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ORIGINAL PAPER

Do horse chestnut trees grow better in a forest or in a mid-field habitat?

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ABSTRACT

Although the horse chestnut is not a native element of the Polish dendroflora, it is frequently planted in cities (parks, avenues, yards), and forms many road-side avenues outside of cities. At present, most horse chestnut trees display the effects of infection by the horse chestnut leaf miner (HCLM) or by the fungus *Guignardia aesculi*. The present study is based on a group of horse chestnut trees forming an avenue in NW Poland, in the vicinity of Krzymów. The avenue was planted in the 2nd decade of the 20th century. The trees forming the avenue are growing in a mid-field habitat (FIELD) and in a forest habitat (FOREST), which enables a comparison among trees growing in these habitats. Dendrometric analyses were performed on 100 trees, and dendrochronological analyses were performed for 32 trees, with equal number of trees sampled in each habitat. The FIELD chronology spans 103 years (1916-2018), the FOREST chronology spans 101 years (1918-2018). Our study aimed to compare the height and crown diameter of the horse chestnut trees growing in a forest and in a mid-field habitat, to examine the rate of radial growth, and to compare the growth-climate relationships in trees from each habitat. The horse chestnut trees growing in the forest habitat are higher than those from the mid-field habitat. The crown diameter is comparable in both habitats, and the breast-height diameter (1.3 m above ground, DBH) is higher in the trees growing in the mid-field habitat. The horse chestnut trees from the mid-field habitat are healthier, their leaves are infected to a lesser extent and fall off later. Also their annual increments are wider. Also the minimum, mean and maximum tree-ring widths, and the cumulative radial growth are higher for the mid-field habitat. We also found differences in the growth-climate relationships established for each site, especially for the year preceding growth (the analyzes were performed for temperature (T) over the period 1948-2018, for precipitation (P) over the period 1951-2018 and for sunshine duration (SD) over the period 1965-2018). For the trees growing in the mid-field habitat, air temperature and sunshine duration for July and August of the previous year are highly significant (negative correlation). Precipitation (positive correlation) and sunshine duration (negative correlation) in September of the year preceding growth are significant for the forest trees. These differences may result from the disparate features of the studied habitats, and the contrasting intensity of tree infestation by HCLM and by the fungus *G. aesculi*.

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KEY WORDS

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Introduction

The horse chestnut *Aesculus hippocastanum* L. has been cultivated in Poland for nearly 400 years. It is especially valued for its silhouette, large leaves and attractive blooming. Up to the present day, it is frequently planted in urban spaces, along streets, in parks, within residential districts, as well as along roads in open landscape, and in historic palace gardens (Seneta, 1991; Spasić *et al*., 2011; Seneta *et al*., 2021). The horse chestnut is indigenous to Greece, Albania, North Macedonia and Bulgaria, where it occurs in humid mountain valleys, up to an altitude of 1000--1200 m a.s.l. It reaches a height of 25-30 m, and forms a thick crown casting a dense shade. It has distinctive leaves resembling spread fingers, and white flowers with yellow specks, growing in cone--shaped panicles, 20-30 cm long, blooming in May. The fruit is a spiky case. The horse chestnut trees are vulnerable to drought and salinity. They prefer warm habitats, sunlit or semi-shaded, fertile and humid soil, in close proximity to agricultural land (Šipcinskij, 1958; Krüssmann, 1960; Bugała, 2000; Seneta *et al*., 2021).

In recent years, the greatest challenge to the horse chestnut cultivation is the butterfly HCLM *Cameraria ohridella* (Deschka and Dimić, 1986) (Gracillariidae, Lepidoptera). It is a moth, whose caterpillar feeds on the leaf ground tissue, which leads to the development of rusty spots and dehydration of leaves, which may be shed as early as mid-July, as well as progressive branch dieback (Thalmann *et al*., 2003; Jagiełło *et al*., 2019). The HCLM issue was first identified in 1984 close to Lake Ohrid in Macedonia (Deschka and Dimić, 1986). At present, HCLM has spread into most European countries, migrating at a rate of about 60 km/year. It is currently noted, *e.g.*, in Spain and France (since 2000), in England (since 2002), in Denmark, Ukraine and Sweden (since 2003) – Gilbert *et al.* (2005). In Poland, HCML was first recognized in 1998 in the vicinity of Wrocław, in the SW part of the country. At present, it is broadly distributed in the entire country (Głowacka *et al*., 2009). In addition to HCLM, there are increasingly frequent occurrences of the leaf blotch disease, caused by the fungus *Guignardia aesculi* (Peck) Stew., accidentally carried from North America (Jagiełło *et al*., 2017, 2019; Kopačka *et al*., 2021). The first symptoms of tree infection include light brown spots on leaves, which become progressively smaller each year (Raimondo *et al*., 2003). After a few years, the yang tree dies (Baraniak *et al*., 2005; Gilbert *et al*., 2005; Snieđkienë *et al*., 2011; Baranowski and Dankowska, 2012; Dzięgielewska *et al*., 2017).

The horse chestnut is rarely the subject of dendroclimaticological analyses. In Poland, the growth-climate relationship in this species was studied by Wilczyński and Podlaski (2007), Bednarz and Scheffler (2008), and Cedro and Nowak (2022). Similar studies were conducted in Lithuania by Jasone *et al.* 2022, and in Slovenia by Simon and Lena (2016). Analyses comparing the relationship between tree-ring width and climatic factors in various habitat conditions, especially during the HCLM invasion, are lacking.

The present study aims to: (i) compare the height and diameter of the crown among the horse chestnut trees growing in a forest and mid-field habitat, (ii) examine the rate of radial growth, and (iii) compare the growth-climate relationship among trees growing in each habitat.

Materials and methods

Study area. A 2.5 km long, east-west trending avenue of the horse chestnut trees *Aesculus hippocastanum* is located along a local road to Krzymów, a village in NW Poland, Western Pomeranian Voivodeship

(52.9824869 N, 14.3481286 E, 45-50 m a.s.l., Figs 1, 2a,b). In Krzymów, there is a baroque palace from the 2nd half of the 18th century, remodeled in the 19th century, surrounded by a landscape-style park established in the 18th century, with numerous tree plantings (Bakalarz *et al*., 2011). Over a 1.5 km segment, the avenue runs through a mid-field environment (FIELD), with agricultural land adjacent on both its northern and its southern side. Over a distance of ca. 1 km, the avenue crosses a mixed forest (FOREST), varied with respect to taxonomic composition and age of trees. With respect to habitat type, it is a fresh forest. The dendroflora is mixed, but the dominant species include: 32 year-old pedunculate oak *Quercus robur* L. on the southern side, and 67 year-old Scots pine *Pinus sylvestris* L. on the northern side. In September 2018, the avenue featured 511 trees, including 407 horse chestnut trees growing in a mid-field habitat, and 104 trees growing in a forest habitat. More trees are preserved along the northern edge of the avenue, *i.e*., 248 trees in the mid-field habitat (versus 159 along the southern edge), and 60 versus 44 trees, respectively, in the forest habitat. Over most of the avenue length, the horse chestnut trees are growing in a single row on each side of the road, but over some segments (especially in the mid-field habitat), two rows of trees are preserved on each side of the road. During field work, we took note of the beginning and end of leaf abscission in both habitats. We observed evidence of numerous cut-down trees. In conjunction with the poor health of numerous trees, this indicates that the number of trees in the avenue continues to diminish.

