DENDROBIOLOGY

2016, vol. 76, 145–156

http://dx.doi.org/10.12657/denbio.076.014

Anna Napierała-Filipiak, Maciej Filipiak, Piotr Łakomy, Robert Kuźmiński, Janusz Gubański

Changes in elm (*Ulmus*) populations of mid-western Poland during the past 35 years

Received: 31 December 2015; Accepted: 12 August 2016

Abstract: Three elm species are native to Poland: wych elm (Scots elm) (*Ulmus glabra* Huds.), field elm (*U. minor* Mill.), and European white elm (fluttering elm) (*U. laevis* Pall.). The epidemic of Dutch elm disease (DED) has led to a decrease in the popularity of elm cultivation. An analysis of forestry data was the first step in the assessment of elm resources. The area of forest stands where elms are dominant has more than doubled since 1978. Lowland alluvial forests rank first in regards to the number of elm localities per unit area of a given forest site type. While this site type is clearly preferred by elms, the majority of elm trees are actually scattered among sites of oak-hornbeam or closely related forests (of the alliance *Carpinion betuli*). Field research revealed a clear dominance of *U. laevis,* a species which in the past was predominantly located out of woodland and rarely cultivated. Data analysis indicated that all trees greater than 70 cm in diameter belonged to this species. Data from plots surveyed directly also suggest that the three elm species have slightly different habitat preferences. *U. laevis* prefers riparian habitats, although the major part of its resources is now on potential sites of oak-hornbeam or closely related forests. *U. minor* even more often than *U. laevis* occurs at less humid sites (mostly potential sites of oak-hornbeam or closely related forests), while *U. glabra* prefers moist slopes. In general, it appears that the impact of DED in the last 20–30 years has been smaller than in the preceding period, however, the disappearance of the disease has not been established. Undoubtedly, *U. laevis* is the elm species that is least impacted by DED.

Keywords: *Ulmus glabra*, *Ulmus minor*, *Ulmus laevis*, Dutch elm disease, alluvial forests

Addresses: A. Napierała-Filipiak, Institute of Dendrology Polish Academy of Science, Kórnik, Poland , e-mail: annafil@man.poznan.pl
M. Filipiak, J. Gubański, Institute of Landscape Architecture, Wrocław University of Environmental and Life Sciences, Wrocław, Poland
P. Łakomy, R. Kuźmiński, Faculty of Forestry, Poznań University of Life Sciences, Poznań, Poland

Introduction

Globally, there are about 30–40 species of the genus *Ulmus* (Richens, 1983), but only three elm species are native to Poland: wych elm (*Ulmus glabra* Huds.), field elm (*U. minor* Mill.), and European white elm (fluttering elm) (*U. laevis* Pall.).

Wych elm (*U. glabra*) is a Holarctic element, Euro-Siberian sub-element, with a centre of distribution in Europe. Its distribution in Poland is transitional, occupying the lowland-montane (mostly in the lower montane zone). Its distribution range includes northern and central Europe, the Balkans, Crimea, the Caucasus, and Asia Minor. It prefers deep soils in the submontane, montane, and subalpine zones. Outside of mountainous regions, it prefers areas with high precipitation, which in Poland includes the uplands and the belt of lakelands. It is a minor component of fertile forms of Carpathian and Sudetian beech forests, montane ash forests, riverine forests on slopes, and oak-hornbeam or closely related forests (of the alliance *Carpinion betuli*), where it usually occurs mixed with the other two native elm species, *U. minor* and *U. laevis* (Richens, 1983; Głaz; 1986; Kosiński, 2007; Jaworski, 2011; Heybroek, 2015).

Field elm (*U. minor*) is a connective element between the Holarctic and Mediterranean Regions. Its distribution in Poland is also transitional, lowland-submontane. It is found in central, southern, and western Europe, North Africa, Asia Minor, southern Siberia. In Poland, it occupies lowlands and the submontane zone, mostly in river valleys, along streams, in riverine forests, and in forests on sunny slopes. It seems to have an optimum preference for alluvial forests in middle sections of rivers, and the uplands of southern Germany and Switzerland (Kosiński, 2007; Jaworski, 2011).

European white elm (fluttering elm) (*U. laevis* Pall.) is a Holarctic element, Euro-Siberian sub-element, with a centre of distribution in Europe. Its distribution in Poland is transitional, occupying the lowland-submontane. It is found in central and eastern Europe but not in its northernmost and southernmost latitudes. Its highest presence is in Baltic states. It is distributed throughout Poland, except in the mountains. It occurs singly or in small groups, mostly on alluvial sites and in oak-hornbeam or closely related forests, especially in moister locations (Jaworski, 2011). According to Matuszkiewicz (2015), in Poland *U. laevis* is always an admixture species in the natural riparian communities and especially in oak-hornbeam forests.

Elms (*Ulmus* spp.) used to be highly valued by both foresters and the timber industry professionals. After the dramatic decline of elms in the 1960s and 70s, however, these trees were not seriously considered for many years in forest planning exercises. Because of the recent decline of other tree species typical of alluvial sites, e.g. pedunculate oak (*Quercus robur* L.) and especially European ash (*Fraxinus excelsior* L.), elms have once again gained interest among forest planners. Due to the long period of neglect, however, little is known about their current distribution and population size (Napierała-Filipiak et al., 2014).

Elms and their wood products have been heavily utilized by humans for thousands of years and humans have had a significant impact on their distribution and population size. Its wood for over 7000 years has assisted in hunting and warfare and its leaves and bark were semi-indispensable for the production of milk and meat (Heybroek, 2015). Elms and lindens were once some of the best known and widely distributed species of large trees in many European countries. Timber of *U. glabra* (wych elm), and *U. minor* (field elm), was highly valued because of its mechanical properties, resistance to water, as well as for the beautiful colour and pattern of its wood (Richens, 1983; Heybroek, 2015). It is commonly believed that most elm species, compared with other tree genera, need relatively fertile soils (Diekmann, 1996). Elms are valuable components of the ecosystem. The addition of as little as 20% of elm leaves to pine litter markedly accelerates its decomposition, and consequently, nitrogen and phosphorus cycling in the ecosystem. Elm leaf litter is decomposes very quickly due to a high concentration of alkaline, and a low concentration of acidic, buffering substances. Elm leaf litter has an alkaline PH ranging from 6.5–7.3, which is higher than the leaf litter of any other native tree species (e.g. Falkengren-Grerup et al., 1998; Polyakova & Billor, 2007; Jaworski, 2011). Jaworski (2011) reported that wych and field elms can be found as valuable minor components of the canopy in a very wide range of forest habitats, representing as many as eleven forest-site types. Timber of the third elm species native to Poland, *U. laevis* (fluttering elm), was traditionally considered to be of lower quality, and so was only sporadically cultivated in forests.

The rapid decline in interest of elm cultivation was associated with the onset of the epidemic of Dutch elm disease (DED). In Europe, it is caused by two fungal species, *Ophiostoma ulmi* and *O. novo-ulmi*, and spread by bark beetles (subfamily Scolytinae). Fungal spores are transferred from infected trees to healthy ones by young beetles that feed after emergence (before reaching sexual maturity) in the crowns of elm trees, excavating galleries or cavities in the young bark and wood of shoots. The processes that regulate the current beetle-fungus symbiosis remain poorly understood. The relationships between elm bark beetles and *O. ulmi* s.l. depend on several factors, such as the climatic and environment characteristics, and the interactions between the components of the biotic community (Brasier, 1991; Santini et al., 2005; Solla et al., 2008; Santini & Faccoli, 2015).

