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Changes in structural composition of field margins and related landscape homogenization following EU accession of Poland

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Field margins have considerable ecological significance in farming landscapes, but are subject to constant changes resulting from natural processes and anthropogenic pressures. Understanding the balance of these processes is important from an ecological and conservation perspective. We measured 20 variables related to margin composition, woody vegetation and adjacent cropland fragmentation in 70 field margins in SW Poland in 2004 and 2006 (Poland's accession to the EU), and then resurveyed in 2021 by using the same protocol. We aimed to examine changes in structural and functional properties of the margins and their response to anticipated agricultural intensification. Over 17 years all field margins still existed in the landscape but there was a significant reduction in margin width, increase of the tree layer, and depth of the ditches. No significant changes were found in the shrub layer nor species composition of woody plants. Cutting trees and shrubs were more visible along roads whereas succession along railways. The mosaic pattern of adjacent fields has clearly reduced due to land consolidation. Overall, despite strong alterations of individual plots, the network of field margins appeared relatively resistant to agriculture transformation. The negative environmental effects of EU accession were more evident in the fields. Our findings emphasize the necessity of preserving various types of field margins that can counterbalance to deterioration of farmland biodiversity.

Keywords Agroecology, Landscape elements, Temporal changes, European Union, Agricultural intensification, Resurvey

Agricultural systems are particularly dynamic landscapes whose structure and spatial configuration vary on different time scales. Changes are associated with farming practices, crop rotations, market volatility, new governmental incentives and subsidies, political directions or climate changes[1,2]. Therefore, tracking temporal alterations in farming areas and their effects on biodiversity is a challenge. The long-term loss of biodiversity at a landscape scale is widely documented[3,4]. However, this change hides more dynamic processes of removal, establishment, and change within the individual biotopes. Meanwhile, the sum of changes in biotopes affects overall landscape changes, so knowledge of the "anatomy" of these habitat-scale alterations is needed for proper biodiversity-friendly landscape shaping[5,6]. Permanent or semi-permanent habitat features, such as field margins, are key for farmland heterogeneity and connectivity, and their presence and characteristics are particularly dependent on the processes mentioned above[7]. In simplified agricultural landscapes, field margins are recognized as biodiversity hotspots, providing essential habitats for reproduction, shelter, and feeding, as well as serving as seed banks[8]. These margins also function as barriers that limit the spread of organisms and as corridors that facilitate species dispersal across the landscape, thereby supporting the connectivity of wild populations[9,10]. Consequently, the network of field margins plays a crucial role in influencing ecosystem health and enhancing the resilience of agroecosystems exposed to ongoing anthropogenic stress[11,12]. Additionally, field margins are a distinctive feature of traditional agricultural landscapes, offering significant socio-cultural

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and aesthetic value[13,14]. These margins contribute to the formation of region-specific landscapes with unique ecological compositions, cultural associations, and vernacular nomenclature[15,16]. Furthermore, the ecological and aesthetic values of field margins may positively impact human well-being and health through indirect effects mediated by cultural pathways[17], which, in turn, could encourage their conservation.

Despite these diverse ecological, cultural, and socio-economic benefits, the loss of field margins is widespread across various agricultural systems. However, the temporal changes occurring within these environments remain insufficiently recognized, particularly with regard to whether the processes that are typically considered beneficial to biodiversity effectively balance those that are detrimental[18]. For example, in times of climate drying, open ditches lose their drainage function, and some are eliminated, while others, unmaintained, become overgrown with high vegetation, increasing landscape heterogeneity[19]. Similarly, opposite processes apply to trees and shrubs. Tree-lined field margins increase overall wildlife richness[20,21], but shrubby margins host more rare and threatened species[22]. Both, trees and shrubs are thus important, but their availability in the dynamic network of field margins is not known, because some are removed or cyclically trimmed, and some are left alone. Description of these complexities is further hampered by the paucity of good empirical data, especially based on resurveying approach. Fine-scale habitats and their vertical structure are difficult to capture by fashionable remote techniques, requiring more subtle and labor-intensive field surveys[23,24], but these are not readily undertaken. As a result, spatiotemporal changes occurring within semi-natural field margins are insufficiently understood.

Central European countries, considered a stronghold for the continent's farmland biodiversity[25], are particularly suitable for studying the transformations of landscape elements. Dominated by agricultural areas, they have retained many traditional components, including a dense network of field margins[13,16,26,27]. The countries also experienced historic changes in agricultural production—a steep decline following the collapse of the socialist economic system (1989), and then strong intensification after accession to the European Union (EU) in 2004[28]. Last decades showed that joining the Common Agricultural Policy (CAP) caused significant deterioration of farmland biodiversity in these countries, mimicking trends previously observed in Western Europe[29,30]. It must have also affected the field margins, but it is not clear how it influenced their density and composition. Most of these permanent habitats are still present in agricultural areas, but permanent does not mean unchanging; natural processes, such as succession, are constantly mixed with increased negative effects of farming pressures. The long-term balance of these processes is unknown.

Our goal was to study the changes in field margins and the surroundings during approximately 17 years after the accession of Poland to the EU. Observing biodiversity loss in agricultural landscapes and the failure of the CAP to reduce the environmental footprint of European agriculture[4,31], we hypothesize that the heterogeneity of field margins has also deteriorated. This may be expressed by reducing the margin network, simplification of their structural complexity, or changing their function. The confirmation of such assumptions must be based on quantitative data resulting from the resurveying approach, and this is the approach we present here. The specific objectives of this paper are to: i) quantitatively compare structural properties of the field margin at the moment of EU accession and a dozen or so years later; we were particularly interested in properties that showed the clash between natural processes and management practices; ii) check the changes in structural composition in groups of field margins containing a functional element—a road, a ditch, track, balk; iii) compare the complexity of agricultural lands adjoining the field margins, expressed by the number of individual parcels.

