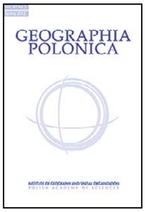

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# TRANSFORMATION OF TREELESS DEPRESSION WETLANDS IN CENTRAL EUROPE OVER THE LAST 100 YEARS: WŁOSZCZOWA BASIN (SOUTHERN POLAND) CASE STUDY

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## Abstract

Historical changes in land use and development over the last century were analysed to identify the main causes and directions of changes in depression wetland ecosystems in the Włoszczowa Basin, an area of 1600 km$^2$ in southern Poland. The analysis of Military Cartographic Institute maps and orthophotomaps, as well as field surveys, made it possible to determine the scale of degradation of 247 treeless depression wetlands. It was shown that the nature and extent of transformation of individual wetlands varied depending on the type of wetland and the method of land use in adjacent areas. However, the main anthropogenic factor affecting these changes was land drainage, of which the greatest intensity in Central Europe was pursued during the socialist rule between 1945 and 1989.

## Key words

wetlands • degradation • agriculture • drainage • Central Europe

## Introduction

The term wetland is defined in more than one manner. Most commonly, wetlands are described as transitional areas between aquatic and terrestrial ecosystems (Wu et al., 2021). These ecosystems are of global importance in terms of maintaining biodiversity (Baron et al., 2002; Gutknecht et al., 2006; Middleton & Souter, 2016; Wu et al., 2021). At the same time, however, wetlands are among the areas particularly vulnerable to degradation as a result of human activities and climate change (Winter, 2000; Bronmark & Hansson, 2002; Keddy, 2010; Okruszko et al., 2011; Acreman, 2012; Junk et al., 2013; Mallakpour & Villarini, 2015; Hu et al., 2020).

Human impact on the environment has been gradually increasing for thousands of years. However, in the 20th and 21st centuries, anthropogenic pressure impacts, including developments in agriculture and, more recently, climate change, have seriously threatened the stability of wetland ecosystems both regionally and globally (Dayong et al., 2012). The results of these threats are severe wetland degradation and a large reduction in wetland area (Khaledian et al., 2017; Wu et al., 2021). The degradation process includes hydrological, soil, biological, physiological, biochemical and biogeochemical processes (Hanet al., 2011). They are manifested, for instance, in a decrease in water retention and a decline in biodiversity, caused by the remodelling of vegetation and, consequently, changes in animal communities. These changes simultaneously affect important ecosystem functions and services, such as water storage, carbon sequestration and water purification (Junk et al., 2013).

Previous studies indicate a global trend of decreasing natural wetlands and their transformation (Groombridge & Jenkins, 1998; Khaledian, et al., 2017). Estimating the extent of wetland areas, however, is difficult (Finlayson & Spires, 1999; Lehner & Doll, 2004; Fluet-Chouinard et al., 2015). This is a result of seasonal changes related to natural dynamics, or changes occurring over longer intervals due to periodic droughts and flooding. It is to be noted, however, that some studies published since the 1970s indicate the opposite trend: an increase in the surface area of wetlands. However, according to Davidson et al. (2018), such a trend should be attributed to the more widespread use of remote sensing methods, and only in some cases, at the local scale, to the expansion of wetlands of anthropogenic origin. Furthermore, the identification of forest wetland ecosystems can sometimes be problematic, as with the extensive use of aerial and satellite imagery analysis, it is not always possible to distinguish these ecosystems from other types of forests (Gallant, 2015).

Despite adopted wetland protection programmes supported by the Ramsar Convention, EU Directives and national regulations (Verhoeven, 2014) as well as numerous attempts at active protection and even restoration of wetlands (Grootjans & Verbeek, 2002; Bragg et al., 2003; Farrel & Doyle, 2003; Vasander et al., 2003; Souter et al., 2010), the problem of degradation and decline of natural wetlands is also affecting Europe to a significant degree. According to high-resolution estimates, continental inland wetlands currently account for 12.5% of the continent's area (Davidson et al., 2018). Despite the impossibility of obtaining accurate data, the loss of wetland area in Europe over the past 1,000 years is estimated at 80% (Spiers, 1999). A similar scale of this phenomenon occurs in Asia, while in North America the decline is estimated at 50% (Verhoeven, 2014). It should be noted that in Europe, the majority of the decline has occurred over the past 75-100 years as a result of rapidly increasing anthropogenic pressure and, more recently, climate change (Groombridge & Jenkins, 1998; EU, 2007). For instance, between 1950 and 1980, many wetlands in both Western and Eastern Europe were deliberately drained and reforested (68%) or converted to agricultural land (10%) (Silva et al., 2007). Alarming climate projections predict that average annual temperatures in Europe may rise more than the global average increase (Čížková et al., 2013). Rising temperatures and changes in precipitation patterns will increase the evaporation-to-precipitation ratio, which could have a significant impact on inland wetlands (Boer & de Groot, 1990). In addition, the greater frequency of extreme meteorological events, such as droughts and floods, particularly in Western and Central Europe, can generate socioeconomic pressure for flood control measures that can threaten water relations in wetlands (Čížková et al., 2013).

The state of wetlands in Central and Eastern Europe (Poland, the Czech Republic, Slovakia, Hungary, Eastern Germany, Romania and Bulgaria) was also affected by the transformation of agriculture under the common agricultural policy during the socialist rule between 1945 and 1989 (Turkowski, 2020). The implemented structural policy was to develop agriculture and increase its productivity primarily through the extension of drainage and irrigation systems. This policy also included land consolidation, often used to create a state sector in the countryside (Kaliński, 2008; Pijanowski, 2011). Therefore, particular attention was paid to this period in history to provide new data on the impact of agricultural transformations on the current state of wetlands in this part of Europe.