DED has a major economic impact, especially in urban green areas, parks, and on roadside plantings. It initially causes dieback of branches and eventually results in tree death. Depending on the country, DED has resulted in the premature death of extremely large numbers elm trees, destroying 50 to 80% of trees in this genus. The disease first reached epidemic levels in the early 20th century, and after a hiatus, reappeared in a new form in the 1950s and 60s. It spread throughout Europe in a relatively short period of time and still persists with varying degrees of intensity. It has also spread to North America and has decimated elm trees there as well. community (Brasier, 1991; Filipiak & Napierała-Flipiak, 2015; Grzywacz, 2015; Santini & Faccoli, 2015).

While the reason that DED reached epidemic levels is still unclear, its rapid development and spread are assumed to be due to some extent to human activity. For example, the utilization of inappropriate methods of drainage and irrigation resulted in disturbance to local water tables, which led to the deterioration of elms on alluvial sites, where they were most abundant (Jaworski, 2011; Filipiak & Napierała-Flipiak, 2015). The 19th-century practice of planting elms along roads and field borders also made the transmission of the disease by small beetles much easier. Several species of the fungus, *Ophiostoma*, are the causal agents of DED and it is highly probable that humans unintentionally facilitated the introduction of one the species, *O. himal-ulmi*, which had only been observed earlier in South-East Asia, into Europe and North America. *O. himal-ulmi* directly caused the second, stronger wave of the epidemic in European and American elms, which had no resistance, or caused it indirectly, as a result of crossing with native strains of *O. ulmi* creating the very virulent species, *O. novo-ulmi* (Brasier, 1991). *U. minor* is the elm species considered to be the most susceptible to DED, while *U.* laevis is considered to be the most resistant since the beetle vectors of this disease colonize trees of this species less commonly (Martín-Benito et al., 2005). The epidemic proportions of DED has led to a decreased interest in elm cultivation, in parks and along roads, as well as in forests. While the disease can cause severe losses in forest plantings, research conducted in the UK and Scandinavia (Diekmann, 1996; Emborg, 1998; Peterken & Mountford, 1998; Oheimb & Brunet, 2007; Solheim et al., 2011) indicates that DED rarely leads to the complete elimination of elms from a given site. The studies cited above suggest that where the contribution of elms dramatically decreased in forest stands in the past due to DED, their current contribution may be considerably higher.

Matuszkiewicz (2015), in his phytosociological monograph, lists elms as important components of a dozen forest and shrub communities in Poland. Głaz (1986) reported that in the 1970s forest stands dominated by elms accounted in the Wielkopolska–Pomerania Region for only 105 hectares (about 0.01% of the total forest area). It seems relevant to determine if the situation with elms has changed since then. The objectives of the present study were to investigate the population size, distribution, and habitat preferences of individual elm species, and to determine the current level of the threat of DED and possibly other factors, on the presence of elm trees. It was also our intent to develop management strategies for forest stands, including elms, which could form a basis for the development of a protective strategy for threatened *Ulmus* spp.

Material and Methods

Study area

The Wielkopolska–Pomerania Region (Kraina Wielkopolsko-Pomorska, III) includes the western and central part of the Polish Lowland (Fig. 1). Woodlands occupy 30.3% of this region, a value that is 1.1% higher than the average in Poland.

Annual precipitation in the Wielkopolska–Pomerania Region is very low (about 500–600 mm), especially in the central and eastern sections. Snow cover lasts 50–60 days in nearly all parts of the region and the growing season is about 210 days. The mean annual temperature in this region is 8.9°C, but in the coldest month (January) the mean temperature is about –0.8°C, whereas in the warmest month (July) it is about 18.9°C. Thus the climate is relatively mild and warm. Nearly the whole region, with the exception of its southern edges, is within the limits of the last glaciation. Soils are mostly of glacial origin, usually sandy, but clays are also common, especially on eroded moraine hills. In valleys, soils are waterlogged and boggy. All of the forest site types characteristic of Polish lowlands are found in the Wielkopolska–Pomerania Region (Zielony & Kliczkowska, 2012).

Fig. 1. Location of the study area (grey) on a map of Europe.

Methods

Forest plots with elms in Poland were identified, located, and initially described (including an estimation of population size) based on the forest inventory (conducted by the Office of Forest Management and Geodesy) data, available in a state-owned database. In Polish forestry, forests are divided by a network of treeless lines into administrative units known as forest divisions, covering about 25 hectares each. The major criterion of their creation is their location in the forest district. It is a regular and artificial classification. Those units are composed of irregular smaller units known as forest plots (in Polish: "wydzielenia leśne"), delimited on the basis of factors related to forest stand structure. A forest plot is a forest patch uniform in respect of economically important characters (e.g. tree age and species composition), which needs to be managed in a uniform way. It is a basic unit of forest description and forest management planning. Its synonyms are: forest subdivision or simply forest stand in jargon. The minimum size of forest plots is 1 hectare if the variation of forest units is low and 0.5 hectare if the variation is high. In nature reserves and experimental forests, forest plots are delimited irrespective of plot size. The smaller units (forest plots) described above were the basis for separating the elm localities in our study.

Since the forestry database does not distinguish between elm species, all three species native to Poland (*U. glabra, U. laevis*, and *U. minor*) were initially analysed collectively. Comparative data were extracted from the report by Głaz (1986), based on the forestry records collected in 1978.

Reduced area (representing an estimation of real area currently covered by elms) was calculated by multiplying the area of the plot with elms by the share of elms in the forest stand (ranked on a scale of 1–10, roughly corresponding to 10–100% with increasing rank). For example, for a rank of 1, plot area was multiplied by 0.1, for rank 2 it was multiplied by 0.2, etc. For the rank of "locally" (below 10% and above 5%), the multiplier was 0.075, while for a rank "individually" (below 5%), it was 0.025.

Forestry documentation usually did not include information on individual species of elm in each of the forest stands. As a result, data on elm species had to be collected in the field. Based on the available information, 150 plots, were selected for a direct physical inventory. Field work included 10 forest districts located in various parts of the study area. Approximately 33% of the total number of the directly investigated plots in the individual forest districts contained elms that represented less than 10%, 10–50%, and over 50% of the plot area. In total, these categories represented 50 forest stands. We also did our best to select plots so that half of them in each category were young (up to 50 years old), while the other half were plots with elms older than 50 years. Direct observations and measurements were made in all 150 plots. The population size of each of the *Ulmus* species was determined in each of these plots. The occurrence of DED symptoms was also recorded, along with a description of the habitat, paying special attention to the location of the plot with respect to major topographic features. DED occurrence was determined on the basis of its commonly known symptoms described e.g. by Hartmann et al. (2007): characteristic withering of leaves, ring-like discolouration within the sapwood, characteristic beetle feeding galleries under the bark of dying trees. From some forest stands, samples were collected and subjected to phytopathological inspection in the laboratory, which usually confirmed the occurrence of pathogenic *Ophiostoma* species, as described in a separate publication (Łakomy et al., in print).

The recorded data from the field assessment was supplemented with information from forest inventories.

Different species of elm present in the investigated plots were recorded and described as a separate position. of The same approach was used for the occurrence of elms in different layers of the stand, but only if the number of elms in the lower layer was not smaller than the number of elms in the higher layer (representing the theoretical possibility of main stand restoration). Three layers were distinguished: upper storey (trees forming forest canopy), lower storey (young trees higher than 1.5 m, and trees present in the combined second and lower storey) and underwood (young trees less than 1.5 m). Using this approach, 197 localities were distinguished in the 150 examined forest plots.

During the fieldwork main types of forest habitats (plant communities) were identified based on criteria adopted in publications of Matuszkiewicz et al. (2013). Considering that in the uplands and mountains of Poland, *U. glabra* is found most frequently in moist forests on slopes, in our study we distinguished specific sites on slopes with an angle of at least 20° (35%) (Figs. 7–9), primarily on the potential sites of oak-hornbeam or closely related forests. Field research was conducted mainly in 2012 and 2013.

