

Impact of climate change on ivy (*Hedera helix* L.) expansion in forests of Central Poland

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ABSTRACT

The article refers to a broader context of scientific debates on the effect of climate warming on shifts in species ranges and describes the recent changes in the distribution and life strategy of *Hedera helix* close to its eastern limit, in light of climate changes. European ivy is an ecotone species, occurring in fringe communities, in deciduous and mixed deciduous forests in fresh and moist habitats that are occupied by oak-hornbeam and riparian alder-ash forests in Central Poland. Since the mid-20th century, the ivy, a species rarely reproducing generatively, has become an expansive plant with a growing number of sites where flowering and fruiting individuals are encountered. We studied the distribution, habitat requirements and flowering of *H. helix* in Central Poland in the years 2015–2017 and compared to the situation in the mid-1970s. Climate changes in terms of average air temperatures and precipitation amounts for the past four decades were also assessed. Within the study area, 474 stands of naturally growing *Hedera* have recently been identified. Ivy was found to reproduce generatively on 121 of those locations. There has been an almost 10-fold increase in the number of fruiting ivy specimens since the mid-1970s of the 20th century. Changes in the species life strategy can be ascribed to the increase in both average air temperatures and solar radiation intensity observed for the past decades. Both enhanced fragmentation of woodland tracts and development of forest ecotones and forest canopy openings promote the expansion of *H. helix*, while its habitat preferences remain unchanged.

KEY WORDS

expansive species, forest habitats, ecotones, climate warming

INTRODUCTION

Climate is one of the major ecological factors responsible for life conditions on the globe (Ellenberg 1988; Odum and Barrett 2005). Consequently, climatic factors are predominantly accountable for changes in the extent of ranges of both plant and animal species (Sykes et al. 1996; Box et al. 1999; Bakkenes et al. 2002; Walther et al. 2002; Fosaa et al. 2004; Thomas et al. 2004; Svenning and Skov 2006; Newson et al. 2009). Global warming observed in the recent decades has a significant impact on changes in the life activity of organisms, due, in particular, to lengthening of the growing season (Menzel et al. 2006; Feehan et al. 2009). The latter has been reported in numerous works as the main cause underlying shifts of tree species ranges as well as changes in the distribution of herbaceous plants and biodiversity (Neilson et al. 1992; Sykes and Prentice 1996; Solomon 1997; di Castri et al. 1988; Parmesan and Yohe 2003; Koca et al. 2006; Svenning and Skov 2006; Feehan et al. 2009; Dullinger et al. 2012; Bernhardt-Romermann et al. 2015; Helm et al. 2017). The evidence accumulated at the turn of the 20th and 21st centuries indicates that climate changes result not only in entire plant formations (biomes) shifting up to several hundred kilometres but also in changes in biomes physiognomy due to the inevitable fluctuations in species composition (Neilson et al. 1992). It is the ecotone vegetation that is particularly sensitive to climate change (di Castri et al. 1988).

Changes in the natural environment because of human activities are another important factor affecting the dispersion of organisms (Daehler and Carino 2000; Cronk and Fuller 2001; Tokarska-Guzik 2005). Considering the origin of dispersing organisms, they may be divided into two groups: invasive and expansive (Richardson et al. 2000). Invasive are those alien species that, after trespassing their natural range limits, first take over the anthropogenic habitats and then colonise the natural ones. Invasive species constitute a very important factor affecting biodiversity (Thomas 1998; Genovesi and Shine 2004; Thuiller et al. 2008; Jones et al. 2010). Expansive organisms, on the other hand, exploit the new environments within the limits of their natural range. This process is typical of native species having high dispersive potential.

We studied the distribution of *Hedera helix* in the forests of Central Poland during the years 2015–2017,

examining an area of more than 250,000 ha, and compared the results with the accessible historical data. The aim of this paper is: 1) to discuss the expansion of ivy within the area of Central Poland shedding light on underlying causes and trends of dispersal and 2) illustrate the impact of climate change on increased fruiting intensity of the vine in Central Poland.