Study area

Field data were collected in southwestern Poland (Fig. 1A), within a fragmented and biodiversity-rich agricultural landscape, characterized by fields ranging up to several dozen hectares and a network of semi-natural habitats. This landscape corresponds to High Nature Value Farmland Type 2[32]. Field margins accounted for 6.6% of the landscape, as measured in six 50-hectare plots located within the study area[33]. In terms of physiography (Fig. 1B), the study area encompasses the central part of the Sudety Foreland macroregion (50 sample plots) and a section of the Silesia Lowland macroregion (20 sample plots)[34]. Due to the presence of fertile soils, this entire area has been used for agricultural purposes for centuries. The Sudety Foreland is more diverse in terms of habitat and topography, with stretches of flat depressions occupied by agroecosystems and forest complexes preserved in the higher parts of the low hills. The Silesia Lowland is more deforested and flat, and, due to favorable climatic and soil conditions, it is one of the main agricultural regions of southwestern Poland. The landscape here is monotonous, with larger fields interspersed with clumps of trees and strips of shrubbery along streams, former railway lines, or dirt roads[35]. Throughout the study area, the dominant crops are wheat, maize, oilseed rape, and sugar beet. The landscape resembles other farmlands in CE countries in terms of land use and farming intensity. Detailed description of the region, study plots and indicators of agricultural production are given in our earlier publications[8,21,22].

In this area, we selected 70 study plots—500 m long sections of field margins sensu Marshall et al.[36], i.e., the areas between adjacent fields, covered by spontaneous semi-natural vegetation. The study sites were selected based on several criteria. First, they were required to represent the diversity of field margins within agricultural landscapes in Poland and Central Europe, as well as their primary functions. The selected margins varied in the proportion of herbaceous to woody vegetation and in structural composition, defined by the presence or absence of functional components such as dirt roads, ditches, or disused railway tracks. Vegetation consisted of a lush, multilayered plant cover, characterized by dominant perennial species in the herbaceous layer, and diverse, only deciduous species in the shrub and tree layers. Second, the field margins were required to serve as independent sampling units. Accordingly, the average minimum distance between the midpoints of two neighbouring sampling plots was 774 m (range: 155–4,177 m), and they were not interconnected. Third, field margins should have a similar origin. Indeed, these margins were initially established by humans for practical purposes, such as drainage and transportation, but have since undergone natural succession. An analysis of pre-1940 geodetic

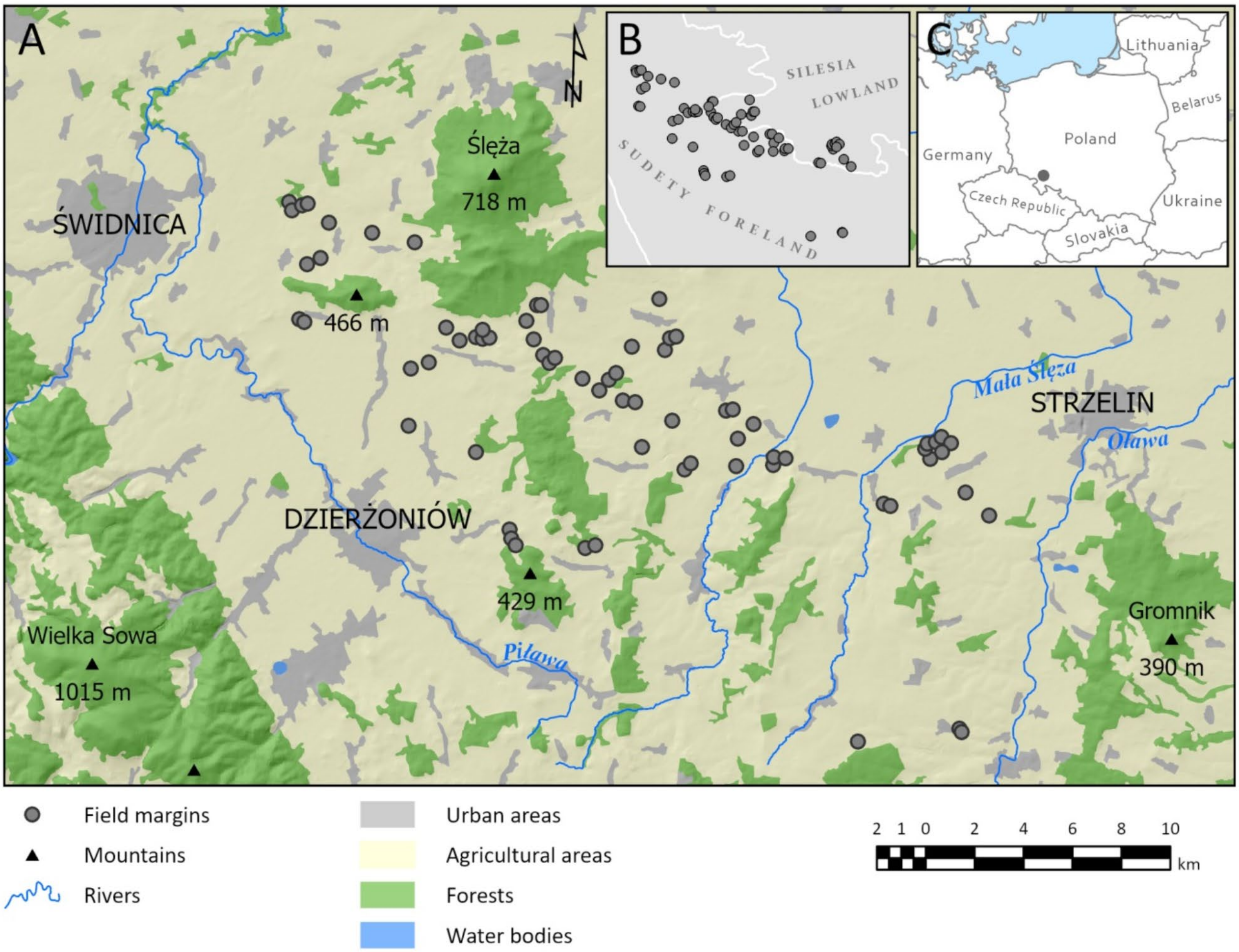

Fig. 1. The distribution of the studied field margins in SW Poland on the background of land cover types (Corine Land Cover 2018) and local topography (**A**). Insert maps present the study area in regional (**B**) and Central European (**C**) contexts. Detailed locations of the study plots are provided in the Google Earth file available on Zenodo[37]. The map was created in ArcGIS Pro 3.3.0 (ESRI Inc., Redlands, https://www.esri.com/en-us/arcgis/products/arcgis-pro/).