The distribution of forest plots with elm in forest sites of various types was compared with distribution of all forest plots in forest sites types in the Wielkopolska–Pomerania Region. The distribution of localities with elm trees showing DED symptoms in habitat type was compared with the distribution of all localities with elms. To compare the distributions the χ^2 test was used.

Results

Analysis of forest documentations

Figs. 2–6 present data obtained from the analysis of forest management records and documents. The most recent forest inventory data indicates that elms are found in 16,307 forest stands (plots) in the Wielkopolska–Pomerania Region (2.54% of all forest plots) and that these plots cover 50,272.41 hectares. Plots with an elm share of “locally” (below 10% and above 5%) are the most numerous (8,852) and cover 29,622.48 hectares. Only 49 forest plots in Wielkopolska are pure elm stands, and they cover 62.40 hectares. The reduced area of forest stands with elms (Fig. 2) was estimated at 3,220.91 hectares, including 208.40 hectares of forest stands that were dominated by elm (score 5–10). A comparison of the data from the current analysis with data from 1978 (Głaz, 1986), reveals that the area represented by elms in such forest stands in the Wielkopolska–Pomerania Region has doubled in this period (102% increase).

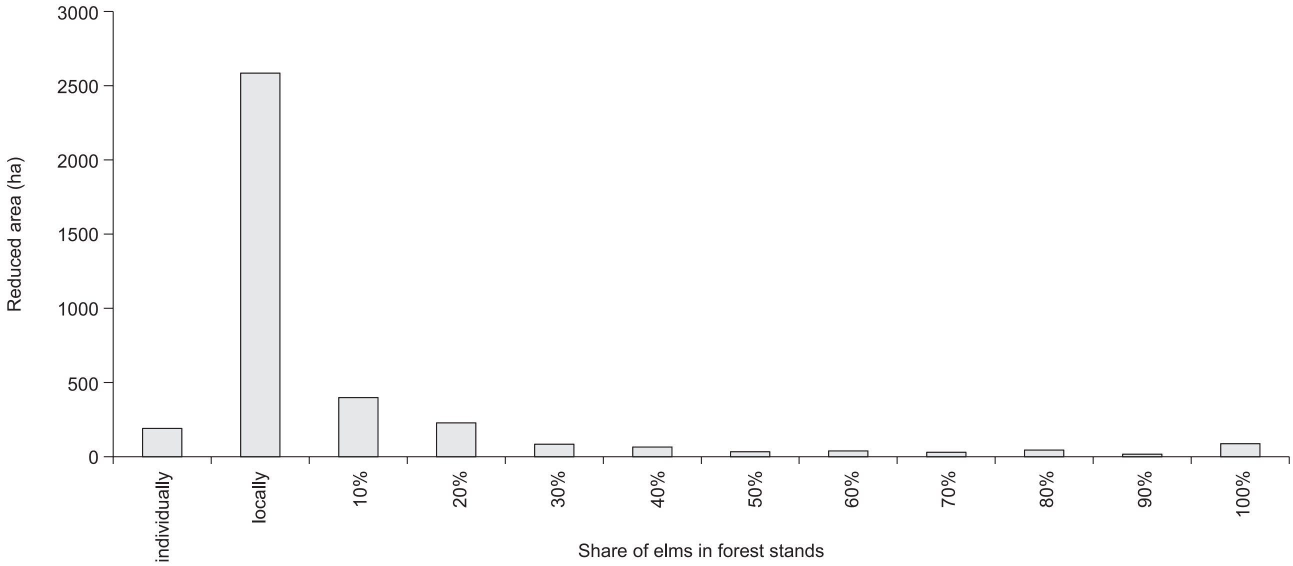

Fig. 2. Real (reduced) area covered by elms in the Wielkopolska–Pomerania Region, with subdivision into classes of their share in the forest stand.

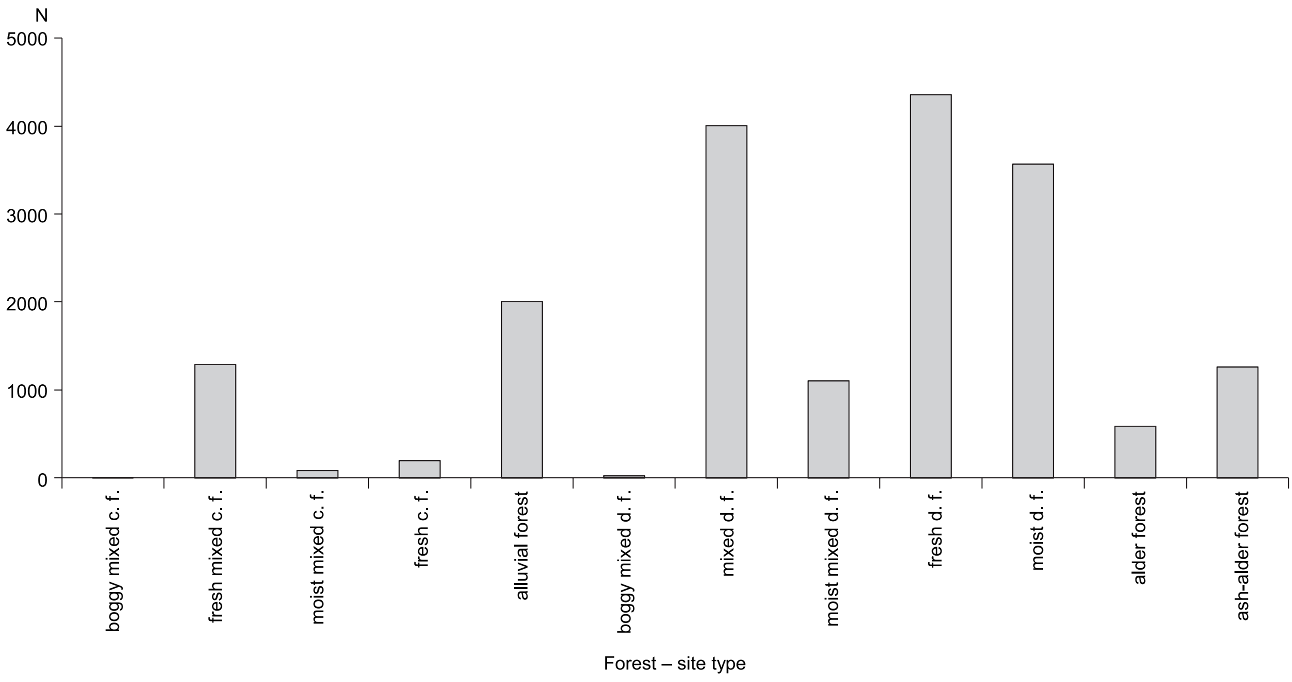

Fig. 3. Number of forest plots with elm in forest sites of various types in the Wielkopolska–Pomerania Region in 2012. c. f. – coniferous forest, d. f. – deciduous forest