MATERIAL AND METHODS

Ivy is native to the Mediterranean and Atlantic regions, while its northern and eastern limits in Europe run through southern Scandinavia, the Baltic countries, Belarus, Ukraine, and the Balkans. An important factor limiting the occurrence of ivy is the winter air temperature. The species does not reproduce sexually on areas subject to the impact of continental climates (Navasaitis 1995). The vine may grow in both open and shady places (Metcalf 2005), but under natural conditions, it grows best in fresh, fertile soils in semi-shaded areas (Ellenberg 1988; Nawrocki 2010). *H. helix* tolerates low temperatures and drought (Laskurain et al. 2004). Owing to its clear range limits (both altitudinal and north-eastern) and structural features that vary with climate oceanicity, ivy has long been considered a species particularly suited to monitoring the shift of forest line because of climate change (Klötzli and Walther 1999). The eastern part of Poland lies at the European eastern border of *H. helix* range. The density of ivy's natural locations within the country decreases from west to east and northeast (Boratyńska 1987; Zajac and Zajac 2001).

Our study was conducted in forest habitats supporting *H. helix*. The average forest area (percentage of land area) in Central Poland varies from a very low, around 5%, in the north, to above 25% in the south. The overall biodiversity of the region was documented for more than half a century by, among others, Mowszowicz (1978) and Jakubowska-Gabara et al. (2011). Historical observations on ivy were provided by earlier works containing data concerning the occurrence of *H. helix* in 1970s and 1980s of the 20th century (Olaczek 1979; Jakubowska-Gabara 1988 and others). The source of the newest data on ivy distribution was both our own survey conducted in the years 2014–2018 and the most recent forest appraisal reports made by the State Forest Directorate of Łódź. In the article, we focused on the

numbers of fruiting specimens only. The term ‘fruiting specimen’ was understood as an ivy specimen climbing support (a tree) and bearing fruits or flowers. Every easily identifiable group of ivy specimens was treated as a stand. The historical data by Olaczek (1974) were used to determine the increase in the number of *H. helix* fruiting and flowering specimens in 16 stands, where the species was first noted more than 40 years ago (Tab. 1). The structure of distribution of values denoting the occurrence of fruiting specimens in two time periods was assessed using Pearson’s chi-squared test.

The occurrence of *H. helix* in forest habitats was determined using the ecological grid of forest site types (Forest Management Manual 2011). Forest habitats vary in terms of fertility and soil humidity gradients. Four levels of site fertility were distinguished, including coniferous forests (Coni.), mixed coniferous forests (Mix. coni.), mixed deciduous forests (Mix. deci.) and deciduous forests (Deci.). Within these units, four moisture levels were taken into account: dry, fresh, moist and swampy. Oligotrophic sites of dry and fresh coniferous forest correspond to the habitats of associations from the alliance *Dicrano-Pinion*, including *Leucobryo-Pinetum*, *Peucedano-Pinetum* and *Quercu roboris-Pinetum* (European Environment Agency typology: nemoral Scots pine forests) (EEA 2007). More fertile sites of mixed and moist coniferous forests are represented by the associations: *Quercu roboris-Pinetum* and *Quercu roboris-Pinetum molinietosum* (EEA typology: mixed Scots pine-pedunculate oak forest). Mixed deciduous forests or mesotrophic habitats with a distinctly more fertile soils (EEA typology: mesophytic deciduous forests) are taken by poorer associations of the pedunculate oak-hornbeam forests: associations *Tilio cordatae-Carpinetum betuli* and *Galio sylvatici-Carpinetum betuli* from the alliance *Carpinion betuli*. These also include the habitats of *Luzulo pilosae-Fagetum* from the alliance *Fagion sylvaticae* (EEA typology: atlantic and subatlantic lowland beech forest). Moist mixed deciduous forests are usually a disturbed communities *Fraxino-Alnetum* from the alliance *Alno-Ulmion*, or swampy alder woods *Ribeso nigri-Alnetum* from the alliance *Alnion glutinosae*. Acidophilous oak forest communities from the alliance *Quercion robori-petraeae* occupy mixed coniferous sites bordering the mixed deciduous sites. Deciduous forests take fertile and very fertile habitats with weakly acidic or neutral soils and

are classified as either fresh deciduous forests, represented by typical communities of *Tilio cordatae-Carpinetum betuli* and *Galio sylvatici-Carpinetum betuli*, or moist deciduous forests, for example, association *Tilio-Carpinetum stachyetosum sylvaticae*. Swamp deciduous forests correspond to habitats taken by the ash-alder communities of *Fraxino-Alnetum* and, less frequently, by *Carici remotae-Fraxinetum* from the alliance *Alno-Ulmion* as well as by *Ribeso nigri-Alnetum* from the alliance *Alnion glutinosae* (EEA typology – riverine and non-riverine swamp forests). The locations of ivy in the area under study were registered in the above grid of forest habitats (Fig. 3).