maps suggests that many field margins have remained in the same locations for several decades, with some potentially persisting for several centuries. Fourth, the study sites should be distributed within a manageable geographic range to facilitate a wide scope of the study, including measurements of margins and adjoining fields as well as the diversity of multiple taxonomic groups. Consequently, all plots were located within a 400 km^2 area, with a maximum distance of 35 km between individual plots. For detailed locations of the study plots, and cross-section transects within each plot, the reader is referred to the Google Earth file available on Zenodo[37].

Field methods

The habitat structure of the field margins was first quantified in 2004 (40 plots) and 2006 (30 plots), and then resurveyed in 2021 (all 70 plots) using precisely the same protocol and by the same people (AW, ZD). Field work was carried out from August to October, in full development of vegetation. Plant composition and studies of other organisms inhabiting the field margins were conducted throughout the growing seasons of 2004–2007, 2021 and 2022.

Changes in the structure of field margins and their surroundings between 2004/2006 and 2021 were characterized using 20 variables presented in Table 1. They relate to tree and shrub layers (13 variables), the margin composition (6 variables) and the fragmentation of adjacent crops (1 variable). The selection of variables resulted from literature data[20,38] and our previous experience[8,21,39] indicating that these features may have impact on the biocenotic parameters of the field margins. They are also easily measurable and repeatable in the field. Some variables are collinear, but were retained as they may be specific to successional processes (e.g. length and height of woody plants) or to margin management (e.g. width of trees and the entire strip).

Two approaches were applied to quantify individual variables (Fig. 2). First, some variables were measured for the whole 500 m section by step counting (e.g. the length of sections with trees and shrubs), or by simple

Variable abbreviation	Variable description (unit)	Method
Tree and shrub layer		
Tree length	Total tree stand length (m)	Whole length
Tree height	Mean tree stand height (m)	Cross-section
Tree width	Mean tree stand width (m)	Cross-section
Tree volume	Total tree stand volume (m^3)	Whole length
Tree species richness	No. of species in tree stand	Whole length
Tree individuals	No. of tree specimens	Whole length
Shrub length	Total shrub layer length (m)	Whole length
Shrub height	Mean shrub layer height (m)	Cross-section
Shrub width	Mean shrub layer width (m)	Cross-section
Shrub volume	Total shrub layer volume (m^3)	Whole length
Shrub species richness	No. of species in shrub layer	Whole length
Woody species richness	No. of species in tree and shrub layer	Whole length
Woody plants volume	Total volume of tree and shrub layer (m^3)	Whole length
Margin composition		
Margin width	Mean width of field margin (m)	Cross-section
Number of gaps	No. of gaps in woody vegetation	Whole length
Patch length	Total length of patches (m)	Whole length
Covered area	Area covered with woody plants (%)	Whole length
Ditch width	Mean ditch width (m)	Cross-section
Ditch depth	Mean ditch depth (m)	Cross-section
Number of parcels	No. of parcels adjoining the margin	Whole length

Table 1. Variables used to quantify changes in structural composition of field margins between 2004 and 2021. The column Method informs whether the variable was obtained from measurements in five cross-section transects, or along the whole field margin (500 m). See Fig. 1 and the text for further details.

counting (species richness of woody plants, number of adjoining parcels). Second, the variables that describe the canopy of trees and shrubs, the width of the margins, and the parameters of the ditch were measured in five 10 m wide cross-section transects: at 50, 150, 250, 350, and 450 m of the section. The transects were determined using GPS receivers and had the same locations in both periods[37]. Measurements were made for canopy outlines as follows: higher shrubs or trees were measured using a height meter, lower shrubs with a scaled stick, and width was taken using a tape. The mean value of all five measurements was used in further analyses. Trees were considered specimens with a breast height greater than 30 cm. Note that three variables describing the volume of tall vegetation (tree volume, shrub volume and woody plant volume) are the product of the remaining variables (volume = length x width x height). They were included because they well characterize the woody vegetation of the entire studied section.

Statistical analyses

Statistical analyses were performed in R 4.4.1[40] using 'tidyverse'[41], 'ggpubr'[42], 'sjPlot'[43] and 'MASS'[44] packages. We used the paired Wilcoxon test to analyze the differences in 20 structural characteristics of field margins between 2004–2006 and 2021. The results were presented graphically using violin plots with nested boxplots. Furthermore, we analysed the effects of functional elements, including roads, ditches, railways, and balks, on changes in the structural characteristics of the field margins. Four groups of field margins were selected according to the presence of the functional component. The balk is understood here as a margin containing no other functional component. We first calculated the change scores, i.e. the difference in a structural variable between 2021 and 2004–2006. Change scores were then used as the predicted variables in multiple linear regression models. Binary variables describing the presence or absence of functional elements were used as predictors. To account for the potential effects of the regression on the mean[45,46], we also added initial values (i.e., values measured in 2004–2006) as predictors when fitting the models.