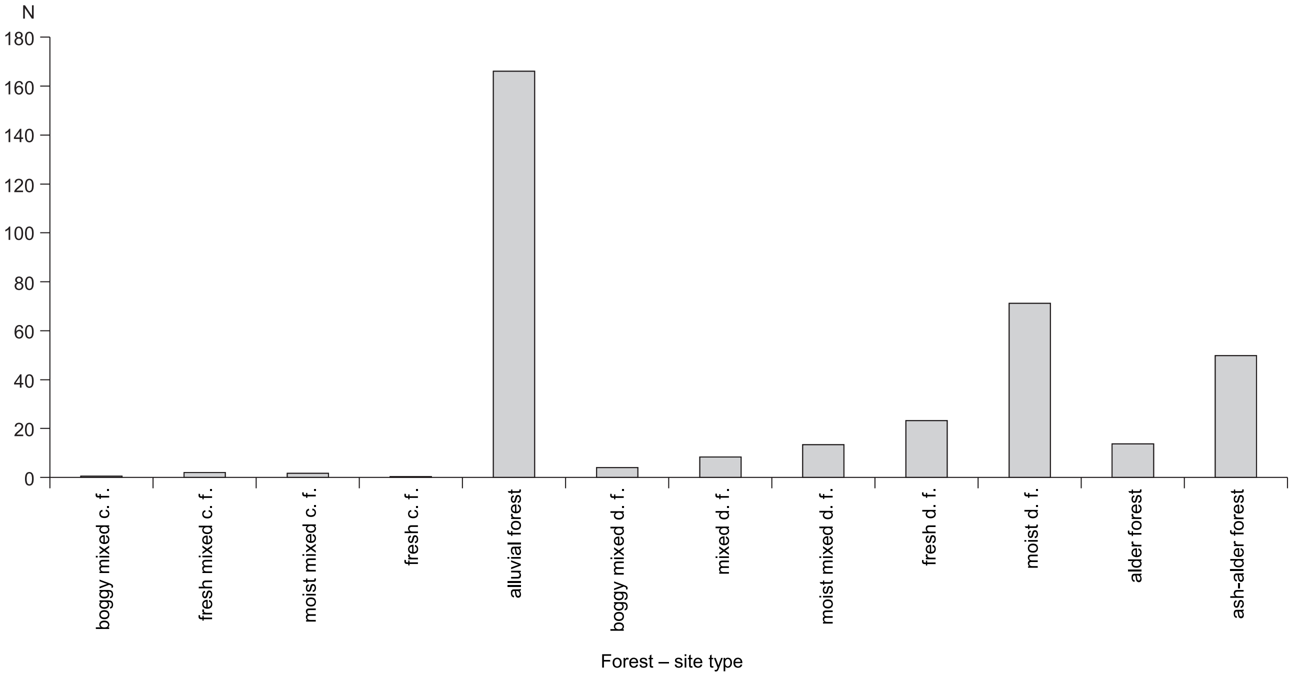

Fig. 4. Number of forest plots with elm per 10 km^2 of total wooded area in forest sites of various types in 2012. c. f. – coniferous forest, d. f. – deciduous forest

Generally, the elm species account for 0.23% of the total forested area in the region.

Most of the forest plots with elms are classified as fresh deciduous forest, followed by mixed deciduous forest, moist deciduous forest, alluvial forest, and fresh mixed coniferous forest (Fig. 3). The comparison of the distribution of sites in Fig. 3 with the overall distribution in the region indicates significant

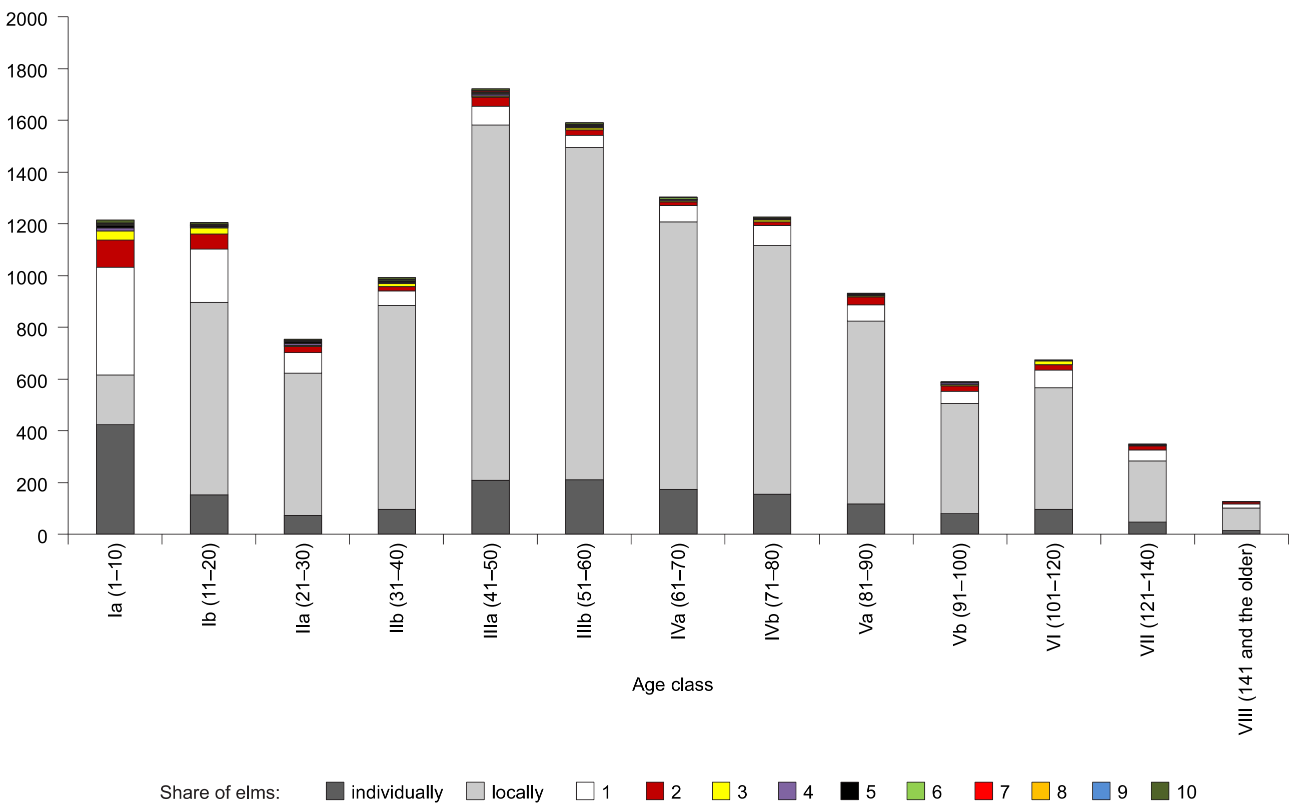

Fig. 5. Age distribution of forest plots with elms, taking into account the share of elms in forest stands in the Wielkopolska–Pomerania Region in 2012. The share of elms of 1–10 corresponding to 10–100%; locally – roughly below 10% and above 5%; individually – below 5%.