Climate change in Central Poland for the study years 1971–2010 was assessed based on the analyses of two data sources: the E-OBS gridded data set for daily temperatures (EU-FP6) and the data archives of the National Oceanic and Atmospheric Administration (NOAA) for temperatures and precipitation. The E-OBS data set, established under the project ENSEMBLES (EU-FP6; Haylock et al., 2008), has currently been updated under the European Climate Assessment & Dataset (EC&D), and data were gridded across a regular rectangular grid of a resolution of 0.25° (ca. 25 km in Poland). The E-OBS data were taken from the set 17.0 version of April 2018. In addition, analyses of changes in the average daily air temperatures and precipitation sums were made for several meteorological stations located in Central Poland, based on the NOAA data. The data were averaged for four seasons in successive decades and plotted on the graphs. The following tools were used to analyse and visualise the results: the Ferret software: Data Visualization and Analysis (Ferret Software), Climate Data Operators (CDO) and the R Project for Statistical Computing (R system).

RESULTS

Climate change

Analyses of meteorological data indicate that Central Poland witnessed a significant climate change for the past four decades. From maps in Figure 1, illustrating the spatial distribution of temperatures for the years 1971–2010, it follows that there was a clear increase in the daily air temperature in Central Poland in successive decades. The most pronounced impact of climate