Results

All 70 field margins surveyed in 2004 and 2006 were present in the landscape in 2021 and could be resurveyed. The margins retained their major structural components such as roads, ditches, and disused railways. We found significant increases in several variables related to trees, including tree height, width, volume, and number of tree specimens (Fig. 3). The number of tree specimens with a DBH > 30 cm increased several-fold in certain plots, for example, from 7 to 33, 0 to 18, and 54 to 104. No significant differences were found in the shrub layer nor species composition of woody plants. The most striking and significant difference was a 9.4% decrease in field margin width, from 11.7 m to 10.6 m. A decrease in width was observed in 52, while an increase occurred in 18 margins. The second most significant difference was a 24% decrease in the number of surrounding parcels (6.3 vs. 4.8 on average in 2004–2006 and 2021, respectively). A reduction in the number of parcels was recorded along 30 field

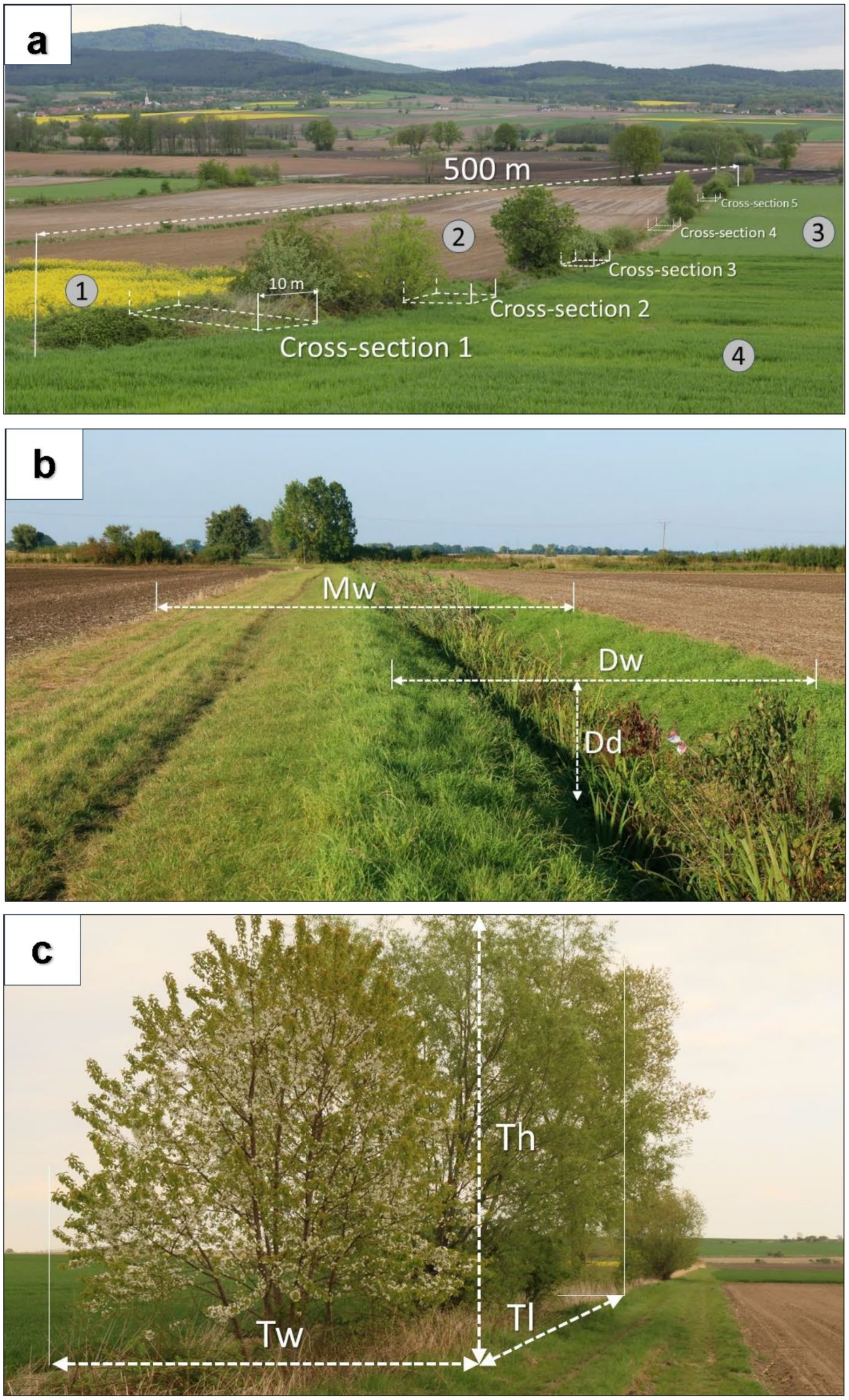

Fig. 2. Measurements of structural composition of field margins: (**a**) location of five cross-section transects along the study plot; gray circles indicate no. of adjacent parcels; (**b**) cross-section with measurements of the ditch width (Dw), ditch depth (Dd), and the total margin width (Mw); (**c**) cross-section with measurements of the canopy: tree height (Th), tree width (Tw), length of the tree clump (Tl).

margins (with a maximum decrease of 15 parcels), while an increase was observed along 10 margins (with a maximum increase of 3 parcels). In addition, we found a significant increase in ditch depth, although the mean value was the same. Overall, significant changes occurred in 7 out of 20 structural characteristics of field margins and adjacent croplands (Fig. 3).