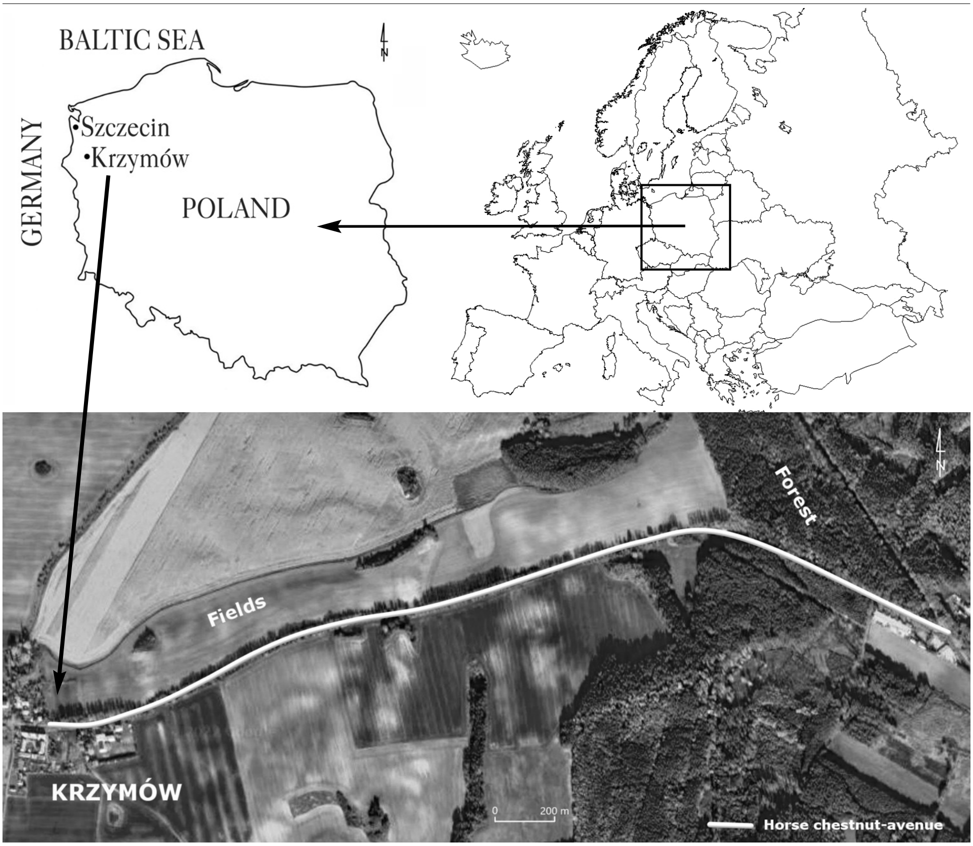

Fig. 1.
Location of the study area
Map source: Head Office of Geodesy and Cartography (GUGiK), www.geoportal.gov.pl