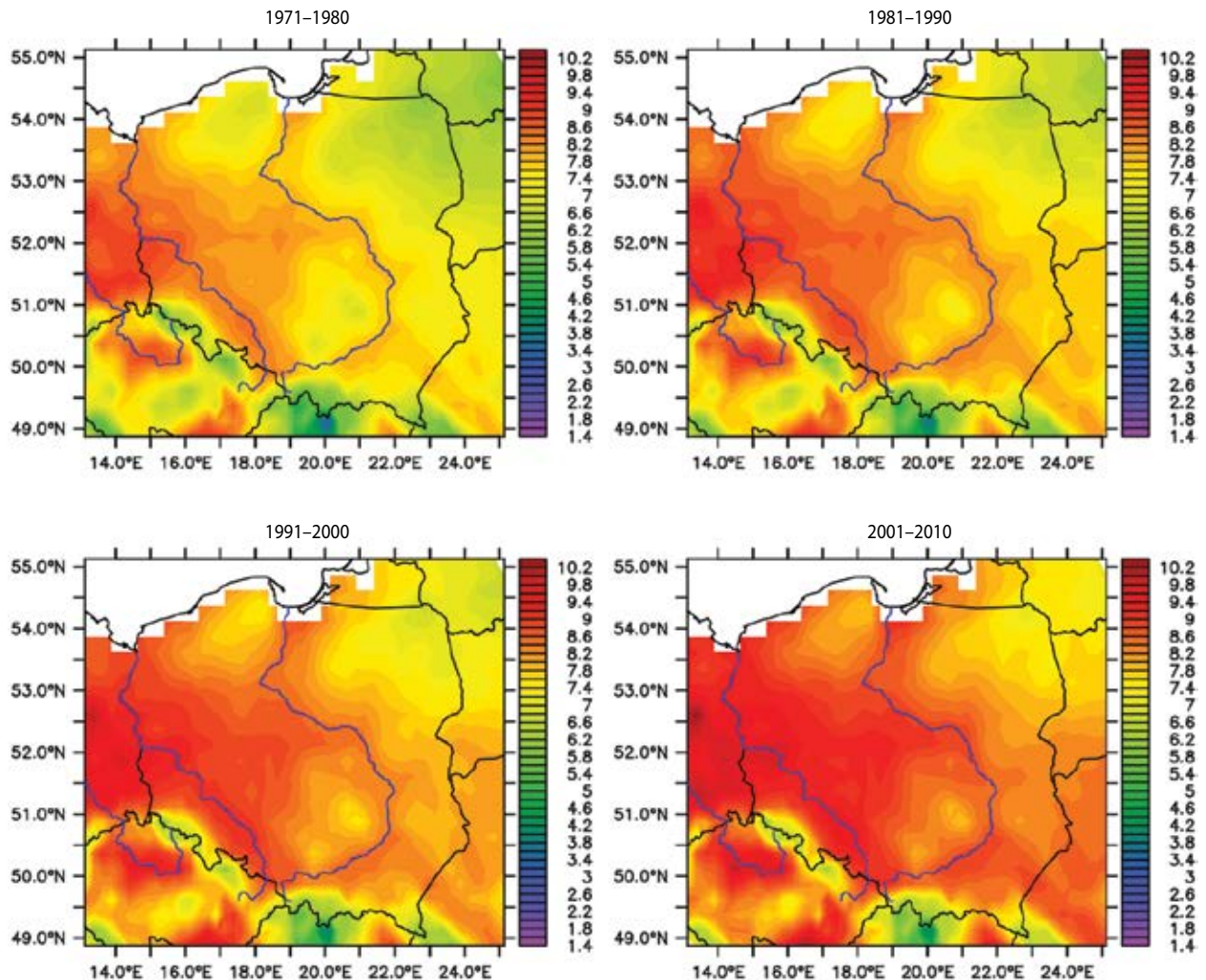


Figure 1. Increase in average air temperature (°C) in Poland in successive decades for the years 1971–2010, based on the E-OBS data

warming was observed in mid-Poland and in south-western parts of the region.

The graphs presented in Figure 2 (DJF, MAM, JJA, SON) illustrate changes in the average air temperatures and precipitation at selected meteorological stations in Central Poland for the period 1981–2010. Each point on the graphs represents sums of daily mean air temperature and of precipitation for a given station, averaged for four seasons and three successive decades. The graphs provide clear evidence of climate warming and the increase in the precipitation amounts at the stations. This is particularly significant for the summer months' temperatures (JJA), which is marked with an arrow on the graph.

SURVEY OF IVY OCCURRENCE

Altogether 474 natural sites of *H. helix* were recorded in the forests of Central Poland. Ivy was encountered in forests having a natural character and in the intensively managed forest stands. In dense stands, ivy was usually creeping on the ground, and climbing individuals were encountered only in the canopy gaps. However, in loose stands, where there was a sufficient sunlight, the vine was found to be readily climbing and producing fruits even under the tree canopy. Flowering ivy was recorded at 121 sites, where total of 1,416 specimens of *H. helix* were registered. Naturally occurring specimens of *H. helix* were recorded in nine forest habitat types (Fig. 3).