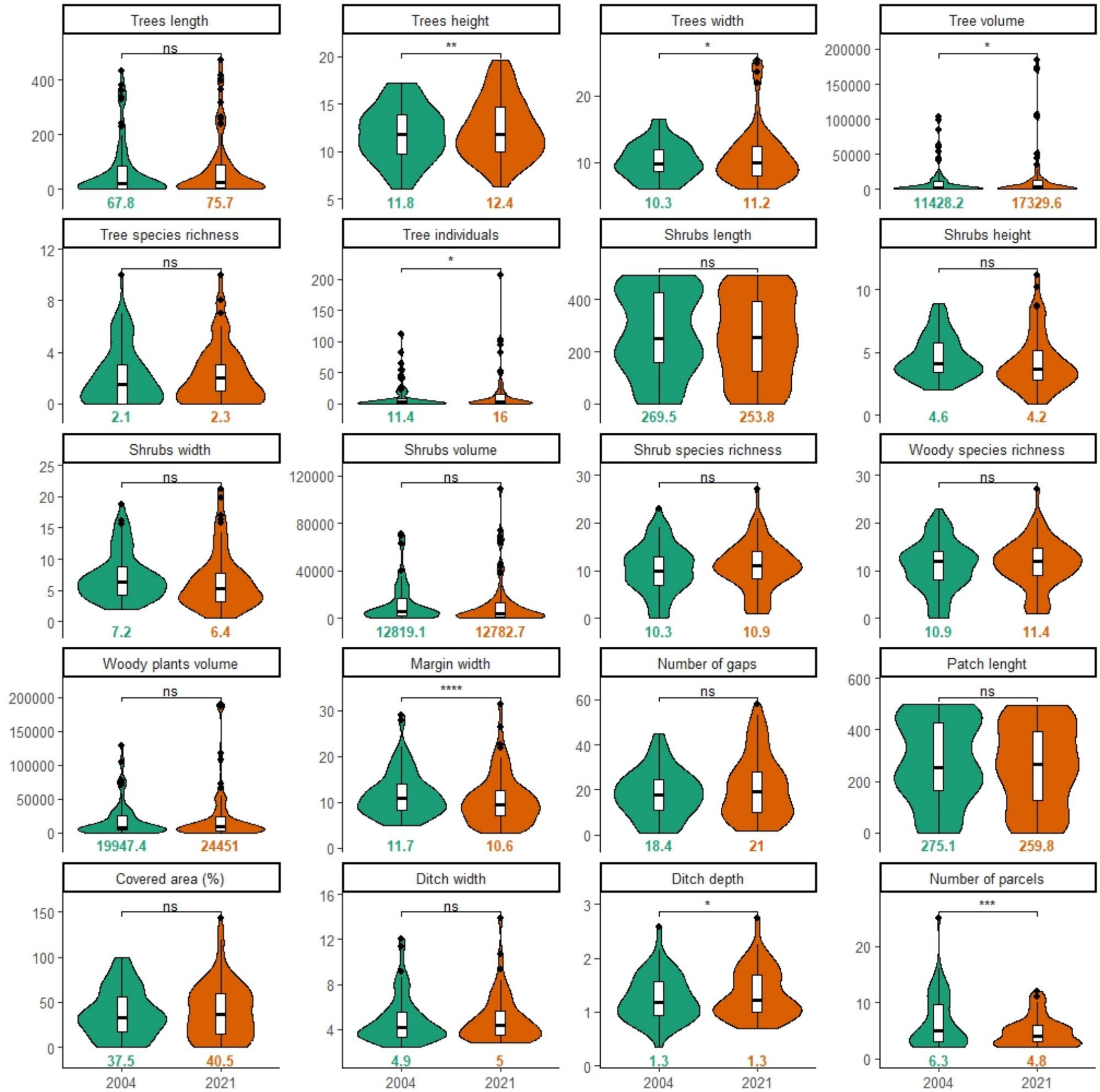

Fig. 3. Comparison of the structural characteristics of the field margins between the two study periods (2004–2006 and 2021). Values below the violins are means. Statistical significance: *ns* not significant, *—$p \leq 0.05$, **—$p \leq 0.01$, ***—$p \leq 0.001$, ****—$p \leq 0.0001$. See Table 1 for variable explanations.

Estimates of the fitted regression models showed that the presence of unused railway tracks had a positive effect on change scores in most of the fitted models, whereas the presence of roads had a negative effect (except for change in the number of tree individuals, the width of the margin, and number of parcels). The effects of ditches and balks were ambiguous (Table 2). Pronounced change scores were observed in association with the presence of railway lines. Specifically, in field margins containing railway lines increases were recorded in shrub and patch lengths (both $p < 0.001$), tree height ($p < 0.01$), and woody species richness ($p < 0.05$). Notably, the presence of each functional element positively influenced margin width, despite a significant overall decline in this parameter across the 70 sample plots.

Discussion

Over the course of 17 years, the characteristics of most studied field margins have considerably changed (Fig. 4). Our analyses revealed significant changes in 7 out of 20 analyzed indices, including two important predictors:

Change score	Intercept	Road (27)	Ditch (51)	Railway (6)	Balk (5)	Initial value	Adjusted R^2	F-statistic	p-value
Trees length	6.18	−3.63	3.36	−0.91	24.64	−0.01	−0.050	0.395	0.850
Tree height	6.65***	−1.64*	−1.2	6.74**	−4.24**	−0.31**	0.317	4.895	**0.002**
Tree width	0.15	−0.55	−1.66	7.39	−2.42	0.26	0.000	0.999	0.432
Tree volume	−1890.32	−2951.47	−1368.76	3699.56	949.55	138.79***	0.228	5.087	**< 0.001**
Tree species richness	0.55	−0.03	0.37	−0.05	1.14	−0.63**	0.100	2.536	**0.037**
Tree individuals	−5.6	0.44	1.71	4.98	5.68	3.41***	0.226	5.022	**< 0.001**
Shrub length	2.84	−26.89	39.94	154.42***	82.69	−0.21**	0.251	5.633	**< 0.001**
Shrub height	1.49	−0.32	−1.28*	−0.44	−0.05	−0.17	0.062	1.840	0.119
Shrub width	1	−0.02	−0.87	2.71	2.3	−0.18	0.101	2.436	**0.045**
Shrub volume	6415.53	−2472.6	−7135.12	1702.67	−706.55	−0.03	−0.013	0.823	0.538
Shrub species richness	1.89	−1.15	1.81	2.94	2.5	−0.25**	0.205	4.552	**0.001**
Woody species richness	1.55	−1.19	2.01	2.95*	2.67	−0.23**	0.240	5.368	**< 0.001**
Woody plant volume	6823.85	−7770.9	−9031.3	2091.4	−2122.32	0.36***	0.137	3.198	**0.012**
Margin width	−2.89**	1.2	1.58*	2.32*	2.38	−0.02	0.043	1.621	0.167
Number of gaps	3.24	−1.55	9.2	1.96	−1.99	−0.36*	0.174	3.906	**0.004**
Patch length	−2.98	−28.34	43.44	153.93***	82.75	−0.19**	0.261	5.879	**< 0.001**
Covered area	9.83	−8.59	−1.25	17.24	23	−0.15	0.152	3.477	**0.008**
Number of parcels	1.56*	0.72	0.49	0.08	0.97	−0.60***	0.683	30.720	**< 0.001**