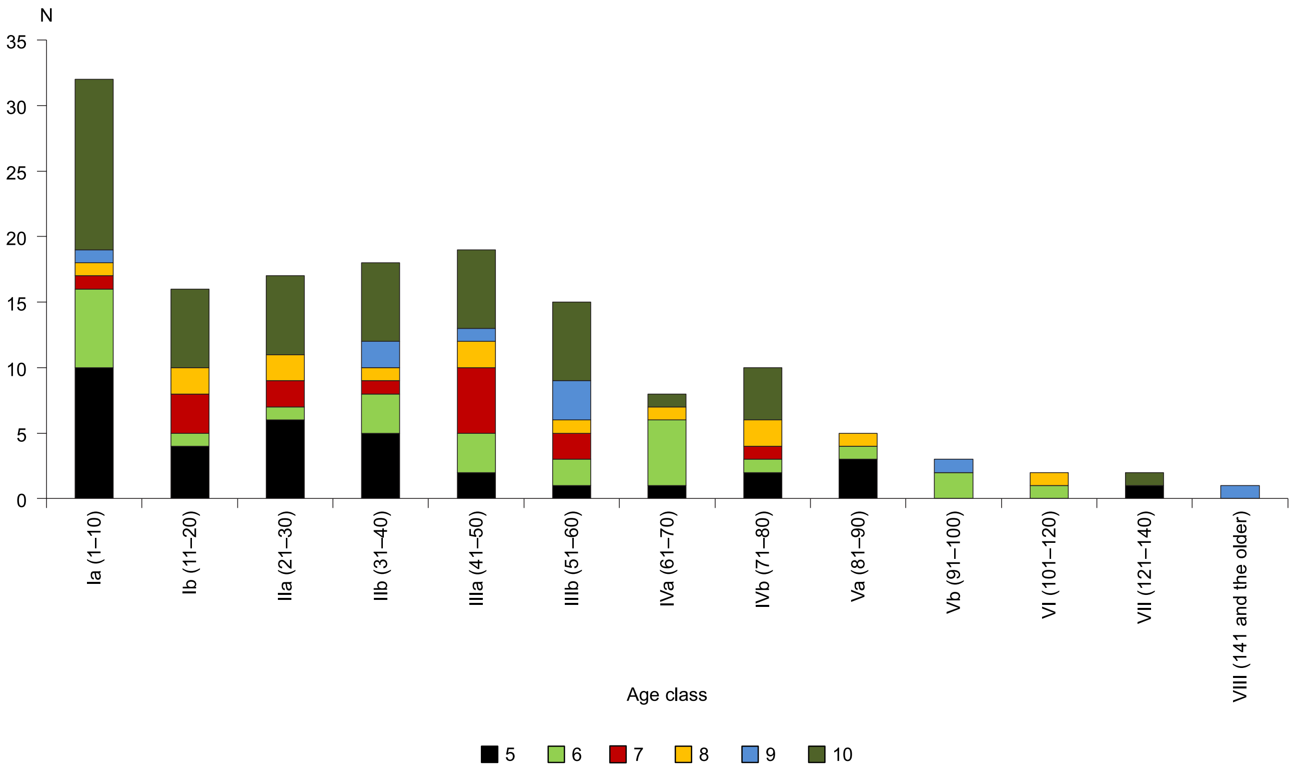

Fig. 6. Age distribution of forest plots dominated by elms, taking into account the share of elms in forest stands in the Wielkopolska–Pomerania Region in 2012. The share of elms of 5–10 corresponding to 50–100%.

differences (χ^2 = 37.5, $P < 0.05$). Fig. 4 shows the number of plots with elms per 10 km^2 of the given forest-site type. In that case, alluvial forest ranks first, followed by moist deciduous forest.

The age distribution of trees in forest plots with elms (Fig. 5, 6) is composed of a larger share of younger trees, especially of trees under the age of 20 years, compared to the general age distribution of forest trees in the study area. This is particularly evident in the case of stands where elm trees dominate (Fig. 6).

Field research and characteristics of the different elm species

Figs. 7–9 present data obtained directly from forest stands in the field. Figs. 7 and 8 show typical locations of individual elm species, taking into account the vegetation layers present within the stand and varying shares of elms. The number of plots within each share class differs from the one adopted in the methodology (33% in each class). This is connected with distinction within some localities the additional forms of occurrence of elm (species, layers). Fig. 9 includes information on the occurrence of DED symptoms.

U. glabra (wych elm) is the least represented elm species in Wielkopolska. Out of the 197 distinguished localities of elms found in the 150 investigated forest plots, only 16 forms were represented by *U. glabra* within 10 plots (Figs. 7–9). Among these fourteen forms, two were in alluvial forests, five in oak-hornbeam or closely related forests, and the other seven were in fertile forests on slopes. An additional 15 places (parks, tree lines along roads) of occurrence were identified for this species. In most of them (11 out of 15), only a single elm tree was found. Forest plots with a higher share of this species are found in the northern part of the region, on steep slopes at lake edges, or on potential sites of slope forests, where *U. glabra* sometimes forms the lower tree layer. It is rarely recorded as a single tree in the lower tree layer or as several saplings in the shrub layer, with the exception for potential sites of coniferous forests.

U. glabra was dominant in two localities where it was present in small patches (covering ca. 100–200 m^2) in the undergrowth. In four other localities, its share was slightly higher than 10%, while its share was below 10% in all of the other locations (plots) (Fig. 7). The largest (up to 50 cm in dbh and 20–23 m high) specimens of *U. glabra* are most likely not of natural origin but were rather planted, as they were occasionally found in old parks, near manor houses, and singly in urban green areas, as well roadside plantings. The majority of trees in forests are mostly younger specimens.

Most of the trees observed in 2012 and 2013 were healthy, but at 25% of forest plots with this species

(Fig. 9), exhibited typical DED symptoms. In two localities (Kórnik, Rawicz) where the occurrence of DED has been monitored continuously, the disease has progressed quickly (within a year, the disease affected nearly the whole tree).

U. minor (field elm) is most frequently found in the western and southern portions of Wielkopolska. Older and larger trees, up to 29 m high and 50 cm in dbh, are very rare, but in four locations, this elm species forms a small forest stand. Three of the locations consist of small, wooded patches (forest islands) surrounded by arable fields, while the fourth location is immediately behind the main flood embankment of the river Oder (Odra) in an elm-ash forest which is gradually being transformed into oak-hornbeam forest due to the absence of flooding.

Currently, In alluvial, elm-ash forests., trees of *U. minor* grow primarily under the canopy of other trees, including mature specimens of *U. laevis*, which are much more numerous in such localities. Most individuals of *U. minor* reside in the shrub layer and lower tree layer (Figs. 7, 8), and many individuals exhibit signs of browsing by deer. While some larger specimens are present, they rarely exceed 5–6 m in height and 10 cm in breast height diameter. It is also noteworthy that in typical alluvial sites, *U. minor* is more frequent in drier sites (behind the flood embankment or on the embankment) than the coexist-