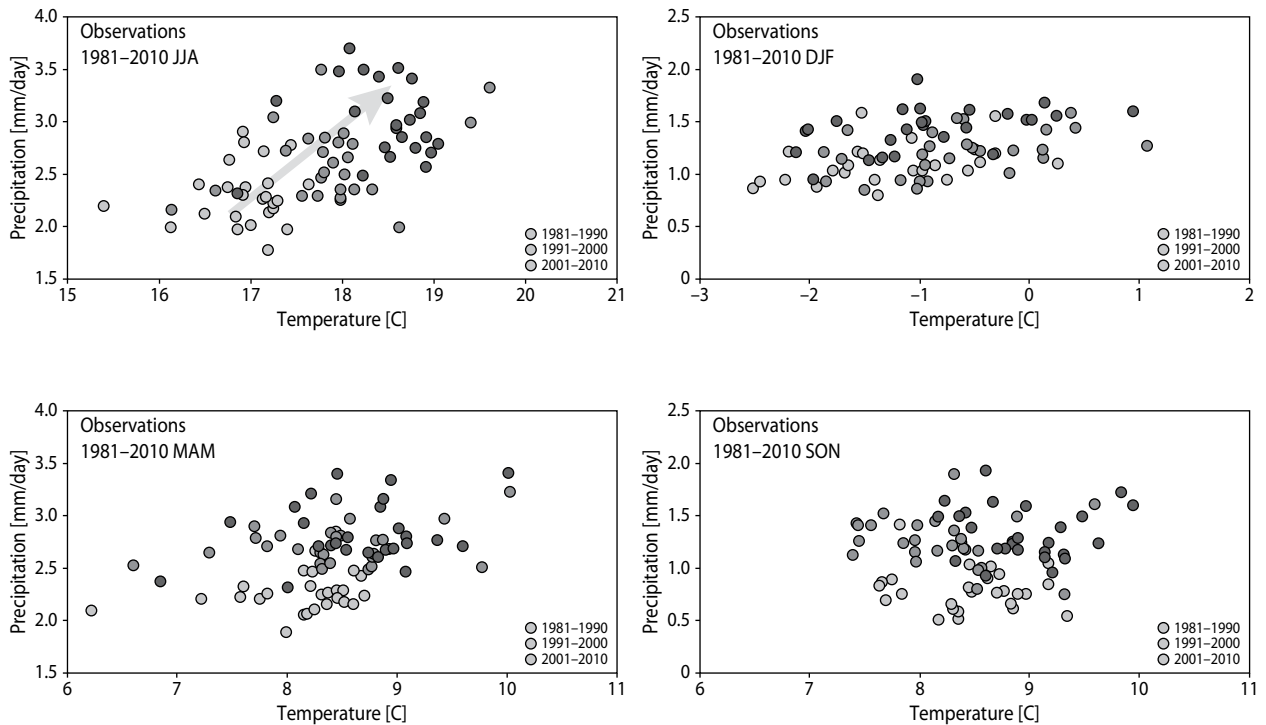


Figure 2. Average seasonal air temperature (°C) and precipitation (mm/day) in Poland at meteorological stations pictured in Fig. 1, each point illustrating temperature and precipitation at individual station, averaged for three decades: 1981–1990 (green), 1991–2000 (blue) and 2001–2010 (red). Data were taken from the NOAA database. Abbreviations denote months of individual seasons: DJF, winter; MAM, spring; JJA, summer; and SON, autumn

The species was most frequently found in fresh deciduous forest sites (at more than half of the sites examined – about 53%), whilst only sporadically in fresh coniferous sites. Considerably less stands of ivy (around 38%) were recorded in moist habitats. The vine was rarely found in habitats of fertile swamp forests (about 10%) and not found at all in dry coniferous forest sites.

The flowering ivy was mainly encountered as a component of fringe communities at forest edges, along roadsides and railway lines cutting across forest tracts. Nearly one-fourth of *H. helix* sites were recorded in the forest interior, in loose stands with a scarce shrub layer. In dense forests, ivy was mostly found climbing trees growing at the peripheries of tree stand gaps (Fig. 4).

The comparison of findings of ivy fruiting specimens in two time periods at selected sites and the results of the Pearson chi-squared test are given in Table 1.

From the results presented in Table 1B, it follows that there was a substantial increase in the numbers

of fruiting specimens of ivy at most of the stands examined.

DISCUSSION

The distribution of *H. helix* in Poland varied greatly over 10,000 years of the post-glacial history. This is well documented based on the results of palynological analyses of vegetation occurring during postglacial succession in Central Poland (Ralska-Jasiewiczowa et al. 2004; Hannah 2010). The presence of ivy pollen in Poland was recorded for the first time in the post-glacial period at the turn of Preboreal and Boreal periods (approximately 9,000 years ¹⁴C before present) in the eastern part of the South Pomeranian Lakeland (Granoszewski et al. 2004). A wider distribution of ivy was noted in the climatic optimum of the Holocene, which fell in the Atlantic period (8,000–5,000 years ¹⁴C BP). In that period, the range of *H. helix* embraced the whole area

