in 1975 and 1855 are accompanied by a decrease in the 10-year average temperature of -0.4°C and -0.2°C, respectively. Fewer herbarium specimens were found in the following years. This could have several reasons. Firstly, there was a change in collectors: after 1975, specimens from collector Kneucker decreased, but those from collector Kleinsteuber increased. The same can be observed after 1855, from Döll to Kneucker. Secondly, it is reasonable to assume that the cold years led to increased species use, resulting in more forest or species being used for other purposes. This is supported by Tables 8-11, which describe the usage characteristics. It is striking that many species were used both as fuel and as animal fodder.

The basic requirement that all species listed in Gmelin's work "Nothülfe" occur in the study area was not fully met. Since not all species were present, the chosen method of herbarium specimens and the distribution map of the flora of Baden-Württemberg could be demonstrated. However, a lack of data is not only due to the absence of the species, but also to the

absence and lack of specimens. Furthermore, the LGRB soil map also confirmed this finding, as the soil conditions are not suitable for some of the species. Therefore, the basic prerequisite does not fully fit the study area.

Furthermore, a broader survey might have revealed a greater density of species. The survey conducted only took place on the paths and can therefore be expanded to include the area off the paths. It follows that further studies extending to the whole of Karlsruhe are necessary to verify the results of this study. An extension to the whole of Baden-Württemberg would also be useful to cover the main area of Gmelin's surveys.

The main contribution of this work is the recognition of species change, as well as the identification of the cultural values of individual species in other regions and the potential for expanded use in this country, especially with regard to historical and cultural use in other regions of the world. Changes in environmental characteristics due to rezoning and other climatic conditions also influence the vegetation of the palace gardens.

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