Treeless wetlands, located in depressions in the landscape, were selected for the current study, as ecosystems particularly sensitive to changes. Their high sensitivity to environmental changes is mainly related to their poor connection with watercourses and standing water (Whigham & Jordan, 2003; Winter & LaBaugh, 2003). As a result, these ecosystems respond very dynamically to climatic changes in the region with fluctuations in water levels (Euliss et al., 2004; Johnson et al., 2004). Forested wetlands were not included due to problems in interpreting their extent using remote sensing methods (Gallant, 2015; Davidson et al., 2018). The goal of the study was to identify the main causes and directions of changes in depression wetland ecosystems over the past 100 years, that is, from the pre-war period to the present day.

## Scope of the study

The study was conducted in southern Poland, in the central and eastern part of the Włoszczowa Basin (Kondracki & Richling, 2000), in an area of approx. 1600 $km^2$ (Fig. 1). The Włoszczowa Basin traditionally had an agricultural character (Bracichowicz & Wierzbanowski, 2004). It is part of a latitudinal dune belt that covers the European Plain and stretches from the Netherlands to Russia (Koster, 1988). In the lowland part of Poland, this belt reaches a maximum width of 200-300 km.

The Włoszczowa Basin is a depression with a flat bottom, consisting of late Cretaceous formations, with the majority of the area covered by Quaternary sediments (fluvioglacial sands and gravels, aeolian sands and glacial till) (Szajn, 1980). It is characterised by numerous dunes reaching 10-15 m in relative height (Szajn, 1978), fields of wind-blown sands and blowouts. Żołnierz (1978) documented 826 dunes in an area of 1,200 $km^2$, which overlaps the study area. Local land relief is conducive to the formation of depression wetlands, including small water reservoirs with different origins, including those of anthropogenic nature. The region is also characterised by a high rate of peat occurrence, at 8%. Some 160 mires of various types are located in the area, covering a total of 21,000 hectares (Okupny & Jucha, 2020). Most of them are mires associated with the valleys of rivers (mainly the Pilica River) and watercourses.

## Materials and methods

Archival topographic maps and orthophotomaps were used to assess changes in wetland ecosystems over the past 100 years.

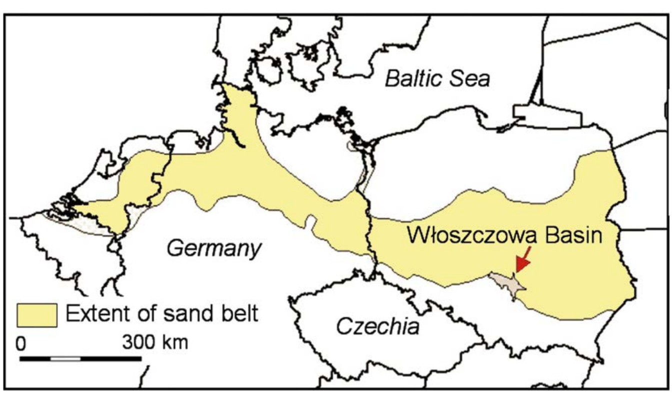


**Figure 1.** The research area on the background of a latitudinal sand belt that covers the European Plain (acc. Koster, 1988)

The basis for the comparison was the topographic maps provided by the Military Geographical Institute (WIG), which was in charge of developing and publishing maps in Poland in the period of 1919-1949 (Krassowski & Tomaszewska, 1979). WIG maps are the oldest available reliable cartographic source for assessing the extent of wetlands, mires and water bodies in the study area. 23 WIG map sheets at a scale of 1:25,000, in quasi-stereographic Roussilhe projection, were used in the study. These maps were based on Russian topographic photographic documentation from 1893-1899, updated in the 1930s, and include the boundaries of forests, agricultural crops, wastelands, mires and swamps, lakes as well as drainage ditches (Osowski, 1955; Krassowski, 1974; Kuna, 2018). In the 1950-70s, intensive land improvement was carried out in Poland, therefore, in addition, solely to assess their impact on wetland transformation, later topographic maps at a scale of 1:25,000 were also used ('1965' layout, quasi-stereographic Roussilhe projection – zone 5 and Gauss-Krüger projection – zone 1, updated for 1982-1989).

The surveyed objects were vectorised and mapped in detail following a common uniform reference system. The current system for medium-scale studies in Poland is the PL-1992 planar rectangular coordinate system, based on the Gauss-Krüger projection and the GRS80 ellipsoid. The contemporary extent of the wetlands was obtained through the interpretation of the orthophotomap (2019). In the case of water reservoirs, sites marked on maps as lakes or ponds, which had in common the absence of obvious anthropogenic elements such as ditches or hydrotechnical facilities, were selected. Among the selected reservoirs, 17 were designated as lakes.

In order to determine the causes of change, wetlands documented on WIG maps, were compared with the contemporary status in terms of changes in area and vegetation cover (Fig. 2). An important marker of changes was the appearance of hydrogenic forest and shrub communities, e.g., swamp forests and alders in an area of treeless wetlands as an element of natural succession. Vegetation changes were also analysed against the backdrop of changes in the management of former wetlands and their conversion to agricultural land, with a focus on land improvement (drainage and irrigation measures) as an anthropogenic cause of wetland degradation. The impact and magnitude of irrigation and drainage measures on the survival or disappearance of wetlands were analysed for wet meadows, mires and water reservoirs. The composition of the forests was verified on forest maps (Forest Data Bank, 2002). In some cases, field verification was necessary.

Considering the potential impact of human management in the immediate vicinity of the wetlands on their evolution, the use of the surrounding areas was also analysed. For this purpose, wet meadows and mires documented on WIG maps were divided by use into three groups:

1. surrounded by non-forest ecosystems (meadows, pastures and wastelands),
2. surrounded by forests,
3. surrounded by forests or non-forest ecosystems, partially covered with shrubs, with small clumps of trees.