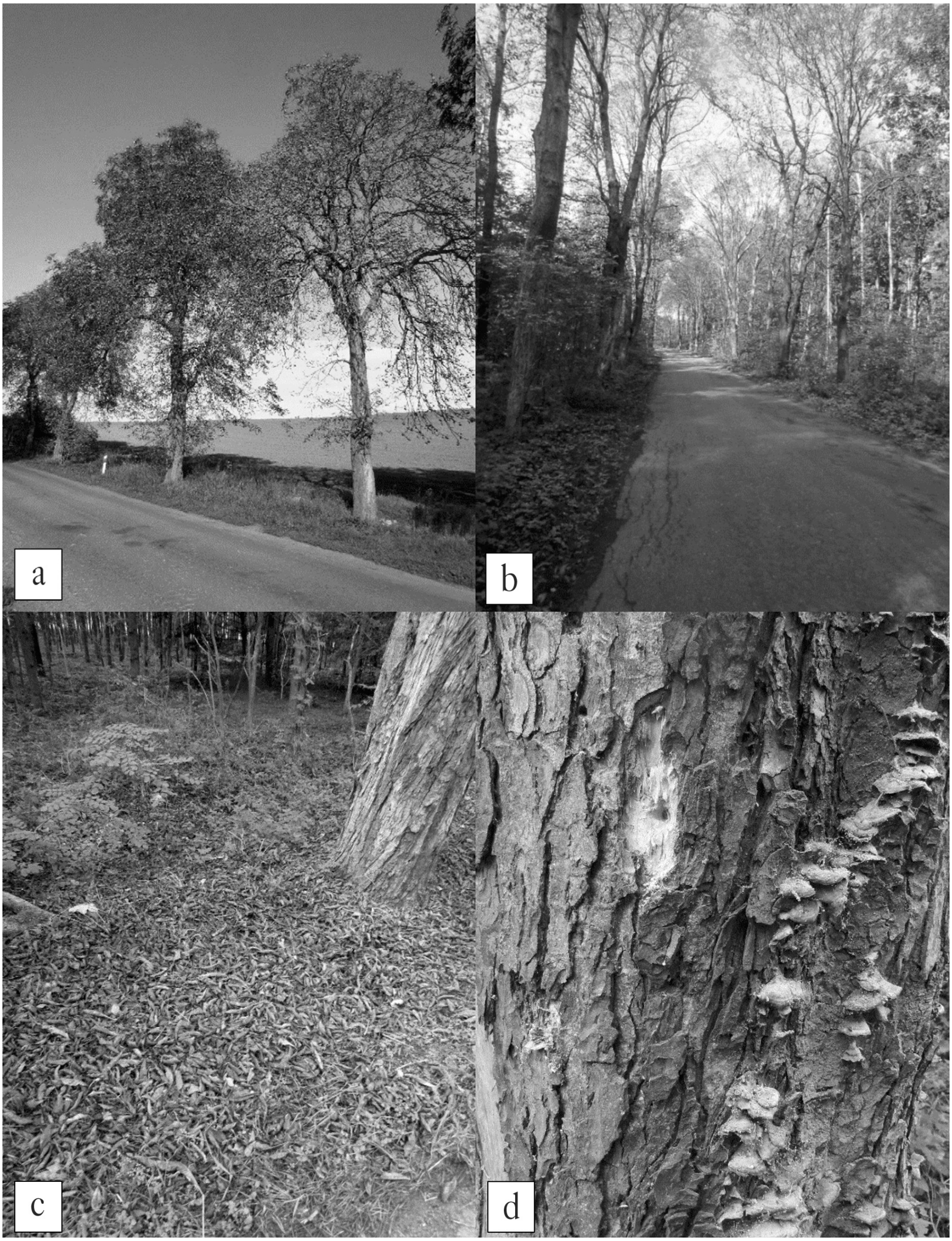

Fig. 2.
Aesculus hippocastanum trees
a – growing in the mid-field habitat; b – growing in the forest habitat; c – leaves resting under the horse chestnut trees in the forest habitat; d – fruiting bodies of the fungus Trametes versicolor (photos by G. Nowak)

CLIMATE. The climate of the NW part of Poland is predominantly influenced by polar-sea air masses from the North Atlantic, and also affected by local circulation from over the Southern Baltic Sea. The mean annual air temperature in Szczecin is 8.8°C, ranging from 7.1 to 10.9°C in the coldest and the warmest years, respectively. With a mean temperature of –0.4°C (ranging from –8.8 to +5.1°C), January is by far the coldest month (Fig. 3). The warmest month is July (Fig. 3), with an overall mean temperature of 18.1°C (range:15.2-22.7°C). Summer is the longest thermal season (92 days), winter being the shortest one (40 days) (Koźmiński *et al.*, 2012; Cedro and Walczakiewicz, 2017). The overall mean annual precipitation total is 546 mm, ranging from <350 to 841 mm in the driest and the wettest years, respectively. The highest seasonal precipitation total (180 mm) occurs in summer (June-August) (Koźmiński *et al.*, 2012; Cedro and Walczakiewicz, 2017). The snow cover in the city persists for as short as about 19 days a year. According to Heinze and Schreiber's (1987) climatic zone and subzone scheme, the area is within subzone 7a, with mean long-term minimum temperature from –17.7°C to –15.0°C.

Dendrometric and tree-ring data. Dendrometric measurements were performed for 100 trees (50 in each habitat). Tree height was measured using a Nikon Forestry Pro II laser rangefinder. Crown diameter was measured using a Topex odometer. Trunk circumference was measured using a tape measure, at 1.3 m above ground (breast-height diameter, DBH).

Sampling for dendrochronological analyses was performed on the healthiest trees, *i.e.*, with no apparent trunk damage. Due to the location of the trees in close proximity to a road, numerous trunks displayed damage and wounds on the side facing the road, healed to a various degree. This was most likely caused by numerous traffic collisions, and damage from agricultural machinery. Cores were taken from 32 trees (16 trees in the mid-field habitat and 16 trees in the forest habitat, one core per tree) using a Pressler borer, in each case on the southern side of the trunk, at 1.3 m above ground. In the laboratory, samples were glued onto boards, dried, and cut with a knife in order to obtain a clear view of the tree-rings. Tree-ring width (TRW) was measured under a stereoscopic microscope down to 0.01 mm, using DENDROMETER 1.0 software (Mindur, 2000). Cross--dating between the individual tree TRW time series was performed using on-screen visual comparisons (high visual similarity), and statistical parameters commonly used as cross-dating coefficients in dendrochronology: Student's t-test, r correlation coefficient and Gleichläufigkeit (GL%) (Huber, 1943; Kaennel and Schweingruber, 1995). To check the annual variability of the

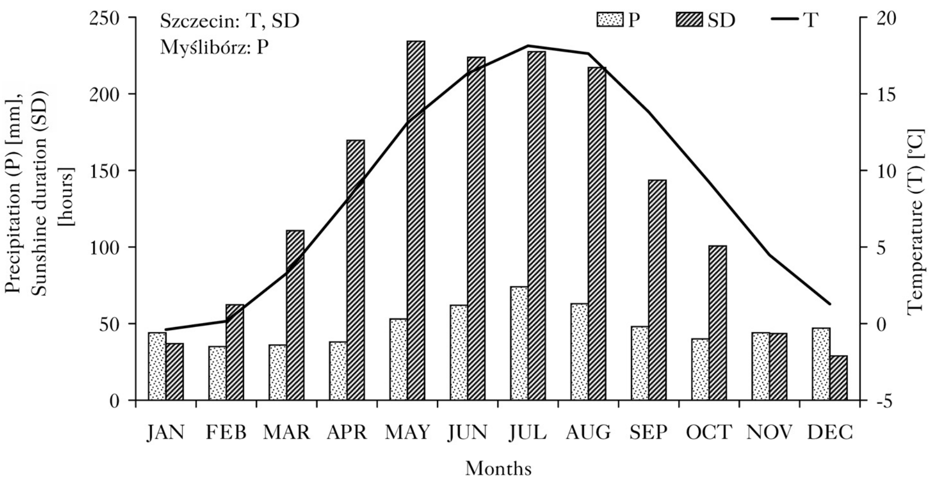

Fig. 3.

Mean monthly air temperature (T) for 1948-2018, and mean monthly precipitation (P) for 1951-2018) and monthly sunshine duration (SD) for 1965-2018. T and SD data from the weather station in Szczecin (12205) and SD data from Myślibórz (252140020)

TRW, standard deviation (STD), mean sensitivity (MS) and autocorrelation coefficient lagged by one year (AC1) were also calculated. TRW raw series from the site were averaged to tree-ring width raw chronology. Trees with the lowest values of statistical parameters (t, r and GL) were removed from the dataset. Only TRW raw chronologies that were successfully cross-dated and yielded a good match among themselves were selected for further analysis (Holmes, 1983 and 1994; Grissino-Mayer, 2001). To remove the influence of the long-term age trend and disturbances of other environmental factors, TRW raw time series were standardized individually using ARSTAN program (Cook and Holmes, 1999), using a two-phase detrending technique, by fitting either a modified negative exponential curve or a regression line with a negative or zero slope). Residual site chronologies (RES) were derived by averaging the individual TRW series from each site, which were previously detrended and had autocorrelation removed (Speer *et al.*, 2009). The EPS coefficient was also computed (Wigley *et al.*, 1984).