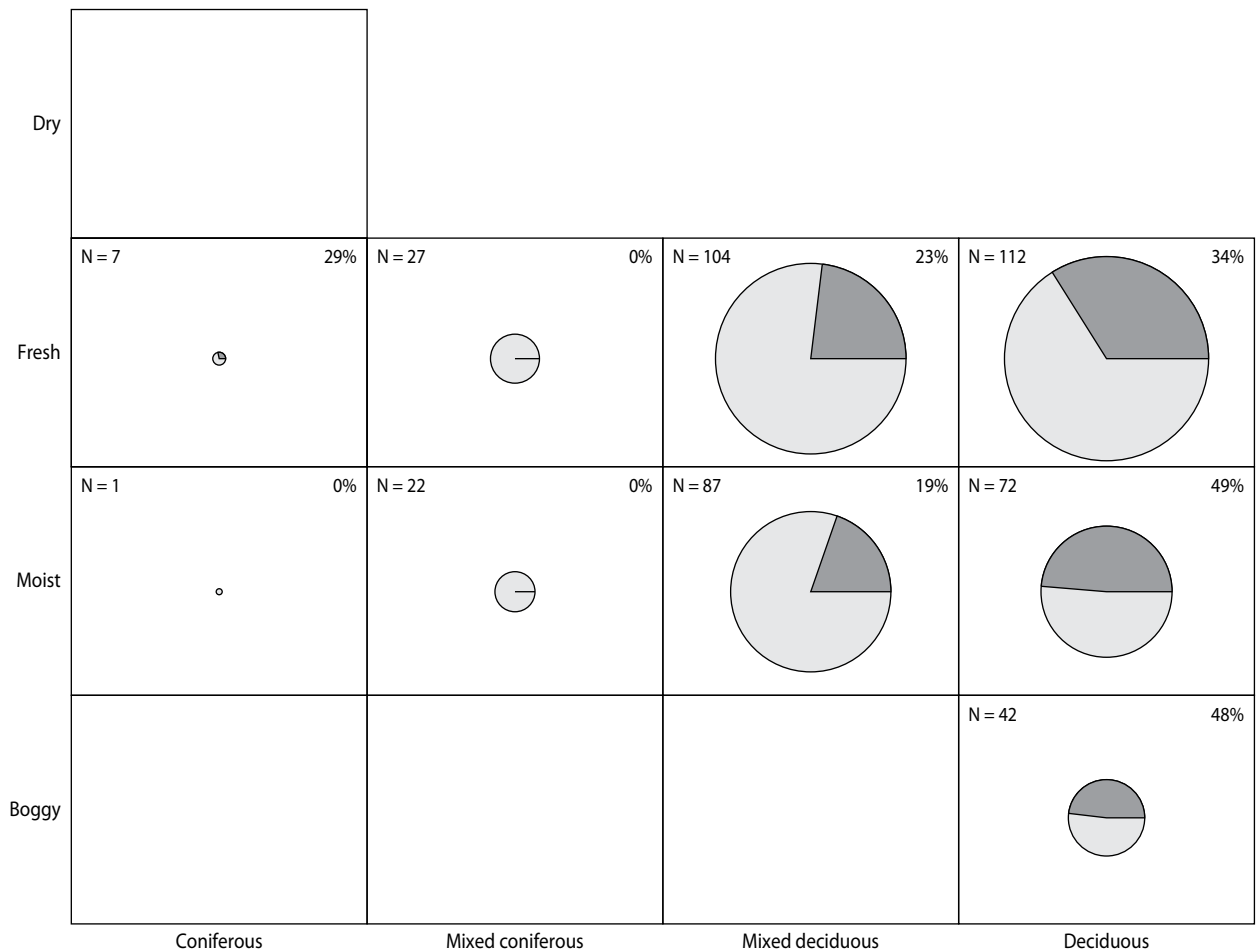


Figure 3. Occurrence of generative/vegetative specimens of *H. helix* in various forest site types: black, generative; white, vegetative

of today's Poland, including its central part, except of its most eastern portions. In the north-central Europe, the average annual temperatures were then higher by 2–3°C, as compared to the present ones, and climate was more humid than today (Berner and Streif 2004). As is evidenced by various studies, the primeval forests of that time had canopy openings because natural mortality of oldest trees, which allowed for the gradual forest renewal (e.g. Rugani et al. 2013). The presence of numerous overexposed gaps could have been a factor conducive to the expansion of ivy under conditions of the favourable light and thermal regimes. About 4,000 years ¹⁴C BP, the vine range clearly receded to the west, since at the end of the sub-Boreal period (3,000–2,500 years, ¹⁴C BP) no more sites with pollen of ivy were found (Granoszewski et al. 2004). Moreover,

no pollen grains of *Hedera* were detected in sediments from the sub-Atlantic period (2500–0 ¹⁴C BP) collected in Poland (Milecka 2005). This indicates that the generative propagation of the vine was very limited at that period.