## Results

The subject of the study was treeless depression wetlands in the central and eastern parts of the Włoszczowa Basin, as documented on WIG maps. In particular, these included wet meadows (wetlands with a mosaic of meadow communities, sedges, tall rushes and herbaceous vegetation), located in depressions in the area, mires in closed (drainless) depressions, some of them in large blowouts and water bodies identified on WIG maps as lakes or ponds. Extensive mires on floodplains in river and watercourse valleys, as well as those which were in contact with flowing waters, were excluded from consideration. The analysis of the WIG maps allowed for documenting 247 treeless depression wetlands. The largest group was wet meadows (148) with a total area of 1549 hectares (Fig. 3) and varying in size between 0.34-230.8 hectares. Less

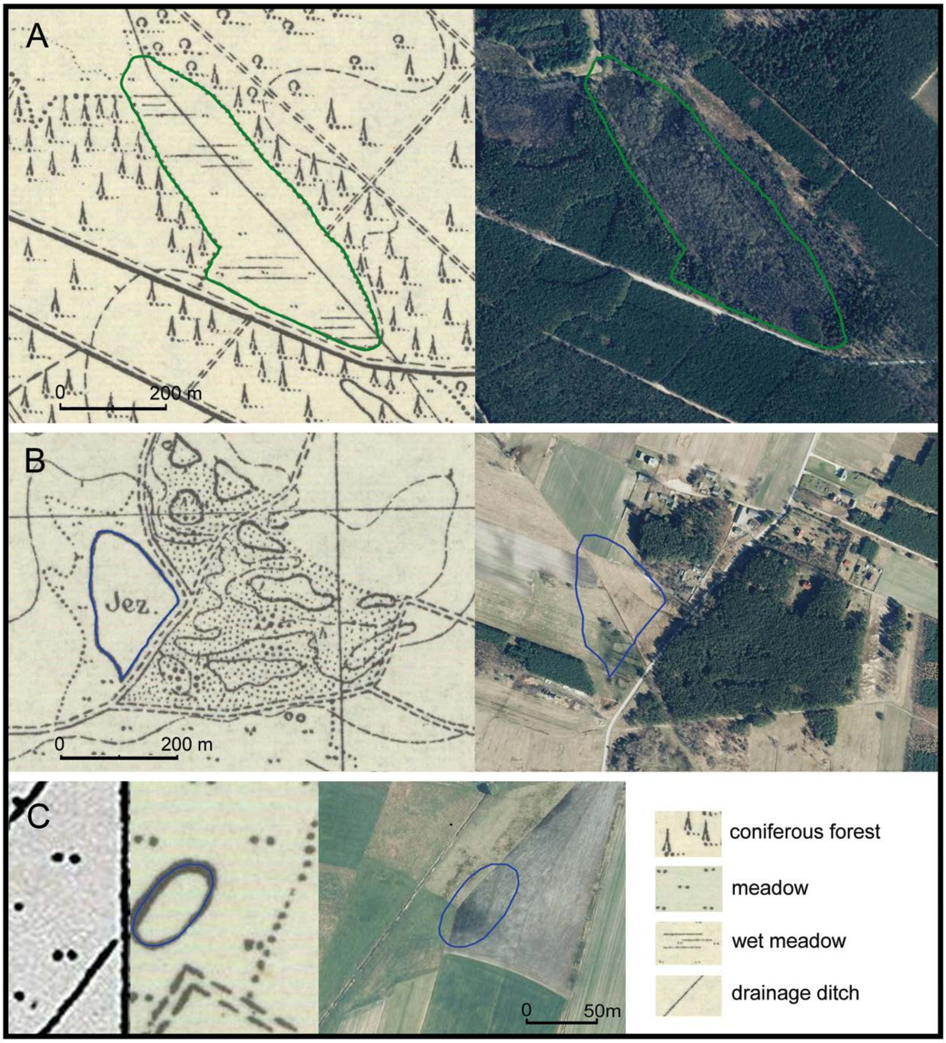


**Figure 2.** Example of wetland use changes on WIG maps and orthophotomaps; A – wet meadow (WIG maps, 19°43’21”, 50°43’47”) and coniferous forest (orthotomaps 2019), B – lake at the back of the dune (WIG maps, 19°56’13”, 50°43’36”) and cultivated fields (orthophotomaps 2019), C – Water reservoir (WIG maps, 20°09’51”, 50°46’38”) and cultivated fields (orthophotomaps 2019)

numerous were water reservoirs (80) and small treeless mires (19).

Wet meadows surrounded by non-forest ecosystems (meadows, pastures and wastelands) were the most numerous groups among the treeless depression wetlands. They also occupied the largest total area (Fig. 4). In addition to small meadows of up to 3 hectares (43%), a significant percentage were meadows of more than 10 hectares (40%). The largest of these spread over 230.8 hectares. Over the past 100 years, however, the nature of these wetlands has changed significantly. The analysis of the orthophotomap (2019) shows that 76% of them are currently used for agriculture (Fig. 5). In some areas, the original ecosystems have disappeared completely, and have been replaced almost

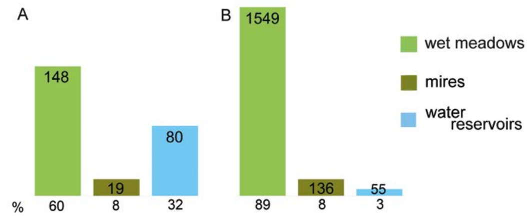


**Figure 3.** Treeless depression wetlands in the Włoszczowa Basin study area, documented on WIG maps; A – number of wetlands and percentage share, B – area of wetlands [ha] and percentage share