To study the growth-climate relationship, correlation and response function analysis and the analysis of pointer years were employed. Monthly mean air temperatures (T), monthly precipitation totals (P) and monthly sunshine duration totals (SD) spanning June of the year preceding growth (pVI) through September of the vegetation year (IX) were used for correlation and response function analysis. The analysis was performed separately for temperature, precipitation and sunshine duration, which yielded r^2 values (regression determination coefficients) for each climate parameter (Cook and Kairiukstis, 1992; Holmes, 1994; Selvamuthu and Das, 2018). For dendroclimatic analyses, we used data (T and SD) retrieved from the IMGW weather station in Szczecin (no. 12205; 53.24°N, 14.37°E; 1 m a.s.l.), situated about 37-38 km to the NNE from the studied avenue. For air temperature (T) the available data span 1948-2018 (71 years), and for sunshine duration (SD), the data span 1965-2018 (54 years). For precipitation (P, 1951-2018, 68 years) data were retrieved from the station in Myślibórz (no. 252140020; 55.55°N, 14.52°E; 65 m a.s.l.), situated about 34 km to the ESE from the avenue.

Pointer year analysis was carried out using TCS software (Walanus, 2002) by calculating interval trend: positive years (+) characterized by an increase in tree-ring width (t=1) relative to the preceding year (t–1), and negative years (–), with a reduction in tree-ring width (t=1) relative to the preceding year (t–1) (Kaennel and Schweingruber, 1995; Jetschke *et al.*, 2019). A given year was considered a pointer year (positive or negative) if the interval trend exceeded a critical threshold – 90% for a minimum of 10 trees.

Results

DENDROMETRIC ANALYSES. The studied trees reached a height from 14.0 to 23.0 m. However, the horse chestnut trees growing in the forest habitat were taller, both their average height (20.3 m), and their maximum height (23.0 m), as opposed to the respective values for the trees from the mid-field habitat (18.0 and 22.0 m). Only the minimum tree height was the same for both habitats, and equalled 14.0 m (Fig. 4). The crown diameter was comparable in both habitats, from 6.5 in the mid-field habitat and 7.0 m in the forest to 11.0 m in both habitats. The average crown diameter was 0.5 m higher in the mid-field environment. The largest differences were observed for the trunk diameter at breast-height (DBH). DBH for the mid-field trees ranged from 46 to 91 cm, with a mean value of 64 cm. The forest trees had more slender trunks (DBH ranging from 35 to 73 cm, with a mean value of 56 cm) (Fig. 4).

Trees growing in the mid-field environment form crowns that are set lower, with overhanging shoots. In trees growing in the forest environment, shoots are raised and the crown forms in the upper part of the trunk. Very strong infestation by *Cameraria ohridella* (horse chestnut leaf

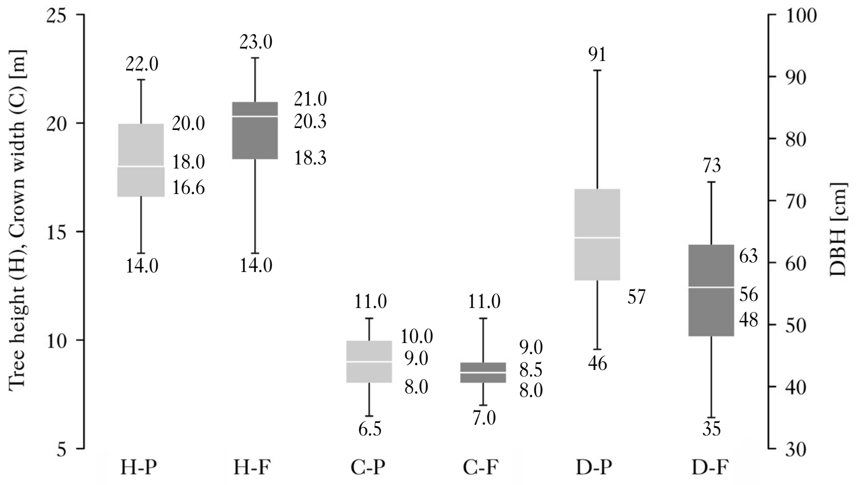

Fig. 4.

The range of tree height (H), crown diameter (C) and DBH (D) of the horse chestnut trees. Boxes indicate interquartile range, while whiskers represent minimum and maximum values. The median is indicated by a central solid line through the boxes; light grey – field (P), dark grey – forest (F)

miner, HCLM) was observed on all the studied trees. It was especially evident in the forest habitat, as it caused earlier defoliation compared to the mid-field habitat. The reason for this may be that fallen leaves, where the HCLM larvae overwinter, accumulate under the trees (Fig. 2c). In the mid-field habitat, the fallen leaves are dispersed by wind, which contributes to a lower degree of infestation by the first generation of the insect, and a slower colonization of the tree crown.

The trees are forming an avenue along a public road, which makes them exposed to mechanical damage from vehicles. The trunks bear bark scars resulting from accidents or caused by agricultural machinery. Tree crowns display branch deadwood and remains of broken branches. Several trunks bear fruiting bodies of the fungus *Trametes versicolor* (L.) Lloyd, which points to ongoing processes of wood decay (Fig. 2d). Signs of woodpecker foraging are also visible, which indicates that insect larvae are breeding inside the trunks, which is detrimental to tree health (Fig. 2d).

Dendrochronology. Despite the absence of the core and the tree rings adjacent to the pith in several cases (rotten central parts of the trunks in 6 out of 16 sampled trees in the mid-field environment and in 10 out of 16 sampled trees in the forest), we managed to successfully determine the age of the trees: the avenue was planted in the 2nd decade of the 20th century. The establishment of the avenue probably took several years. Preparing such high number of young trees (we estimate that the avenue originally comprised >2000 trees), and subsequent planting of horse chestnut trees in place of those that died early, which is reflected in the age differences among the analyzed trees – the length of the tree-ring series ranged from 84 to 103 years (at 1.3 m above ground). The mid-field habitat chronology (FIELD) was compiled based on 15 individual tree TRW time series and spans 103 years from 1916 to 2018 (EPS>0.85: 1922-2018). The average tree-ring width for the horse chestnut trees in this habitat equals 3.35 mm (ranging from 2.77 to 3.59 mm) (Table 1). The forest habitat chronology (FOREST) was also compiled based on 15 best-correlated individual growth sequences. It spans 101 years (1918-2018, EPS>0.85: 1929--2018). The average tree-ring width equals 2.82 mm, ranging from 1.56 to 3.31 mm (Table 1) (Cedro and Nowak, 2023). The initial three decades in each chronology are characterized by a typical strong age trend, *i.e.*, tree-ring width diminishes with increasing tree age (average tree-ring widths ranging from 3 to 9 mm). In the subsequent stage, tree-ring widths stabilize at 2-4 mm, with a period of elevated tree-ring widths in the late 1970s and in the 1980s. The last three decades in both chronologies display strong growth depressions (Fig. 5). This is especially evident in the trees from the forest habitat, in which most trees have tree-ring widths close to 1 mm and below. The year 2000 is considered to be the beginning of the significant impact of the HCLM invasion on the studied trees, as HCLM was first observed in Poland in 1998 (Łabanowski and Soika, 1998; Cedro and Nowak, 2022). In that year, over 90% of trees from Krzymów display a decrease in tree-ring width relative to the preceding year, and the reductions persist over the next several years (Fig. 5). Out of 101 years spanned by both chronologies, the tree-ring growth of the horse chestnut trees from the forest habitat is higher than that observed for the mid-field trees only in 25 years: 1918, 1921, 1924, 1927, 1956, 1958, 1960, 1980-81, 1984-86, 1989-98, 2001 and 2015-16 (Fig. 5). For the whole study period, the cumulative radial growth is higher for the horse chestnut trees growing in the mid-field habitat (Fig. 6). Following over 100 years of growth, the cumulative radial growth difference between the two analyzed habitats equals nearly 61 mm, which translates into 12 cm difference in DBH.