There is a large body of evidence to suggest that significant changes in Poland's climate have occurred since the mid-20th century (Kožuchowski 2004; Przybylak 2011). The past 40 years has been the warmest period in the history of instrumental observations in Poland (Klimada 2013). The average daily air temperatures have been increasing and, in particular, a slow process of 'warming up' of the winter period was observed (Kožuchowski and Żmudzka 2001). The above warming up, including the rise of the average annual temperatures, and especially those of autumn and win-

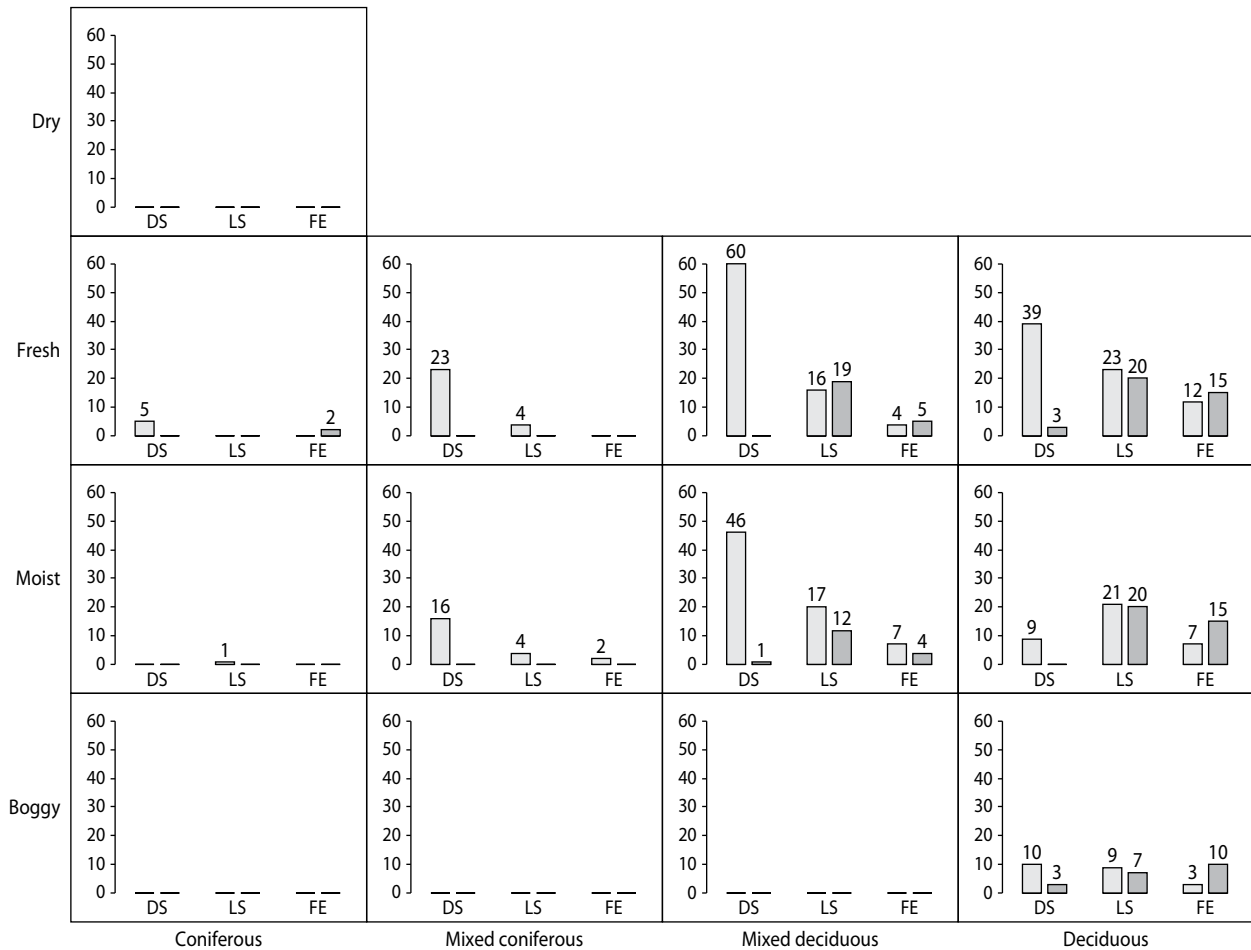


Figure 4. Number of flowering ivy specimens in dense stands (DS), in loose stands (LS) and at the forest edge (FE): black, generative; white, vegetative

ter months, bears some resemblance to the conditions of the Atlantic climatic optimum period, which favoured the then spread of *H. helix* to the east.