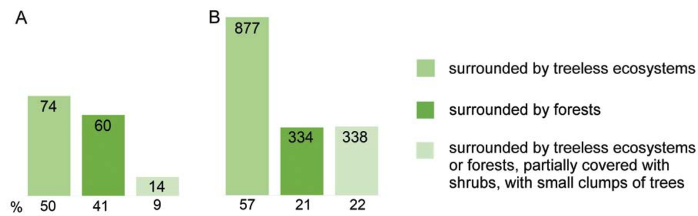


**Figure 4.** Wet meadows in the study area of the Włoszczowa Basin, documented on WIG maps A – number of wet meadows and percentage share, B – area of wet meadows [ha] and percentage share

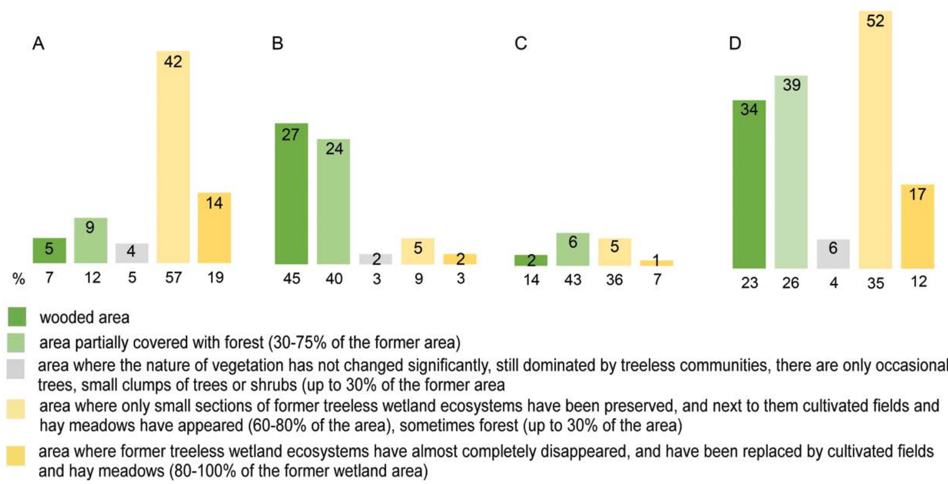


**Figure 5.** Contemporary condition of former wet meadows in the study area of the Włoszczowa Basin A – Wet meadows surrounded by treeless ecosystems, B – Wet meadows surrounded by forests, C – Wet meadows surrounded by forests or treeless ecosystems, partially covered with shrubs, with small clumps of trees, D – Total wet meadows. Number of wet meadows and percentage share.

Source: Based on Orthophotomap (2019).

entirely by agricultural land. For the most part, however, wet meadows have survived, although they have noticeably diminished in size, while cultivated fields and hay meadows have appeared alongside them. Today, forests with the prevalence of Baltic pine *Pinus sylvestris* grow in the area of some of the former meadows. Less common are small patches with black alder *Alnus glutinosa* or silver birch *Betula pendula*.

The second group of meadows documented on WIG maps are wet meadows surrounded by forests. These were mostly small mid-forest meadows, of which more than 65% were less than 3 hectares in size, and only 18% exceeded 10 hectares. Meadows surrounded by forests were only slightly less numerous than those surrounded by treeless ecosystems, however, they covered an area 2.5 times smaller (334 hectares) (Fig. 4). Almost exclusively coniferous forests grew in their vicinity. Due to the types of soils, the main component was likely Baltic pine *Pinus sylvestris*. Today, most of these areas are completely or partially covered with forest (85%) (Fig. 5). *P. sylvestris* still grows here, but there is also black alder *A. glutinosa*, silver birch *Betula pendula* and downy birch *B. pubescens*, and willows *Salix* sp. Some plantings of *P. sylvestris* as well as occasional logging have also been reported. These areas are used for agriculture to a small extent and only partially (Fig. 4). In only two cases did agricultural land occupy the entire area of the former wetlands.

Wet meadows surrounded by forests or non-forest ecosystems, partially covered with shrubs, with small clumps of trees are the third group of meadows documented on WIG maps (Fig. 4). Some were located adjacent to forests, but most were located in the vicinity of treeless ecosystems (79%). These meadows, although few in number, occupied a similar total area to the much more common wet meadows surrounded by forests. Their size varied from 1.6-167.8 hectares. Today, these areas are only partially used for agriculture and are largely subject to natural vegetation succession. Some of them have become completely overgrown with forest, in others this process is less advanced, and meadow communities are still developing over a significant area. Agricultural land is found only within the area of six former wetlands, but only in one case does it occupy its entire former area (Fig. 5).

Treeless mires located in depressions in the area were few (Fig. 3) and small (0.8-44 hectares). The most diversification in size was typical of mires surrounded by treeless ecosystems, they also boasted the largest total area (Fig. 6). The largest mire (44 hectares) also belongs to this group. Among the mires surrounded by forest, the largest occupied 5.2 hectares. Within one of them, a water reservoir was found, which allows us to assume that it was a transitional fen.

Today, most of the mires are completely or partially covered with pine forest (68%) (Fig. 7). This applies not only to mires that were previously surrounded by forests but also to those surrounded by treeless ecosystems. Hay meadows occur only in the area of four of them. Six of the mires are covered by water at least periodically.

In the area of many wet meadows and mires, drainage works were carried out, which began back in the early 20th century (Fig. 8).

The limnic ecosystems in the Włoszczowa Basin, documented on WIG maps, are small water bodies with sizes in the range of 0.04-5.2 hectares. More than 80% of them were less than 1 hectare in size. Most were surrounded by treeless ecosystems (70) and nine were located behind dunes.