Dendroclimatology. Correlation and response function analysis indicates the weather conditions in June of the growth year as the dominant factor shaping tree-ring widths in the horse chestnut trees (Fig. 7). Lower than average air temperature and lower sunshine duration in that

Table 1.

Basic statistics of measured and index (residual) horse chestnut chronologies (FOREST, FIELD). Abbreviations: TRW, tree-ring width; SD, standard deviation; 1AC, first order autocorrelation; MS, mean sensitivity; EPS, Expressed Population Signal

Lab. code	No. of years	Time span	No. of samples	Mean TRW (min-max) [mm]	Measured chronology			Residual chronology			EPS>0.85
					SD	1AC	MS	SD	1AC	MS	
FOREST	101	1918-2018	15	2.82 (1.56-3.31)	1.787	0.756	0.354	0.264	–0.088	0.267	1929-2018
FIELD	103	1916 -2018	15	3.35 (2.77-3.59)	2.252	0.804	0.354	0.257	–0.089	0.295	1922-2018

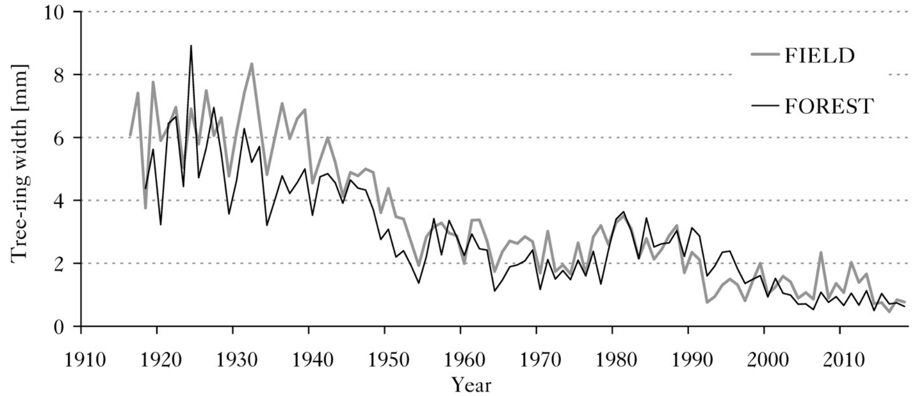

Fig. 5.
Local horse chestnut chronologies (FIELD, FOREST)

month (negative correlation values), and higher than average precipitation (positive correlation values) make a positive impact on the tree-ring width. Negative values of the statistical indices for temperature and sunshine duration persist also through the remaining summer months (July and August). In April, the horse chestnut trees prefer high temperature (positive r and r^2 values). In the year preceding the given growth season, the late autumn/early winter weather is significant (pOCT-pDEC for the mid-field environment, pDEC for the forest environment).

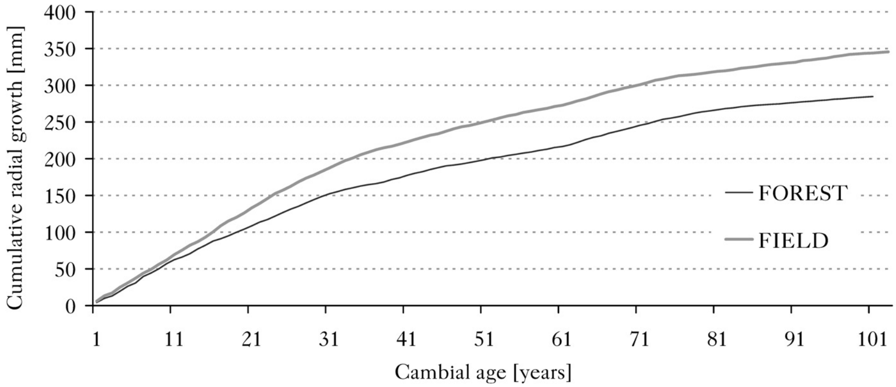

Fig. 6.
Cumulative radial growth of the horse chestnut trees from FOREST and FIELD