Table 2. Parameters of models predicting change scores in structural indices of field margins grouped according to the presence of a functional component: road, ditch, railway line or balk. Numbers in brackets indicate the number of field margins containing a given functional component. Each row corresponds to an individual model. Change scores (predicted variables) refer to differences between 2021 and 2004–2006. The initial value refer to the measurement of a structural index in 2004–2006. Statistical significance: *—$p \leq 0.05$, **—$p \leq 0.01$, ***—$p \leq 0.001$. Significant values are in [bold].

the width of the margin and the mosaic structure of the surrounding fields, suggesting an overall deterioration in the ecological value of Poland's agricultural landscape following its accession to the EU.

Contrasting trends in tree and shrub layers

We observed opposing trends for trees (increase) and shrubs (decrease). Despite tree cutting was recorded in many field margins, several parameters of the tree layer across the analyzed habitats increased significantly; for example, the total number of tree specimens rose from 801 to 1,118, and the mean volume of this layer over a 500-m section increased by 52%. No significant changes were recorded in the shrub layer. However, traces of shrub reduction or removal were visible in many field margins, especially those surrounded by intensive agriculture. In some field margins that were not subjected to human pressures (e.g., logging, clearing) during the study period, shrub layers grew into tree layers, which caused the canopy to become denser. A similar process of tree layer development and the associated increase in shade-tolerant plant species following management cessation has been observed in field margins elsewhere in Europe[38,47]. Overall, these results are a consequence of the balance between anthropogenic pressures and spontaneous regeneration. Polish legislation has long upheld the general principle of protecting trees and shrubs outside forests[48]. However, in practice, the protection of trees is more stringent and effective than that of shrubs, especially young and short ones, which are common in the field margins. This is due to the easier acquisition of permits for shrub removal or exemptions from such requirements, lower fees for shrub removal, or lesser penalties for their illegal clearance. As a result, the complete removal of shrubs from mid-field strips while leaving tree specimens intact is a widespread practice (but see[49]).

Balance between human pressure and natural regeneration

The presented data reveal the rapid pace of succession, likely driven by specific local conditions, such as light, water (in riparian margins) and nutrients availabilities. Habitat conditions and disturbances are among the most significant factors influencing the rate of vegetation succession[50–52]. We found that disturbances resulting from agricultural pressures that affected some of the margins were compensated by natural succession and tree regeneration that predominated in other margins. Therefore, average values of the compared indices remained unchanged. Spontaneous establishment of woody plants has been reported to be more successful in moderately wet and fertile sites than in dry or highly fertile wet sites. The long-term prevention of woody plant establishment due to strong herbaceous competition[52,53] and browsing by herbivores[54] should also be considered. However, it is important to emphasize that our data only reflect the state of field margins at two time points, potentially masking rapid changes that may have occurred at the annual time scales. Management practices in field margins are inherently irregular. Alignier and Baudry[55] demonstrated a clear discontinuity in five different practices in field margins in Brittany, France, over two decades. Interestingly, they also observed an increasing trend toward the absence of intervention as a management option—a situation similar to that observed in many field margins in Poland.