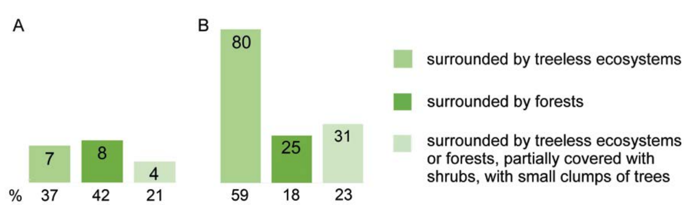


**Figure 6.** Mires in depressions in the study area of the Włoszczowa Basin, documented on WIG maps; A – number of mires and percentage share, B – area of mires [ha] and percentage share

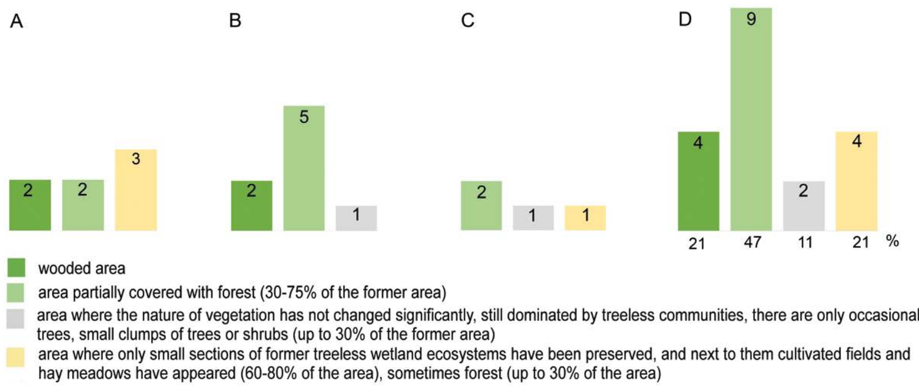


**Figure 7.** Contemporary condition of mires; A – surrounded by treeless ecosystems, B – surrounded by forests, C – surrounded by forests or non-forest ecosystems, partially covered with shrubs, with small clumps of trees, D – total mires. Number of mires and percentage share (D)

Source: Based on Orthophotomap (2019).

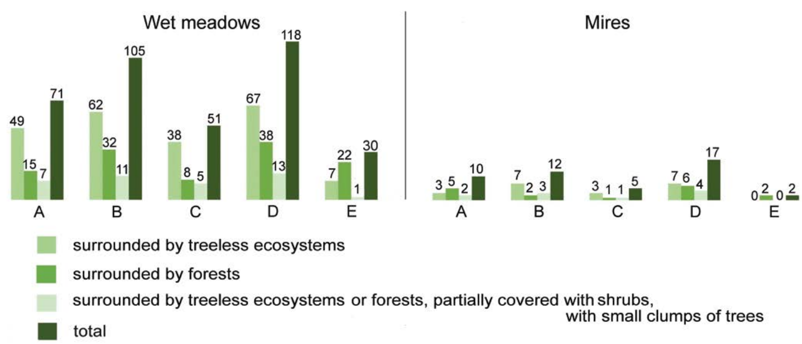


**Figure 8.** Number of drained treeless depression wetlands in the study area of the Włoszczowa Basin A – on WIG maps, B – on topographic maps in the '1965' layout, C – on both WIG maps and maps in the '1965' layout, D – total land improvement, E – undrained wetlands

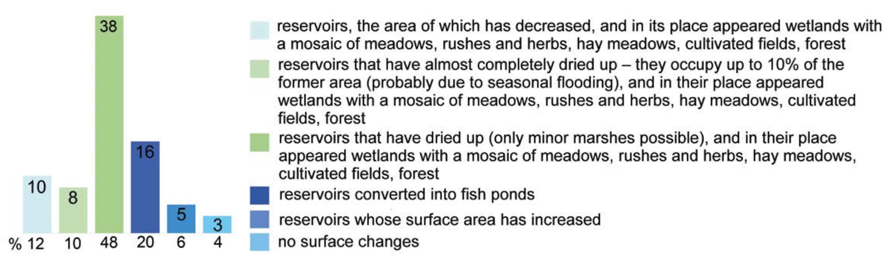


**Figure 9.** Water reservoirs in the study area of the Włoszczowa Basin. Contemporary state based on Orthophotomaps (2019). Number of reservoirs and percentage share.

Over the past 100 years, most of the water bodies have dried up or significantly reduced in size (Fig. 9). Occasionally, small marshes are still visible in the former basins, indicating the possibility of periodic stagnant water occurrence. In many terrestrialised areas, shrubs, clumps of trees and, in places, patches of deciduous or mixed forests have appeared. It is also common to find hay meadows and, less frequently, cultivated fields next to individual trees and small clumps. In only two cases, agricultural land occupies the entire former basin of the small reservoirs.

Despite the general trend of the reservoirs drying out, the area of five of them increased by a total of 36%. Most of the reservoirs, which have been converted into fish ponds, have survived unchanged in size. For six of them, an increase in surface area was recorded.

As in the case of wet meadows and mires, areas adjacent to reservoirs were also subject to large-scale drainage works (Fig. 10).

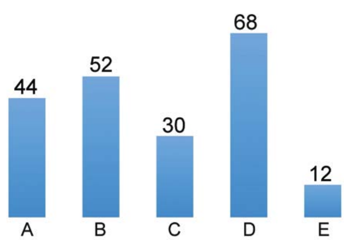


**Figure 10.** The number of water reservoirs in the study area of the Włoszczowa Basin, in the vicinity of which land improvement was carried out documented; A – on WIG maps, B – on topographic maps in the '1965' layout, C – on both WIG maps and maps in the '1965' layout, D – total land improvement, E – no land improvement.

## Discussion

Identifying a single key factor responsible for changes in wetland ecosystems is difficult (Berezowski et al., 2018). As in the case of landscapes, changes occurring at the level of ecosystems are the result of the interaction of natural factors such as climate and anthropogenic factors such as management and development, which alter together with socioeconomic and political changes (Hudson & Zorn, 2019). In addition, alterations occurring in different periods, overlap (Gregory, 2010), and the effects of past development may have an impact on contemporary processes, making it difficult to identify their causes (Berezowski et al., 2018).