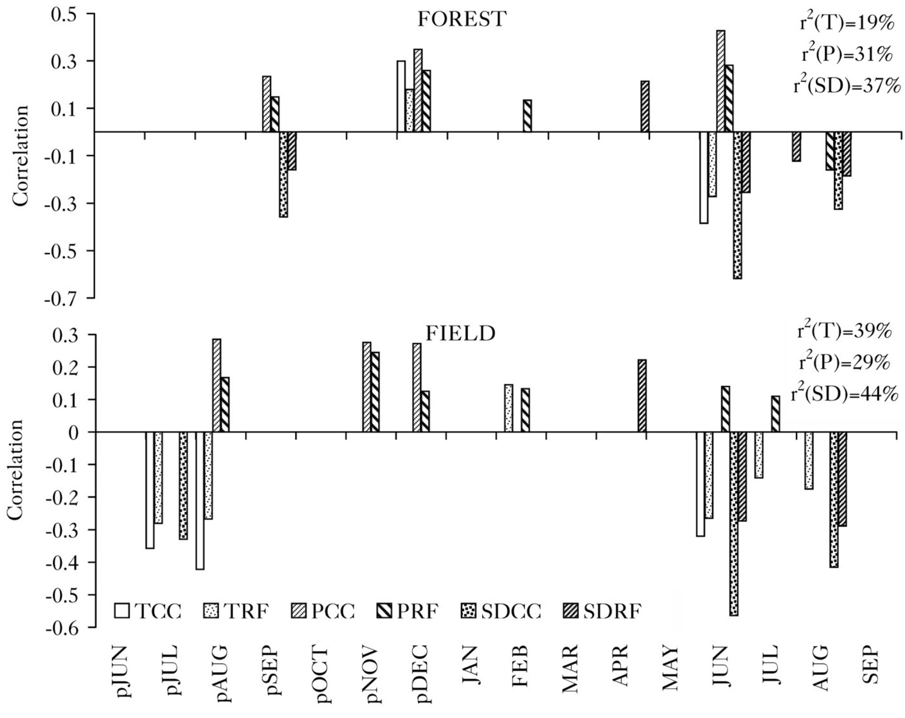

Fig. 7.
Results of correlation (CC) and response function (RF) analyses for the horse chestnut chronologies (FOREST, FIELD) for temperature (T), precipitation (P) and sunshine duration (SD); time span: T 1948-2018, P 1951-2018, SD 1965-2018. Bars denote significant values ($p \leq 0.05$); *p*, previous year

Through this period, high precipitation and higher than average air temperature (especially in December, positive r and r^2 values) favour the formation of wide tree-rings in the upcoming vegetation season. The differences between both habitats are manifested mainly in the summer season of the year preceding growth: the weather conditions of September (pSEP: low sunshine duration and high precipitation sums influence to the formation of wide tree-rings) are important for the forest habitat. The weather conditions of July and August (pJUL, pAUG) are the most important for the mid-field habitat: hot and sunny weather through this period results in narrower tree-rings. For the trees growing in the forest, sunshine duration has the strongest influence (r^2=37%), precipitation – 31% and air temperature has the weakest influence (r^2=19%). For the mid-field environment, the highest r^2 for the analyzed weather elements was obtained for SD (44%), followed by T (39%) and P (29%).

A total of 68 pointer years were computed for both chronologies. In 21 years, the same incremental reactions (pointer years) occur in both habitats (FIELD and FOREST). These include 18 negative years: 1940, 1944, 1949, 1951, 1954, 1964, 1970, 1976, 1983, 1992, 1997, 2000, 2004, 2006, 2008, 2012, 2014 and 2016, and 3 positive years: 1961, 1977 and 2007. During positive pointer years, summer was usually rather cool, with higher than average precipitation, and lower than average sunshine duration. In 2007, however, despite rather high temperatures in the summer months, extremely high precipitation has been noted (the wettest year in the study period, with precipitation totals exceeding 100 mm in July and August). During negative pointer years, the summer air temperature and sunshine duration were above average, and precipitation shortages occurred in the summer (often lasting as long as 2-3 months). An exception here was the year 1997, which was a negative pointer year despite rather high annual precipitation and summer precipitation sums. Very low air temperatures in December of the previous year, and hot, sunny and stormy weather in August (short, high-intensity rainfall) may have contributed to tree-ring width reduction. Also the year 2000, despite rather favorable weather conditions (cool summer, no precipitation deficits, medium to low insolation), was a negative pointer year, which may be associated with the onset of the HCLM invasion in NW Poland (Cedro and Nowak, 2021). The results of the pointer years analysis corroborate the growth-climate relationships obtained in the correlation and response function analysis.

Discussion

As indicated by the measurements performed here, the studied trees reached a different height, depending on their habitat. The trees growing in the forest were higher, which is probably influenced by competition for sunlight. These differences are significant, as they reach on average over 2 m. This is consistent with the data presented by Jagodziński and Oleksyn (2009). As reported by Nilsson (1994) and Dervishi *et al.* (2022), tree height may also be influenced by limited access to water and nutrients, because competition for resources increases with plant height. Slight differences were observed in the case of tree crown diameter. This was comparable at both habitats, and likely influenced mostly by the similar spacing of the trees during planting.

The largest differences were observed for the trunk diameter at 1.3 m above ground (DBH). The average DBH value for trees growing in the mid-field habitat was 12 cm higher than that for the horse chestnut trees growing in the forest. This could be influenced by the higher fertility of the habitat, as noted *e.g.*, by Jaszczak (2008) and Wójcik (2000) in cultures of the Scots pine *Pinus sylvestris*. An increase in fertility results from the use of fertilizers in the surrounding agricultural land, with part of the mineral elements being carried underneath the crowns of trees. The weaker growth of trees observed for the forest habitat may result from higher and more rapid defoliation caused by HCLM. In the forest habitat, the fallen leaves, where HCLM larvae overwinter (Deschka and Dimić, 1986; Łabanowski and Soika, 1998; Gilbert *et al*., 2005; Bystrowski *et al*., 2008), remain intact, while in the field, the leaves are dispersed by wind over larger distances. The spacing between the horse chestnut trees is consistent over the entire avenue. The trees growing in the forest habitat, however, are subject to stronger competition for water, nutrients and sunlight, which may influence the narrower tree-rings. Thus, in spring, the insect invade leaves at an earlier time in the forest habitat, thus causing a higher gradation of the insect. High air temperatures in winter months occurring in recent years in Western Pomerania may result in an elevated survival rate of HCLM larvae, and consequently, their higher abundance after overwintering (Balder *et al*., 2004). HCLM infestation of the horse chestnut leaves may cause a second phase of leaf development and flowering in autumn, which makes a negative impact on tree health and tree-ring formation (Salleo *et al*., 2003; Percival *et al*., 2011; Percival and Holmes, 2016; Jagiełło *et al*., 2019). According to Takos *et al*. (2008), HCLM may also influence seeds and seedlings.

The tree-ring width in the studied trees very strongly depends on the habitat. In the FIELD habitat, the average annual growth equals 3.35 mm (ranging from 2.77 to 3.59 mm) and is 16% higher compared to the FOREST habitat (2.82, 1.56 and 3.31 mm, respectively). Both the average value and the minimum and maximum values are lower for the forest habitat.