By the mid-20th century, the generatively reproducing *H. helix* was a rare component of the Polish forests, and the species was subject to legal protection until 2014 (Kucharski 2014). From the 1960s to the 1980s, the evidence started to accumulate on the increased presence of ivy in natural locations, with an enhanced occurrence of generatively reproducing individuals. The number of sites with flowering and fruiting specimens was increased by more than 450% during that time (Browicz and Gostyńska-Jakuszczyńska 1969). Most of the stands with flowering ivy were located in the western, southern and central parts of the country. No ivy specimens with flowers were then recorded in north-

eastern Poland (Browicz and Gostyńska-Jakuszczyńska 1969; Boratyńska 1987). Only at the turn of the 20th and 21st centuries, 36 sites of common ivy were found in the central-eastern part of the country, including three of them with flowers and fruits and seven with vines climbing the trees (Ciosek 2000). The inventory of ivy occurrence in Central Poland, at the end of 1970 of the last century, provided evidence of 147 flowering specimens growing on 24 sites (Olaczek 1979), whilst our studies in 2015–2017 indicated 1416 flowering and fruiting individuals on 121 sites. Consequently, there was a fivefold increase in the number of locations with flowering and fruiting specimens of *H. helix* in Central Poland for the past 40 years.

The vast majority of flowering and fruiting specimens of *H. helix* in Central Poland are encountered in

Table 1.

A. Fruiting specimens of *Hedera helix* at natural stands in Central Poland in two time periods

No.	Stand	Number of fruiting specimens of ivy	
		1974*	2014–2018
1	Głowno	1	33
2	Szczawin	1	4
3	Gostków	1	9
4	Reserve Polesie Konstantynowskie	10	247
5	Zofiówka	1	4
6	Rydzyń	2	9
7	Wojślawice	12	47
8	Pyszków	11	21
9	Złoczew	22	55
10	Szustry	46	125
11	Reserve Ryś	3	3
12	Lasek Kurowski	2	9
13	Siemkowice	13	19
14	Wistka	2	31
15	Wielopole	1	4
16	Łódź Ruda	2	102

* Data by Olaczek 1974.

B. Results of the Pearson chi-squared test

No.	N ₁	N ₂	χ^2	p	P _(B.-H.)
1	1	33	30.12	<0.000001	<0.000001
2	1	4	-		
3	1	9	6.4	0.0114	0.0171
4	10	247	218.56	<0.000001	<0.000001
5	1	4	-		
6	2	9	4.45	0.0349	0.04188
7	12	47	20.76	<0.000001	<0.000001
8	11	21	3.12	0.077	0.084
9	22	55	14.14	0.00017	0.000291
10	46	125	36.5	<0.000001	<0.000001
11	3	3	-		
12	2	9	4.45	0.0349	0.04188
13	13	19	1.13	0.29	0.29
14	2	31	25.48	<0.000001	<0.000001
15	1	4	-		
16	2	102	96.15	<0.000001	<0.000001
Total	130	722	411.34	<0.000001	

disturbed forest communities or on the forest edges. In dense stands, ivy shows the capacity to reproduce generatively only in the canopy openings. Generally, fragmentation of habitats is conducive to changes in species distribution, what was confirmed by the results of study on the increased share of vines in disturbed forest communities (Travis 2003; Londré and Schnitzer 2006).

At the same time, no evidence was found that the increased incidence of natural sites and flowering specimens of *H. helix* might be linked to changes in the ivy habitat preferences. The first extensive study on ivy distribution in Central Poland showed that most of its flowering specimens in natural locations were encountered in the oak-hornbeam or the alder-ash carr (Olaczek 1979) and this is still valid. Thus, the key driver behind the spread of the species beyond its eastern limit is climate 'warming up'. Another important factor that favours the ivy range shifts is the increased fragmentation of forest tracts.

CONCLUSIONS

1. Since the mid-20th century, *H. helix*, a rare species in the forests of Central Poland, with a weak capacity for generative reproduction, has become an expansive plant with increasing number of locations with flowering and fruiting individuals. The number of natural sites with generatively reproducing specimens increased, as much as fivefold in some cases.
2. The impulse for changes in the life strategy of *H. helix* is the increase in the average air temperatures, precipitation and solar radiation intensity, which has been observed for the past several decades.
3. The shift of the ivy range is favoured by the fragmentation of forest tracts, the increase in the proportion of forest edge zones and the loosening of tree canopy, in particular, in the old no longer economically managed stands.

4. Habitat preferences of ivy at its eastern limit have not been changed, according to other studies. The species is found mainly in fresh and moderately wet habitats in the oak-hornbeam or alder-ash forest.

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