Precipitation-dependent ecosystems devoid of any connections with the local river network are particularly vulnerable to changes, due to the delicate balance between precipitation and evaporation (Clair, 1998; Dawson et al., 2001, 2003; Euliss et al., 2004; Johnson et al., 2004). Although the wetlands of Southern Europe are identified as areas of the highest risk in climate change projections (Christensen et al., 2007), major changes are occurring and are likely to exacerbate the situation in Central Europe as well (Čížková et al., 2013). One good example is the Biebrza Valley – one of the largest and best-preserved fen complexes in Europe. Berezowski et al. (2018) described a locally persistent trend of increasing temperature, evapotranspiration and changes in the phenology of spring flooding, as well as the relationship of these changes to the conversion of occurring vegetation toward communities preferring less humid habitats.

The degradation and decline of wetlands, which have intensified in the last 100 years (Mitsch & Gosselink, 2000; Amezaga et al., 2002; Verhoeven, 2014), also apply to Central Europe (Kopeć & Michalska-Hejduk, 2012). The 56% reduction in the area of treeless depression wetlands in the Włoszczowa Basin is well in line with the prevailing trends and corresponds to the reduction in the area of mire and swamp ecosystems in Poland, estimated at 43% in 1946-1990 (from 1596.3 thousand hectares to 688.6 thousand hectares). In contrast, the decline is significantly lower than, for instance, the changes observed in the Czech Republic, where an estimated 73% of wetlands have disappeared since the 1950s (Mioduszewski, 1999).

The greatest loss in the area of treeless depression wetlands in the Włoszczowa Basin was in wet meadows (57%), particularly in meadows located in the vicinity of treeless ecosystems (meadows, pastures and wastelands), whose surface area has decreased more than threefold in the last 100 years (Fig. 11). The area of mires and water bodies decreased to a lesser extent, 48% and 44%, respectively. Estimates of changes in the surface areas of reservoirs may be subject to slight error in some cases. This is due to natural changes in water levels (both seasonal and multi-year), with their various stages potentially reflected on maps. This is particularly true for drying reservoirs, where water is present in a small part of the former basin, as well as reservoirs where only small marshes with seasonally fluctuating water levels persist. Similar problems in assessing changes in reservoir areas characterised by seasonal variations were pointed out by, among others, Davidson et al. (2018).

Most researchers point to the impact of human activity, particularly agriculture, as the main factor responsible for the decline of wetlands (Kracauer Hartig et. al., 1997; Silva et al., 2007; Davies et al., 2009; Poole et al., 2013; Verhoeven, 2014; Flávio et al., 2017). Taking into account the nature of the environment of the Włoszczowa Basin and its use over the past 100 years, it can be assumed that agricultural development associated with socioeconomic and political changes was the main reason for the disappearance of many wetlands in the area. At the same time, climate change in recent years (Čížková et al., 2013, Berezowski et al., 2018) has played a secondary role in this process. The Włoszczowa Basin is an example of a typically agricultural region. It lacks major industrial plants; the area is sparsely urbanised and has a relatively undeveloped road network. The population density is approx. 40 residents per 1 km$^2$, and the forest cover metric is above the national average (Bracichowicz & Wierzbanowski, 2004).

Of the activities associated with agricultural development, drainage systems are widely recognised as the most important factor responsible for wetland decline (Spaling, 1995; OECD/IUCN, 1996; Zhang et al., 2010; Koprowski et al., 2012; Flávio et al., 2017). In Poland, as in Central Europe in general, the first stage of larger-scale implementation of drainage measures occurred at the turn of the 19th/20th century (Ostromęcki, 1957). However, a clear increase in drainage works took place somewhat later, only in 1926-1930, with the goal of increasing agricultural production (Lipiński, 2006, Hildebrandt-Radke & Przybycin, 2011). The policy has also been reflected in the Włoszczowa Basin area. By the outbreak of World War II, 49% of terrestrial wetlands and 55% of areas with water reservoirs had been subjected to drainage measures. The works were conducted more often in wet meadows located in open areas than in forest settings (Fig. 8). The share of drained wetlands of the Włoszczowa Basin may be underestimated during this period, as some of the small drainage ditches, which are not of military importance, may not have been plotted on maps. The lack of sources quantitatively describing the extent of drainage and irrigation works in the area and confronting these descriptions with the results of map analysis has made it even more difficult

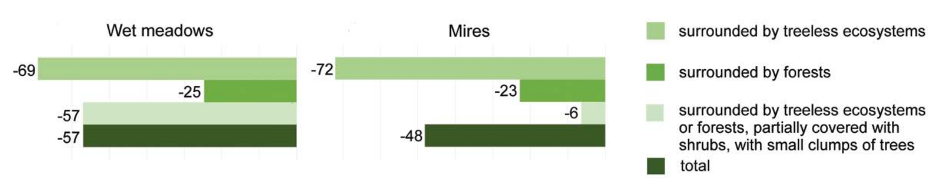


**Figure 11**. Loss of area of treeless depression wetlands in [%]

Source: Based on WIG maps and Orthophotomap (2019).

to assess the extent of these measures. After an agricultural crisis in the 1930s and stagnation during World War II, a resurgence of drainage works took place between 1950 and 1990, with a peak in 1961-1976. At the time, agricultural land was subject to drainage works at a rate of approx. 200-280,000 hectares per year (Lipiński, 2006). This acceleration was related to the agricultural policy pursued during the socialist rule, which involved intensive drainage works, aimed at increasing agricultural production (Kaliński, 2008; Pijanowski, 2011; Turkowski, 2020). A similar trend was also true for the Włoszczowa Basin. This is confirmed by the marked increase in the number of irrigation and drainage ditches on the maps in the 1965 layout. At the time, land improvement projects covered an area of 70% of the terrestrial wetlands. As before World War II, wet meadows surrounded by treeless ecosystems were most often altered with drainage systems (Fig. 8). In line with policy at the time, much of the work focused on expanding and repairing the existing infrastructure. The network of drainage and irrigation ditches has expanded over 35% of the wetlands.