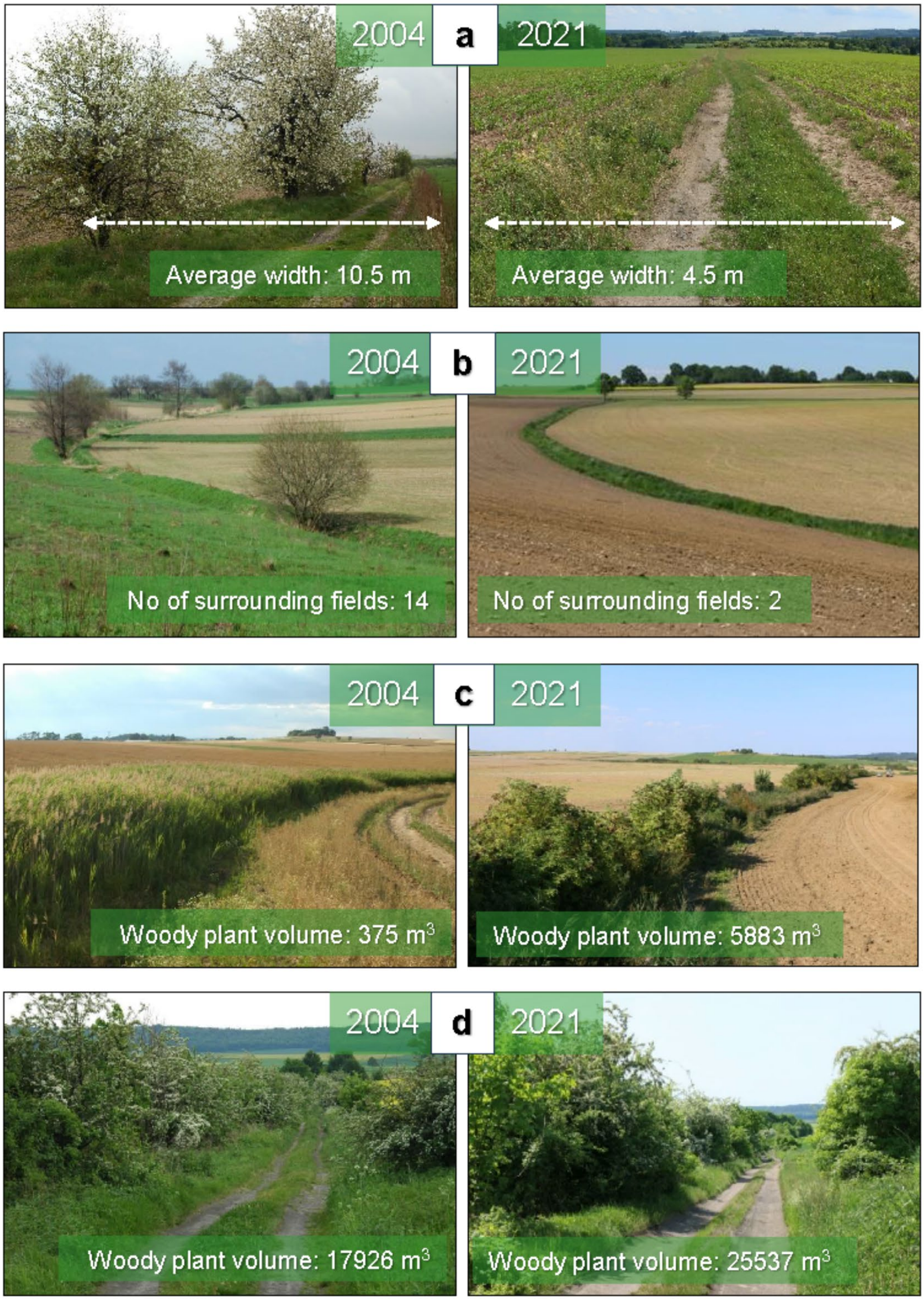

Fig. 4. Example changes of field margins over time: (**a**) reduction of margin width and woody vegetation; (**b**) reduction of woody vegetation and consolidation of adjoining fields; (**c**,**d**)—increase of woody vegetation.

In our study plots various types of human activities were observed during the second study period (2021–2022), including clearing of ditch slopes, tree and shrub pruning and removal, or reactivation of disused railways (Fig. 5). Due to the rapid succession, the traces of such activities disappear quickly, creating a misleading impression of stability in the field margins' structure, or conversely, slow but directional changes. With this in mind, we emphasize that the strength of the presented results lies in their cumulative nature, showing changes over a decade-long period. Interestingly, these opposing processes of reduction and succession essentially

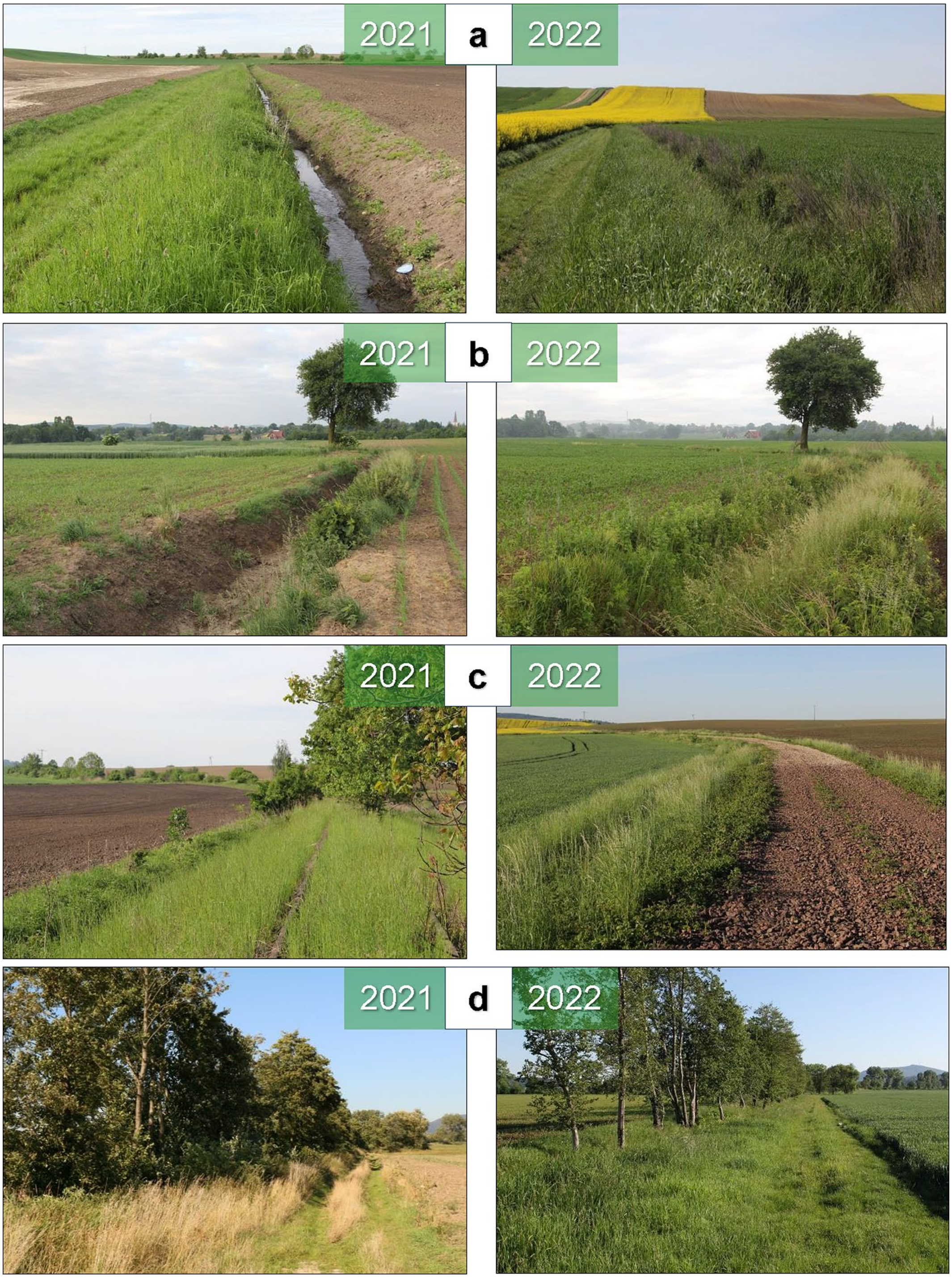

Fig. 5. Recent episodes of structural transformation in the field margins, between 2021 (left) and 2022 (right): (**a**,**b**) maintenance of ditches; (**c**) restoration of railway line; (**d**) pruning of trees and shrub cutting.

balanced each other over this period. Notably, this balance was observed on the scale of 70 surveyed plots, rather than individual margins, where changes were often intense.