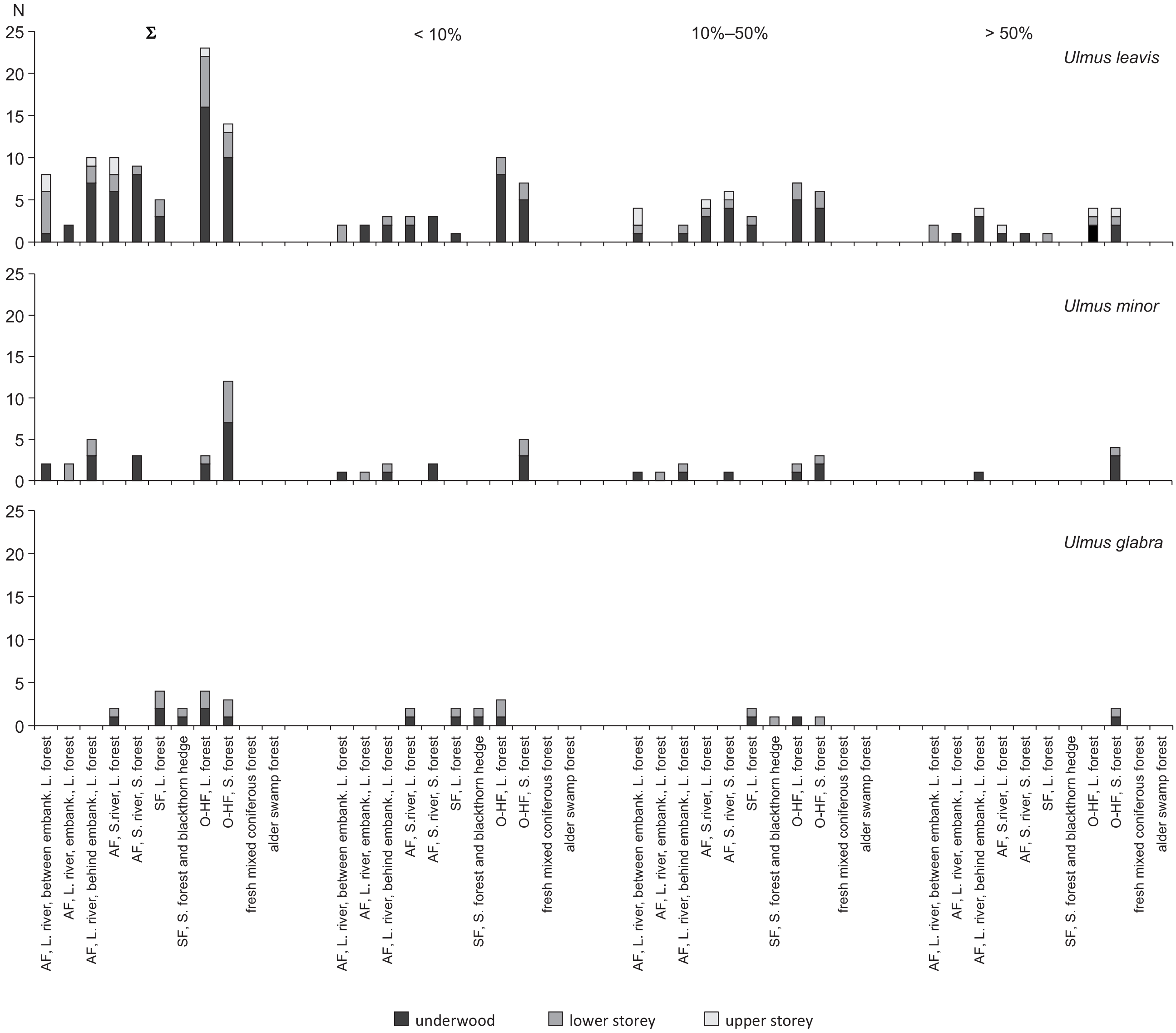

Fig. 7. Typical locations of individual elm species, taking into account the vegetation layers present within the stand and varying shares of elms. A – trees younger (< 50 years).
Σ – in total; < 10%, 10%–50%, > 50% – localities with varying shares of elms.
AF – alluvial forest, SF – slope forest, OH-F – oak-hornbeam or similar forest, L. river – at a large river (Warta, Oder), S. river – near a small watercourse, L. forest – large and medium-sized forest complexes, S. forest – small forest complex, between embank. – between flood embankments, embank. – area of flood embankments, behind embank. – behind embankments.

ent *U. laevis*. *U. minor* is also much more frequently affected by DED than *U. laevis* in sites where the two species co-exist. Symptoms of DED were observed on 47% of the localities. *U. minor* is frequently affected by DED, but readily regenerates from root suckers, which allow it to survive. Outside of alluvial forest sites associated with large rivers, the species is mainly found in farmlands in the Wielkopolska–Pomerania region. This elm species is frequently found on grassy field borders, roadsides, and especially near larger ditches. *U. minor* is also a component of blackthorn hedges and forest islands in farmlands, especially those having small bodies of water or waterlogged sites. Specimens of *U. minor* are found at the forest edge in these locations, as saplings up to 3–5 m high, either self-sown or having developed from root suckers. Other individuals regenerate from basal shoots after the death of the tree crown. The existence of older and larger trees of *U. minor* is very rare.

Out of the 197 distinguished localities of elms that were identified in the 150 investigated forest plots, only 32 localities were represented by *U. minor* within 19 plots (Figs. 7, 8). Various forms of this species are found in oak-hornbeam or closely related forests (56%), while the other 44% were found in alluvial forests. In the direct analysis of field plots, the share of *U. minor* was greater than 50% in only six of the field examined plots. In most plots, its share was below 10%.

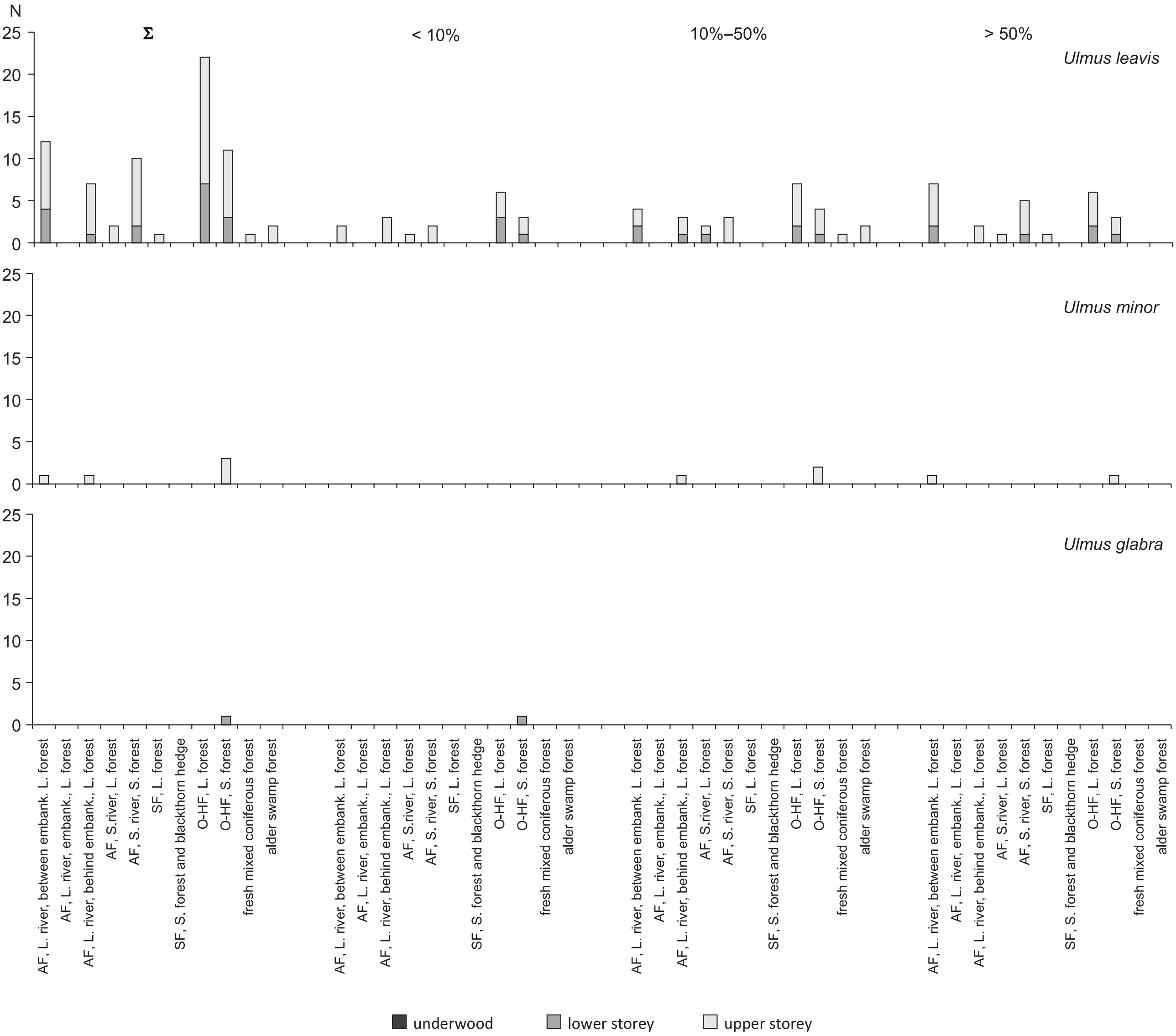

Fig. 8. Typical locations of individual elm species, taking into account the vegetation layers present within the stand and varying shares of elms. B – trees older (> 50 years).

Σ – in total; < 10%, 10%–50%, > 50% – localities with varying shares of elms.

AF – alluvial forest, SF – slope forest, OH-F – oak-hornbeam or similar forest, L. river – at a large river (Warta, Oder), S. river – near a small watercourse, L. forest – large and medium-sized forest complexes, S. forest – small forest complex, between embank. – between flood embankments, embank. – area of flood embankments, behind embank. – behind embankments.