The pace of drainage works only slowed noticeably in the late 1980s. The government's efforts in the 1990s came to a head with the emerging political and economic changes that brought the dismantling of large state farms and reduced funding. Since 1991, a regression in land improvement measures as well as the degradation of infrastructure, including drainage and irrigation ditches were recorded (Lipiński, 2006).

Drainage works carried out with varying intensity over the past 100 years have affected a total of approx. 80% of wet meadows and 90% of mires. Such a high percentage of altered mires may have been due to the potential attractiveness of organic land for conversion to grasslands (Lipiński, 2006; Pijanowski, 2011). In addition, the pursued drainage measures allowed for unrecorded peat exploitation for domestic use. The much more frequent use of drainage works for wetlands located in the vicinity of land already used for agriculture was probably related to the ownership structure. Land that was located in the vicinity of agricultural areas remained mostly in private hands, in contrast to the state ownership of most forests. A significant portion of the wet meadows in the vicinity of open areas may also have been temporarily excluded from management or used very extensively, which is difficult to capture in cartographic materials.

The development of depression wetlands following drainage measures has changed the nature of these areas. In some cases, their impact on the course of natural vegetation succession cannot be ruled out. Wet meadows were being converted to agricultural land, however, vegetation changes were also taking place, resulting in the expansion of forests. The relationship of drainage measures to the emergence of new hay meadows and agricultural land is well illustrated by the very high percentage of reclaimed wetlands on which agricultural land has emerged (Fig. 12). In the case of over 82% of wet meadows, which were surrounded by open areas, agricultural land now occupies 60-100% of the surface area. Within the group of wet meadows surrounded by forests, transformations of this type were much less common and, more often than not, agricultural land occupied a small area. It was much more common for hay meadows to appear in place of drained former wetlands, compared to cultivated fields. They also tended to occupy much larger areas. The preference for developing wetlands into grasslands was fostered by the potential of crop production in a wider range of habitats, in terms of water content and soil type (Lipiński, 2006; Wasilewski, 2009) and the development of livestock farming, mainly dairy cattle, requiring ever-increasing animal feed production (Gorzelak, 2010). The absence of cultivated fields and only occasional occurrence of hay meadows in the case of wetlands where water relations were not directly altered, confirms the role of drainage measures in these transformations. On the other hand, the increase in the area of wet meadows observed in several cases was

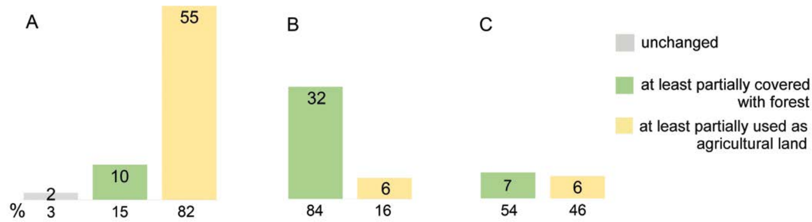


**Figure. 12.** Land use in drained meadows (number of wet meadows and percentage). Current status based on Orthophotomap (2019); A – wet meadows surrounded by treeless ecosystems, B – wet meadows surrounded by forests, C – wet meadows surrounded by forests or treeless ecosystems, partially covered with shrubs, with small clumps of trees

likely the result of obstruction and degradation of the drainage ditch infrastructure, as confirmed by field verification.

Management for agricultural purposes played a minor role in the case of mires. The complete lack of attempts to alter "mid-forest" mires for the purposes of agricultural production and the small percentage of such areas within meadows surrounded by forests is probably due to their management methods and the fact that these areas belong to the "State Forests" National Forest Holding. Due to the low extent and resources, peat exploitation, indicated as one of the main causes of mire degradation in Europe and Canada (Mitsch & Gosselink, 2000), was of little importance. Peat exploitation in five peat mires has led to succession reversal and the proliferation of patches of peat-forming vegetation, typical of wet open mires, by secondary succession. This type of regeneration of mire vegetation is common in former peat workings exploited to a limited degree (Girard et al., 2002; Beltman et al., 2011; Koprowski & Łachacz, 2013).

The land left over from dried bodies of water has also been used for agricultural purposes, mainly as grasslands. This was particularly true of reservoirs, where intensive drainage contributed to their total or partial disappearance as early as the 1960s. The effectiveness of such drainage, particularly for shallow reservoirs, has been confirmed by Koprowski et al. (2012), using the example of lakes in northern Poland, as well as other researchers.

Forest drainage, which was a common occurrence in Poland, was aimed at increasing the productivity of forest habitats (Babiński et al., 1989). They were also used in swampy areas, mainly to improve the growing conditions for Baltic pine *Pinus sylvestris* (Krajewski et al., 1988). In the case of the Włoszczowa Basin, their significance was limited.

Despite favourable water conditions, conversions of wet meadows into fish ponds were also marginal. However, this method of management was quite common for pre-existing reservoirs. The regulation of water conditions enabled converting 16 reservoirs into fish ponds, resulting in the increase of their total area by 35%. Land improvement measures have also affected the direction of evolution of some limnic ecosystems. Reconstruction of reservoirs at a later date, most likely due to degradation of the drainage and irrigation infrastructure, indicates a possibility of applying effective measures to restore previous water relations. The lack of a draining effect of land improvement measures on reservoirs, whose surface area has increased or remained unchanged, may in some cases be due to effective measures aimed at deliberately preserving water conditions – connecting them to the local hydrological network with ditches. In another case, the increase in surface area, recorded as early as the 1960s, may be the result of the location of the reservoir in the spring zone, which provided recharge, as well as draining more water from the surrounding meadows into the reservoir.