Reduction of margin width and landscape heterogeneity

In contrast to the aforementioned changes in the biotic elements of the field margins, which are reversible due to succession, the decline in total width and the mosaic structure of surrounding fields appears to be permanent and, given the ongoing intensification of agriculture, is likely irreversible in the near future. It is revealing that the strongest changes were observed in these parameters. A reduction in the average margin width by 1.1 m across the sample of 70 field margins (35 km in total length) translates to a loss of 4 hectares of non-productive habitats, which are crucial for landscape heterogeneity and its biocoenoses. If such changes occurred in this relatively small sample of strips, the area of marginal habitat loss on a national scale in Poland is enormous, leading to a significant decline in biodiversity. The loss of semi-natural habitats in farming landscapes has recently been reported from other EU countries as well[1,56].

Another environmentally significant large-scale phenomenon is the reduction of configurational heterogeneity of the agricultural landscape, having harmful effects on biodiversity[57–59]. Data from the first stage of our study showed a strong positive effect of the mosaic structure of crops surrounding field margins on their flora[8] and some bird species nesting in the margins[21], though the impact on the bird community was weak. In contrast, our repeated study revealed a clear decline in crop mosaic structure: the total number of fields adjacent to the studied strips decreased by 24% (from 444 to 336), indicating a significant nationwide trend. Notably, the changes observed in the study area were not the result of a land consolidation project funded under the government's Rural Development Programme, which is developing rapidly (https://www.gov.pl/web/rolnictwo/scalanie-gruntow). It can therefore be concluded that the simplification of the agricultural landscape in the study area is not complete and may even intensify. The environmental consequences of the land consolidation that has already occurred and further consolidations should be the subject of separate studies.

Changes in field margins incorporating roads, railways, or ditches

Numerous studies have demonstrated the effects of the structural composition of field margins on associated biocenoses[19,20,60]. However, little is known about how the presence of functional elements influences changes in the structural characteristics of the margins themselves, and our results are among the first to present such findings. Regression models constructed for groups of field margins containing functional elements highlighted the impact of human pressure on the structure of the margins. The use of roads for the needs of intensifying agricultural production (transport and movement of increasingly large machines) has led to the removal of trees and shrubs. As a result, the pressure of human activity was more evident in strips with roads, while successional processes occurred predominantly in strips without roads or along roads that had ceased to function. Opposite trends were observed in railway areas. The temporary regression of rail transport in Poland (currently being rebuilt) and the non-agricultural ownership of railway lands resulted in the cessation of railway use in the study period. This led to significant vegetation growth, particularly in the shrub layer, giving railway strips the appearance of dense hedgerows, which serve as refuges for flora and fauna[61]. Similarly, the presence of ditches significantly enriches the agricultural landscape[62], especially in Poland, which, among North- and West-European countries, probably has the largest area (1.5 million hectares) of lands drained by well-vegetated, open-field drains[19]. However, the observed structural changes in field margins with ditches are difficult to interpret and even seem random. For example, they contradict the expected stronger succession of woody vegetation in strips with ditches, which are theoretically less accessible to interventions. This may be related to the great diversity of margins with ditches, ranging from open dry ditches to tree-lined streams, as well as the frequent coexistence of ditches and roads within the margin structure. Changes in the structure of margins resembling balks (without other functional elements) were also inconsistent, which may be due to the small sample size (5 plots). Interestingly, the presence of each functional element had a positive effect on the width of the margin. This was likely due to the function and specificity of these elements. Roads and ditches cannot be excessively plowed over, as they would lose their primary transport or drainage function, while railway strips, created as stone embankments, are physically protected from plowing.

Conclusions

Our data revealed the diversity of changes occurring in linear habitats and the variety of factors driving these changes. Considering the average values of the studied parameters, a surprising result is the relatively small number of strong (statistically significant) changes that should be expected after the adoption of the CAP assumptions by Polish agriculture. It is worth emphasizing the non-obvious fact that all margins in our sample survived in the landscape throughout the analyzed period. Overall, this suggests that either agricultural transformation is occurring slowly, or that the traditional farming system in Poland is relatively resilient to the changes being introduced, or that field margins themselves possess such resilience. It is also possible that a 17-year period is too short to reveal directional trends. For example, studies on the dynamics of plant communities often recommend a longer observation period[47,63]. For instance, Wesche et al.[64] recommend selecting reference data collected prior to the onset of agricultural industrialization and/or spanning five decades or more to fully capture the effects of intensification. Irrespective of the observation period, the radical nature of changes observed in individual strips in recent years (Figs. 3, 4), as well as the strong directional changes in critical parameters such as margin width and landscape heterogeneity, are concerning. These facts create the impression of only temporary stability in field margins and a sense of impending changes, heralded by well-known processes of biodiversity decline in farmlands[2,65]. Before such changes occur, maintaining the existing network of field margins in all their diversity, as well as the internal structural heterogeneity of the margins, should be one of the goals of effective farmland management.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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Author contributions
AW and ZD developed the study conception and methodology, and collected field data. RP and KK performed statistical analyses. The first draft of the manuscript and the revision were written by AW. All authors commented on previous versions of the manuscript, read and approved the final version.

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Declarations

Competing interests
The authors declare no competing interests.

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