The horse chestnut trees growing in an avenue in Buk (about 60 km N of Krzymów) reach a similar TRW compared to the studied avenue trees, *i.e*., 3.54 mm, ranging from 2.22 to 4.31 mm (Cedro and Nowak, 2022). The tree-ring width of similar-aged horse chestnut populations from Kraków in Poland (growing in a park and a cemetery), equals about 2.2-3.0 mm. Note, however, that in this case, the minim growth is observed around 1950. In the late 1950s, and early 1960s there is an increase in tree-ring width. The 1980s and 1990s are a period of TRW reduction. From 1993 to 1996, TRWs increase again. Since the onset of HCLM invasion in 1997 to the end of the chronology in 2005, there are TRW reductions (Bednarz and Scheffler, 2008). In a forest habitat in the Świętokrzyskie Mountains, the horse chestnut trees reach a tree-ring width of 4.06 mm (the trees are about 80 years old). In this population, growth depressions are noted in the 1960s. In the 1970s and 1980s TRWs increase (Wilczyński and Podlaski, 2007). Despite their young age (about 50 years old), the horse chestnut trees growing in Lithuania have low TRWs, ranging from 0.93 to 1.11 mm (Jasone *et al*., 2022). The reason for such narrow TRWs may be the cool climate of this part of Europe. In Slovenia, the horse chestnut trees growing in park conditions reach an average growth on the order of 3 mm (from ca. 1 to 6 mm). Single missing rings are also reported (Simon and Lena, 2016). Trees of this species growing in Italy (the city of Trieste and its suburbs) reach an average annual growth on the order of 1.35 mm through the period 1992-1996 (*i.e*., before the onset of HCLM invasion), and display a surprising increase in TRW in the initial years of the invasion (1997-2001), up to 2.20 mm (Salleo *et al*., 2003). False rings have also been reported from these same trees, from the HCLM invasion period (Salleo *et al*., 2003).

The horse chestnut is rarely the focus of dendrochronological studies. Cedro and Nowak (2022) studied the horse chestnut trees growing in a very similar habitat (a mid-field avenue) and in the same climatic conditions (temperate warm transitional climate). Strong TRW reductions were reported for the first decade of 21st century, caused by HCLM invasion. The year 2000 was assumed as the onset of the invasion, as despite favorable weather conditions, most trees displayed a reduction in tree-ring width, lasting until 2010. The growth-climate relationship was examined for two periods: prior to the HCLM invasion (1948-1999) and during the invasion (2000-2016). Before the invasion, the tree-ring width depended mostly on precipitation totals (positive correlation and regression values), temperature and insolation (negative correlation and regression values) in May and June of the growth year. During the HCLM invasion, the dependency period was shifted to the preceding vegetation season, and the relationship strength increased (also positive correlation and regression values for precipitation, negative values for temperature and sunshine duration). The obtained results indicate a relationship between tree-ring width and the number of HCLM (after years with cool, humid growing season with low sunshine duration during, the number of HCLM decreased, which resulted in improved tree health and the development of wider tree-rings in the following year). In the final years of the record (2011-2016), despite HCLM damaging the studied trees each year, the health of the trees improved, and the tree ring width increased (Cedro and Nowak 2022).

Other dendrochronological studies on the horse chestnut trees in Poland were conducted in the Świetokrzyskie Mountains by Wilczyński and Podlaski (2007). Their results point to winter (December-March) and August air temperature, and precipitation in December of the year preceding growth. The considerable differences in growth-climate relationship in comparison to the avenue at Krzymów may be caused by the higher elevation (280 m a.s.l.), large distance separating both study plots (about 500 km), and considerable habitat differences (the trees studied by Wilczyński and Podlaski, 2007, grew in the *Fraxino-Alnetum* plant community with a high groundwater level, and were not infested by HCLM).

Bednarz and Scheffler (2008) conducted an analysis of the impact of HCLM infestation on tree-ring width and growth-climate relationship in the horse chestnut trees from southern Poland. The horse chestnut trees growing within the city limits of Kraków proved vulnerable to the weather conditions of the year preceding growth: negative correlation coefficients are noted for air temperature in July, August and September, and positive values for precipitation totals in August of the year preceding growth and June of the current year. The onset of HCLM gradation in Kraków was determined at 1997: strong growth reductions were noted between that year and 2005 (Bednarz and Scheffler, 2008).

Jasone *et al.* (2022) studied young horse chestnut trees (<50 years old) growing in forest conditions in the cold climate of Lithuania, infested by HCLM in 2002. The growth-climate relationships here depended on the analyzed period. For the entire study period (1978-2019), positive correlation values were obtained for: precipitation in August of the year preceding growth, March and July of the current year, and for SPEI (Standardized Precipitation Evapotranspiration Index) in August and September in the year preceding growth, and for March, April and July of the current year. When considered from the perspective of the HCLM invasion onset (prior to the invasion: 1978-2002 versus during the invasion: 2003-2019), the growth-climate relationships display a radical change. Before the invasion, air temperature of June, July and September, and precipitation totals for August of the previous year were significant (positive values of r). For the invasion period, significant relationships (positive values of correlations) were obtained for: August (precipitation and SPEI) and September (SPEI) of the previous year, and for the current year: for precipitation in March and July, and for SPEI in March, April and July (Jasone *et al.*, 2022).

In Slovenia, which has a Mediterranean climate, the radial growth in this species depends on humidity (precipitation – SPEI) of the summer months: June-August (positive value of correlation coefficient), and droughts cause strong tree-ring width reductions (Poljansek and Marion, 2016).

The data from the horse chestnut trees from Krzymów presented above, and the results obtained by previous authors point to a high significance of climatic conditions, habitat, and the

HCLM gradation impact on tree-ring widths in this species. In the period of climate change (temperature increase, extreme weather conditions, (IPCC, 2021)), anthropogenic habitat changes (Laurance, 2010; Hinckley *et al*., 2013, Deutsch, 2014; Scanes, 2018; Kapos *et al*., 2019; Radić and Gavrilović, 2020; Hussain and Kalita, 2021) and migrations of insect species hitherto absent in a given area, studies on adaptation of various tree species to the ongoing changes are increasingly more important (Turnhout and Purvis, 2020).

Conclusions

The horse chestnut is a very important species used in green areas. Its distinctive crown, leaves and flowers are an indispensable element of both rural and urban landscapes. The horse chestnut leaf miner, whose invasion has been ongoing for the past several decades, causes leaf damage leading to premature defoliation, and a diminished aesthetic value and deteriorating health of the trees. Studies on the impact of the insect, in the context of habitat and climate conditions, are an important contribution to the current knowledge on plant protection and invasive species. The results obtained here indicate that in recent years the health of the infested trees has been improving. In the forest habitat, where leaves accumulate under the trees, a stronger and earlier gradation of the leaf miner was observed, which influenced radial growth of the trunks, and the aesthetic value of the trees. Our observations indicate that the gradation of the first generation of the insects on trees growing in the mid-field habitat is less intense, which results in limited damage to the horse chestnut leaves. The results obtained in this study indicate that the horse chestnut trees grow better in the mid-field habitat. In order to improve the tree health, it is essential to undertake active protective measures, like eliminating fallen leaves, used for overwintering by the HCLM larvae, from underneath the trees.