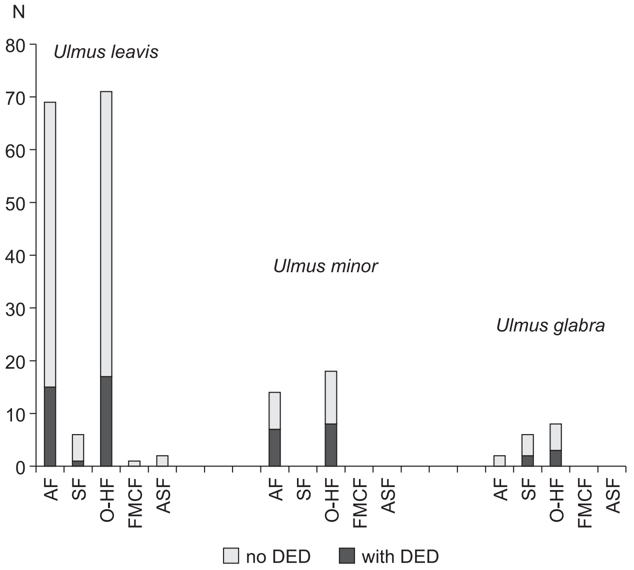

Fig. 9. Occurrence of Dutch Elm Disease (DED) symptoms in the Wielkopolska-Pomerania Region in 2012. AF – alluvial forest, SF – slope forest, O-HF – oak-hornbeam or similar forest, FMCF – fresh mixed coniferous forest, ASF – alder swamp forest

U. laevis is currently the most highly-abundant and frequently observed elm species in the Wielkopolska–Pomerania Region. Its dominance over the other elm species is so overwhelming that it can be assumed that the results presented in Figs. 2–6 primarily represent this elm species. Its prevalence is most conspicuous when only large trees are considered. More than 94% of trees in the directly investigated plots that were taller than 15 m were identified as *U. laevis*. All trees greater than 70 cm in diameter belonged to this species.

Forest inventory documentation seems to suggest that most of trees of this species are scattered on potential sites of oak-hornbeam or closely related forest, which, however, are much more common than potential sites of alluvial forests. Most of the forest stands with a large share of *U. laevis*, however, are found on various alluvial sites. Our field research indicated that this type of site was present in 46% of the observed forest plots (Figs. 7–9). These plots included alluvial forests covering large areas in valleys with large rivers (26%), and much smaller areas, linked with valleys having smaller rivers and streams (20%). For example, a nearly pure elm stand (covering ca. 500 m^2), of high quality, is located on an alluvial site on the edge of the river Oder in Sulechów forest district. Specimens of *U. laevis* located there exceed 35 m in height and 90 cm in diameter. On alluvial sites, this species is present in all layers of forest, from the upper tree layer to the shrub layer. In frequently flooded zones (willow-poplar forests), it is usually self-sown, forming small groups under the canopy of poplars. On non-alluvial sites, forest stands with a high share of *U. laevis* were recorded primarily on potential sites of oak-hornbeam or closely related forest. DED symptoms were the least frequent in localities possessing *U. laevis* trees, being observed in 22% of localities and generally in about 5% of trees. DED symptoms were observed primarily on older trees but traces of the bark beetles were also found on some trees that were less than twenty years old.

Overall, for all the studied species, there was no relationship between habitat type and the number of localities with trees showing DED symptoms (χ^2 = 13.8, P > 0.05) (Fig. 9).

The localities of the different elm species showing DED symptoms are located in different parts of the study area, but a large-scale decline (a majority of elm trees showing DED symptoms) was observed in only two localities (1.3%).

Discussion

An inventory of the occurrence of a species is a prerequisite for establishing any gene conservation programme (Eriksson, 2001; Venturas et al., 2015). The area of forest stands where elms are dominant has more than doubled between 1978 and 2012. The results presented in Fig. 6 may suggest that this is partly associated with an increase in the number of young forest stands (aged up to 20 years) and increased planting of elms. Despite this increase, however, the area occupied by elm trees in forested lands remains small.

In Fig. 3, the distribution of elm trees does not correspond with their habitat preferences, as their distribution is strongly affected by the area covered by a given forest-site type. Habitat preferences are more precisely reflected by the number of plots with elms per 10 km^2 of the given forest-site type (Fig. 4). In that case, alluvial forest ranks first, followed by moist deciduous forest, i.e. a site-type that in about 50% of cases is a potential site of alluvial forest according to Matuszkiewicz et al. (2013).

Our field research revealed a clear dominance in the presence of *U. laevis*, a species which in the past was rarely cultivated in forested lands.

Trees with DED symptoms were the least frequent in localities with *U. laevis,* which supports the premise that bark beetles transmitting the DED pathogen infest this elm species much less than the other elm species (Martín-Benito et al., 2005). The greater resistance of *U. laevis* to DED is also supported by the data on its abundance from the present study, as well as by other studies (Pinon et al., 2005; Venturas et al., 2015). DED symptoms were still visible, however, in 22% of the localities with *U. laevis*. Phytopathological analyses confirmed the presence of the pathogen (Łakomy, 2016), so this species is not completely resistant. It is noteworthy, that the data from our study indicates that this species clearly prefers alluvial sites, where its share of the number of elm trees is the highest. Despite this observation, however, most of elm trees grow on the more widespread potential sites of oak-hornbeam or closely related forest. A similar phenomenon was observed for European ash trees (Filipiak et al., 2004). Data presented in Fig. 9 indicate that the habitat preferences of the individual elm species varies. *U. laevis* prefers a typical floodplain habitat. Although Fig. 9 indicates that the number of forest stands dominated by elms on potential sites oak-hornbeam or closely related forest is slightly higher than on alluvial forest sites, it should be taken into account that the total area of oak-hornbeam or closely related forest sites in the Wielkopolska–Pomerania Region is nearly 15-fold greater (Matuszkiewicz, 2015). Trees of *U. minor* are more frequent on slightly drier sites, behind a flood embankment or on the embankment of typical alluvial sites, and on potential sites of oak-hornbeam or closely related forest that have a relatively high moisture content. Forest plots with a higher share of *U. glabra* are relatively often found on sites located on slopes with an angle of at least 20°. Those habitats are probably similar to a moist slope forest *Adoxo moschatelinae-Aceretum* (of the alliance *Tilio platyphyllis-Acerenion*),reported from Wielkopolska, or to a fertile maple-linden forest *Aceri platanoidis-Tilietum cordatae* (of the alliance *Carpinion betuli*) reported from northern Poland, and on several sites to the alluvial elm forest *Violo odoratae-Ulmetum*. The total area of such habitats of slope forests on the plains of Wielkopolska is definitely smaller than the area of potential sites of typical alluvial forest and oak-hornbeam or closely related forest. *U. glabra* had the largest percentage of trees with symptoms of DED. Therefore, *U. glabra* appears to be the elm species that is most susceptible to DED, which is in agreement with the results reported in another study (e.g. Pinon et al., 2005).

The share structure (Fig. 1) may suggest that DED is much more prevalent in forest stands with a high share of elms than in areas where elms are scattered. The localities of the different elm species showing DED symptoms are located in different parts of the study area, but in most of the investigated forest stands one to several dozen trees were affected by the disease. These results are consistent with the suggestions that the impact of DED has decreased in the last 20–30 years, and is now less severe than in the past (Diekmann, 1996; Peterken & Mountford, 1998; Oheimb & Brunet, 2007; Solheim et al., 2011; Napierała-Filipiak et al., 2014; Filipiak & Napierała-Filipiak, 2015).