In addition to anthropogenic factors, where the strongest pressure was exerted by drainage, often leading to the creation of agroecosystems, the changes taking place in the wetlands of the Włoszczowa Basin were also the result of natural vegetation succession. Its final result was the formation of diverse forest communities depending on local conditions, including groundwater level and recharge method, trophy, pH and calcium carbonate content (Matuszkiewicz, 2013). Such changes were mainly observed in wet meadows surrounded by forests. The pressure to carry out drainage works and land management was negligible in such cases, and the evolution of the wetlands, despite the forest management carried out in the vicinity, was rather undisturbed. This is further confirmed by field verification of some cartographic materials, documenting the occurrence of vegetation compatible with the habitat and fitting into the classical succession sequences described in phytosociological literature (Matuszkiewicz, 2013). Most commonly, these included phytocenoses dominated by Baltic pine *Pinus sylvestris*, referring in their species composition to assemblages from the broadly defined swamp forest group (Matuszkiewicz, 2013), or less frequently, phytocenoses with black alder *Alnus glutinosa* and willows *Salix* sp., referring to the association of *Alnion glutinosae* in more fertile habitats (Matuszkiewicz, 2013). Field verification showed that a significant portion of the wetlands which evolved into forest ecosystems retained their wetland character with a persistently high water table.

In addition to affecting the water regime of drained areas, drainage works often affect the adjacent areas, causing not only a lowering of the water table, but also, as a result of mineralisation of organic matter, changes in the physical and chemical properties of habitats, affecting species composition and the overgrowth rate (van der Molen et al., 2007). In the case of most terrestrial and limnic wetlands where drainage measures were carried out, it is difficult, and in many cases impossible, to ascertain their impact on the sections of ecosystems that were not converted to agricultural land and experienced natural plant succession. However, studies of boreal mires indicate that lowering the groundwater table and stabilising its water table can result in accelerated encroachment of shrubby vegetation and trees (Laiho et al., 2003) as well as species depletion of the resulting phytocoenoses (Laine et al., 1995). Therefore, it is reasonable to assume that a similar process may also have occurred in the drained treeless depression wetlands of the Włoszczowa Basin, resulting in exacerbated overgrowth. Another important factor inhibiting succession in the ecosystems located in the vicinity of the emerging agricultural land may have been direct human impact, involving the removal of shrubs and trees, as well as other measures.

The intensive drainage of wetlands may also have resulted in health ramifications. The large-scale efforts to diagnose and control mosquito larvae occurrence may also have contributed to the elimination of malaria. As recently as 1948, 9,941 cases of the disease were recorded annually, mainly along the Vistula River, as well as in the Bug and Narew River basins (Dzbeński, 2008). However, as a result of an intensive malaria eradication campaign, only cases imported from areas endemic to the disease have been recorded since 1963 (Szata, 1997).

The directions of the transformation of the treeless wetlands of the Włoszczowa Basin over the last century, among which the predominant direction was transformation into agricultural land, were in line with trends observed in other countries of the former socialist bloc and Western Europe (Mioduszewski, 1999, Lipinski, 2006, Silva et al., 2007). The transformation of depression wetlands and the reduction of their surface area have adversely affected the ecological conditions of the region. Drainage measures have contributed to a weakened retention potential and a decline in biodiversity, as was the case in other regions of Europe (Okruszko et al., 2011).

## Conclusions

The transformation of the treeless depression wetlands of the Włoszczowa Basin has been largely related to the socio-economic and political changes that have taken place over the past 100 years. The main anthropogenic factors affecting the alterations and reduction of the surface area of wetlands were irrigation and drainage measures. The greatest increase in works of this type was recorded during the socialist rule, starting in 1945 and ending in 1989. However, the extent of the drainage and irrigation works carried out in the pre-war period may have been underestimated due to the possible lack of identification of some of the small ditches that were not of military importance on WIG maps. The surface area of treeless depression wetlands of the Włoszczowa Basin (wet meadows, mires and reservoirs) has decreased by 56% over the past 100 years. The nature and magnitude of the transformation of individual wetlands varied, depending on whether they had functioned in a forest setting or among open areas, as well as on the advancement of the initial stage of vegetation succession. However, regardless of the location, a significant decrease in total area was recorded for all three types of depression wetlands. Wetlands located among open areas were the most vulnerable to degradation, and the greatest loss of surface area was identified for wet meadows (57%).

The transformation of the Wetlands of the Włoszczowa Basin took place in several directions. The drained meadows were most often replaced with agricultural land. Former wetlands were much more frequently converted into hay meadows than cultivated fields. They also occupied much larger areas. In addition to agricultural land, the less fertile and still waterlogged areas of the former meadows underwent natural vegetation changes, resulting in the encroachment of forests. Alterations in management for agricultural purposes played a minor role in the case of mires, most of which are currently covered with forests (68%). Peat mining was not of significant importance. Most of the water bodies dried up or were significantly reduced in terms of their surface area. On the other hand, the conversion of 16 reservoirs into fish ponds has increased their surface area.

The increase in the surface area, recorded in the case of some of the wetlands, was a result of the obstruction of drainage ditches, redirecting additional water from the surrounding drained meadows, conversions of reservoirs into fish ponds and peat exploitation, which simultaneously led to the reversal of succession and the expansion of patches of peat-forming vegetation typical of mires through secondary succession. Undisturbed natural succession, which was responsible for the transformation of primarily undrained wet meadows surrounded by forests, resulted in the development of swamp shrub and forest communities dominated by Baltic pine *Pinus sylvestris* or, less frequently and in more fertile habitats, with black alder *Alnus glutinosa* and willows *Salix* sp.

Editors' note:
Unless otherwise stated, the sources of tables and figures are the author's, on the basis of their own research.

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