Authors' contributions

Conceptualization – A.C. and G.N.; methodology – A.C. and G.N.; software – A.C.; validation – A.C. and G.N.; formal analysis – A.C. and G.N.; investigation – A.C. and G.N.; resources – A.C. and G.N.; data curation – A.C.; writing-original draft preparation – A.C. and G.N.; writing-review and editing – A.C. and G.N.; visualization – A.C. and G.N.

Conflicts of interest

The authors declare no conflict of interest.

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STRESZCZENIE

Czy kasztanowce lepiej rosną w siedlisku leśnym czy śródpolnym?

Kasztanowiec biały *Aesculus hippocastanum* L. jest uprawiany w Polsce od niemal 400 lat. Jest sadzony w przestrzeni miejskiej, przy drogach w krajobrazie otwartym oraz spotykany w lasach. Największy problem w uprawie kasztanowców w ostatnich latach stanowi szrotówek kasztanowcowiaczek *Cameraria ohridella* Deschka and Dimič, 1986. Jest to motyl, którego gąsienica żeruje, zjadając miękisz liści, co prowadzi do ich odwodnienia i osłabienia drzew. Celem badań było porównanie wysokości i średnicy korony kasztanowców rosnących w siedlisku leśnym i polnym, zbadanie tempa przyrostu radialnego oraz porównanie zależności przyrost-klimat drzew w obu siedliskach.

Aleja kasztanowców białych o przebiegu wschód-zachód, długości ok. 2,5 km, usytuowana jest przy lokalnej drodze prowadzącej do wsi Krzymów (NW część Polski, województwo zachodniopomorskie, 52,9824869 N, 14,3481286 E, 45-50 m n.p.m.) (ryc. 1 i 2a, b). Aleja na odcinku ok. 1,5 km przebiega w środowisku polnym, a na odcinku ok. 1 km przez las mieszany. We wrześniu 2018 r. aleja liczyła 511 drzew, w tym 407 kasztanowców w siedlisku śródpolnym i 104 w leśnym.

Pomiary dendrometryczne objęły 100 drzew (po 50 w siedlisku polnym i leśnym). Do poboru prób dendrochronologicznych wybierano drzewa w jak najlepszej kondycji zdrowotnej, bez widocznych uszkodzeń pnia. Świdrami Presslera pobrano próby z 32 drzew (16 w siedlisku polnym i 16 w siedlisku leśnym), od kierunku południowego, na wysokości 1,3 m od poziomu gruntu. Chronologię złożono, stosując standardowe metody dendrochronologiczne. Do analiz dendroklimatologicznych wykorzystano dane ze stacji IMGW w Szczecinie (nr 12205, 53,24 N, 14,37 E, 1 m n.p.m.), oddalonej o 37-38 km w kierunku NNE od badanej alei (ryc. 3).

Badane drzewa osiągały wysokość 14-23 m. Kasztanowce w siedlisku leśnym były wyższe w porównaniu do drzew z siedliska śródpolnego (ryc. 4). Średnica korony w obu siedliskach była porównywalna: od 6,5 m na polu i 7 m w lesie do 11 m. Największe różnice zaobserwowano w przypadku średnicy pnia na wysokości 1,3 m nad poziomem gruntu. Drzewa na polu osiągały średnicę od 46 do 91 cm, ze średnią wartością 64 cm, natomiast kasztanowce w lesie miały pnie smuklejsze: od 35 do 73 cm, ze średnią wartością 56 cm (ryc. 4).

Na drzewach obserwowano porażenie liści przez szrotówka kasztanowcowiaczka. W siedlisku leśnym było ono szczególnie zauważalne, gdyż prowadziło do wcześniejszego opadania liści. Przyczyną takiej sytuacji może być zaleganie opadłych liści, w których zimują poczwarki (ryc. 2c). Na pniach drzew widoczne są odarcia kory, a w koronach drzew posusz gałęziowy i konarowy oraz ślady po odłamanych konarach. Na kilku pniach widoczne są owocniki grzyba wrośniaka różnobarwnego *Trametes* versicolor (L.) Lloyd (ryc. 2d). Można zauważyć także ślady żerowania dzięcioła, co świadczy o bytujących wewnątrz pni larwach owadów, które osłabiają drzewa (ryc. 2d).

Chronologia dla środowiska śródpolnego (FIELD) została złożona na podstawie 15 indywidualnych krzywych przyrostowych i liczy 103 lata (1916-2018). Średnia szerokość przyrostu rocznego kasztanowców w tym siedlisku wynosi 3,35 mm (od 2,77 do 3,59 mm) (tab. 1). Chronologia dla lasu (FOREST) powstała także na podstawie 15 najlepiej skorelowanych indywidualnych sekwencji przyrostowych i liczy 101 lat (1918-2018). Średnia szerokość słoja wynosi 2,82 mm, w zakresie od 1,56 do 3,31 mm (tab. 1). Rok 2000 przyjmuje się za początek widocznego wpływu inwazji szrotówka kasztanowcowiaczka na badane drzewa. Ponad 90% drzew notuje w tym roku spadek szerokości przyrostu rocznego w stosunku do roku poprzedzającego, a redukcje trwają przez następne kilka lat (ryc. 5). Skumulowany przyrost promieniowy jest dla całego okresu analizy większy dla kasztanowców rosnących w siedlisku polnym (ryc. 6). Obserwuje się także różnice w zależnościach przyrost-klimat dla obu siedlisk, głównie w roku poprzedzającym przyrost (ryc. 7). Analizy wykonano dla temperatury (T) w okresie 1948-2018, dla opadów (P) w okresie 1951-2018 i dla usłonecznienia (SD) w okresie 1965-2018. Dla drzew śródpolnych istotne znaczenie mają temperatura oraz usłonecznienie w lipcu i sierpniu roku ubiegłego (ujemne wartości korelacji i regresji), zaś dla drzew leśnych istotne są warunki we wrześniu roku ubiegłego (wielkość opadów i usłonecznienia). Dla obu chronologii obliczono łącznie 68 lat`wskaźnikowych. W pozytywnych latach wskaźnikowych lato jest zazwyczaj dość chłodne, z opadami powyżej średniej, a usłonecznienie poniżej średniej. W negatywnych latach wskaźnikowych notuje się temperaturę i usłonecznienie miesięcy letnich powyżej średniej oraz niedobory opadów w lecie. Także rok 2000, pomimo wystąpienia dość sprzyjających warunków pogodowych, jest rokiem negatywnym, co można wiązać z początkiem inwazji szrotówka kasztanowcowiaczka na teren NW Polski (Cedro i Nowak 2021).