An increase in the number of stands with elm trees and but limited DED pressure, suggests that the share of elm trees in the forests of the study area and the neighbouring regions can be increased. The high frequency of DED that is still observed, however, suggests that their share will not exceed several percent. It seems that only *U. laevis* has any economic potential. Specifically, *U. laevis* can be a source of quality timber, whose qualities are only slightly less than those that are found in *U. glabra* and *U. minor* (Kokociński & Surmiński, 2015). The existing localities with *U. glabra* and *U. minor* trees should be preserved, and where possible, new plantings with a limited number of trees should be established. It should be understood, however, that the existence of forested stands of these elm are mostly to preserve the species and the quality of the environment. Currently, the resources representing all three species of elm are strongly scattered, which may lead to a reduction in the gene pool (Pinon at al., 2005; Vakkari et al., 2009; Venturas et al., 2015). Therefore, the *in situ* protection programme should be extended to establish *ex situ* gene banks, within which the beetles responsible for spreading DED are controlled using a variety of methods, including appropriate insecticides and removal of trees, particularly those attacked in the previous growing season (Grzywacz, 2015; Menkis et al., 2016). These efforts can help to ensure that these plantings represent an important element in the future for extending the seed base of elm and the genetic diversity within that seed base. It is important to maintain accurate records of all the efforts related to the *ex situ* and *in situ* protection of these elm species (Collin & Bozzano 2015) and to monitor the impact of these efforts.

Acknowledgement

This study was financially supported by the National Science Centre, Poland, grant No 2011/01/B/NZ9/02883 "Assessment of the present population size, distribution, and condition of elms (*Ulmus* spp.) in Poland".

References

Brasier CM (1991) *Ophiostoma novo-ulmi* sp. nov., causative agent of the current Dutch elm disease pandemics. Mycopathologia 115:151–161.

Collin E & Bozzano M (2015) Implementing the dynamic conservation of elm genetic resources in Europe: case studies and perspectives. iForest – Biogeosciences and Forestry 8: 143–148. doi: 10.3832/ifor1206-008.

Diekmann M (1996) Ecological behaviour of deciduous hardwood trees in Boreo-nemoral Sweden in relation to light and soil conditions. Forest Ecology and Management 86: 1–14.

Emborg J (1998) Understorey light conditions and regeneration with respect to the structural dynamics of a near-natural temperate deciduous forest in Denmark. Forest Ecology and Management 106: 83–95.

Eriksson G (2001) Conservation of noble hardwoods in Europe. Canadian Journal of Forest Research 31: 577–587.

Falkengren-Grerup U, Brunet J & Diekmann M (1998) Nitrogen mineralisation in deciduous forest soils in south Sweden in gradients of soil acidity and deposition. Environmental Pollution 102: 415–420.

Filipiak M, Dolatowska A, Kmiecik M & Pilarek Z (2004) European ash in the Bardzkie Mountains – species characterization based on forest documentation. Dendrobiology 52: 17–21.

Filipiak M & Napierała-Filipiak A (2015) Zarys ekologii: Wiązy (ed. by W Bugała, A Boratyński & G Iszkuło) Bogucki Wydawnictwo Naukowe, Poznań, Poland, pp. 133–181.

Głaz J (1986) Wiąz w Lasach Państwowych. Sylwan 130: 23−33.

Grzywacz A (2015) Ważniejsze choroby infekcyjne: Wiązy (ed. by W Bugała, A Boratyński & G Iszkuło) Bogucki Wydawnictwo Naukowe, Poznań, Poland, pp. 324–367.

Hartmann G, Nienhaus F & Butin H (2007) Farbatlas Waldschäden: Diagnose von Baumkrankheiten. Eugen Ulmer KG, Stuttgart, Germany.

Heybroek HM (2015) The elm, tree of milk and wine. iForest – Biogeosciences and Forestry 8: 181–186. doi: 10.3832/ifor1244-007.

Jaworski A (2011) Hodowla lasu. Charakterystyka hodowlana drzew i krzewów leśnych. Powszechne Wydawnictwo Rolnicze i Leśne, Warszawa, Poland.

Kokociński W & Surmiński J (2015) Właściwości techniczne i zastosowanie drewna: Wiązy (ed. by W Bugała, A Boratyński & G Iszkuło) Bogucki Wydawnictwo Naukowe, Poznań, Poland, pp. 432–442.

Kosiński P (2007) Rozmieszczenie oraz warunki występowania drzew i krzewów w polskiej części Sudetów Wschodnich. Acta Botanica Silesiaca. Monographiae 1., Wrocław, Poland.

Łakomy P, Kwaśna H, Kuźmiński R, Napierała-Filipiak A, Filipiak M, Behnke K & Behnke-Borowczyk J (2016) Investigation of *Ophiostoma* population infected elms in Poland. Dendrobiology 76: 137–144.

Martín-Benito D, García-Vallejo MC, Pajares JA & López D (2005) Triterpenes in elms in Spain. Canadian Journal of Forest Research 35: 199–205.

Matuszkiewicz JM (2015) Rola wiązów w zespołach roślinnych Polski: Wiązy (ed. by W Bugała, A Boratyński & G Iszkuło) Bogucki Wydawnictwo Naukowe, Poznań, Poland, pp. 181–235.

Matuszkiewicz W, Sikorski P, Szwed W & Wierzba M (2013) Zbiorowiska roślinne Polski – ilustrowany przewodnik. Lasy i zarośla. Wydawnictwo Naukowe PWN, Warszawa, Poland.

Menkis A, Östbrant IL, Wågström K & Vasaitis R (2016) Dutch elm disease on the island of Gotland: monitoring disease vector and combat measures. Scandinavian Journal of Forest Research 31: 237–241. doi: 10.1080/02827581.2015.1076888.

Napierała-Filipiak A, Filipiak M & Jaworek J (2014) Rozmieszczenie zasobów drzew z rodzaju wiąz (*Ulmus* spp.) w lasach Polski w świetle dokumentacji leśnej. Sylwan 158: 811–820.

Oheimb G & Brunet J (2007) Dalby Söderskog revisited: long-term vegetation changes in a south Swedish deciduous forest. Acta Oecologica 31: 229–242.

Peterken GF & Mountford EP (1998) Long−term change in an unmanaged population of elm subjected to Dutch elm disease. Journal of Ecology 86: 205−218.

Pinon J, Husson C & Collin E (2005) Susceptibility of native French elm clones to *Ophiostoma novo-ulmi*. Annals of Forest Science 62: 689–696.

Polyakova O & Billor N (2007) Impact of deciduous tree species on litterfall quality, decomposition rates and nutrient circulation in pine stands. Forest Ecology and Management 253: 11–18.

Richens RH (1983) Elm. Cambridge University Press.

Santini A & Faccoli M (2015) Dutch elm disease and elm bark beetles: a century of association. iForest – Biogeosciences and Forestry 8: 126–134. doi: 10.3832/ifor1231-008.

Santini A, Montaghi A, Vendramin GG & Capretti P (2005) Analysis of the Italian Dutch elm disease fungal population. Journal of Phytopathology 153: 73–79.

Solheim H, Eriksen R & Hietala AM (2011) Dutch elm disease has currently a low incidence on wych elm in Norway. Forest Pathology 41: 182–188.

Solla A, Dacasa MC, Nasmith C, Hubbes M & Gil L (2008) Analysis of Spanish populations of *Ophiostoma ulmi* and *O. novo-ulmi* using phenotypic characteristics and RAPD markers. Plant Pathology 57: 33–44.

Vakkari P, Rusanen M & Kärkkäinen K (2009) High genetic differentiation in marginal populations of European white elm (*Ulmus laevis*). Silva Fennica 43: 185–196. doi:10.14214/sf.205.

Venturas M, Fuentes-Utrilla P, López R, Perea R, Fernández V, Gascó A, Guzmán P, Li M, Rodríguez-Calcerrada J, Miranda E, Domínguez J, González-Gordaliza G, Zafra E, Alcántara MF, Martín JA, Ennos R, Nanos N, Lucena JJ, Iglesias S, Collada C & Gil L (2015) *Ulmus laevis* in the Iberian Peninsula: a review of its ecology and conservation. iForest – Biogeosciences and Forestry 8: 135–142. doi: 10.3832/ifor1201-008.

Zielony R & Kliczkowska A (2012) Regionalizacja przyrodniczo-leśna Polski 2010. CILP, Warszawa.