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Original Research

The Trajectory of Wetland Development in the Middle Part of the Elbe River Basin in the Past 180 Years

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Abstract

In this article, a change in wetland coverage and the representation of different wetland categories over the last 180 years was analysed for the middle part of the Elbe River basin. Historical maps of the Stable Cadastre, the current orthophoto map, and GIS layers of the current location and classification of different types of land cover were used as sources. Based on the study of the available documents, the following three types of wetlands were classified: swamps and marshes, wet meadows, and wet meadows with woody vegetation. The area of wetlands has dramatically decreased from 1,125.68 ha in 1841-42 (9.55% of the researched area) to 51.04 ha in 2022 (0.43%). While the majority of the area of historical wetlands was wet meadows (97.12%), at present, the largest area of wetlands is swamps and marshes (85.56%). Almost 60% of the area of the disappeared wetlands is now occupied by arable land; therefore, the observed changes can be attributed mainly to an increase in agricultural production. The obtained information can be used in landscape planning with regard to the protection and management of wetlands, or in proposing measures to improve the ecological status of surface water bodies.

Keywords: archival maps, wetlands, GIS, landscape changes, water in landscape

Introduction

Wetlands are of extraordinary importance for the preservation of genetic biodiversity, they are among the habitats with the greatest biological activity, and they are also extremely important for the preservation of valuable biocenoses [1]. Wetlands play a number of roles in a landscape, mainly the non-production ones, such as hydrological and ecological roles, e.g., they help to retain water in the landscape and have an important role in the flood protection system as they retain sediments, nutrients and pollutants on their way to the river system [2, 3]. This means that during the dry season, wetlands are able to recharge the local hydrographic network by gradual release of the water they accumulated during the rainy season. And, conversely, during periods of heavy rainfall, precipitation can accumulate in the wetland area and thus mittigate the course of floods and slow down their progress [4-6]. Wetlands are also among the most efficient elements in the renewal of the short water cycle in the landscape [7].

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Unfortunately, the favourable role of wetlands used to be underestimated and wetland areas were mainly drained for agricultural uses on a worldwide scale, particularly during the 20^{th} century. An estimated 64-71% of wetlands have been lost due to this draining, resulting in a number of adverse environmental impacts. This trend was present to a lesser extent before the 19th century and the first half of the 20^{th} century, when large-scale amelioration projects were implemented [8]. Of course, this trend has also taken place in the Czech Republic. In the past, the population in the area of today's Czech Republic used wetland biotopes to its needs without endangering the wetlands or inappropriately affecting their functioning (regular wetland meadow mowing and reed cutting), and also maintained the optimum moisture of the natural wetlands by means of amelioration ditches. This type of management is rare today and, as a result, wetlands have almost disappeared from the Czech landscape (except for ponds and some sites in specifically protected areas) [9].

Information on the historical development of wetlands at the landscape level is not only important from the theoretical aspect in order to gain insight into the forces and pressures acting on the changes of the wetland biotopes, but also as an inspiration for wetland restoration in the landscape. In fact, historical understanding of wetland formation and dynamics is the basic precondition for the implementation of effective wetland management, protection and renewal measures. In addition, the past landscape structure was often better able to play its environmental as well as economic roles than the present landscape structure [10]. Nowadays, a number of activities focuses on the rehabilitation and restoration of wetlands, as the awareness to extent of hydrological as well ecological values of wetlands in multifunctional landscapes increases. Largely, the success of wetland restoration depends on site selection. In this case, the relevant knowledge of historical locations of wetlands based on the mapping of former wetland sites in the GIS can play an important role. But then more detailed reconnaissance of the terrain must follow. The local knowledge of natural and socio-economic conditions can be an advantage in the selection of sites for implementation of wetland restoration with the aim to improve the state of the landscape affected by climate change and more frequent hydrometeorological extremes [11].

The main goal of the research presented in this article is the analysis and evaluation of long-term changes in wetland habitats at the landscape level. The cadastral districts in the middle part of the Elbe River basin, intensively used for agriculture, were selected as pilot areas. The following main research questions were addressed:

– What is the dynamics of changes (expressed by the representation of continuous, disappeared, and new wetlands) and the development trajectory of wetlands in the middle part of the Elbe River basin?
– How has the structure of the representation of different wetland categories changed over the course of history?

Material and Methods

The basis for data processing was archival maps, current maps, and a field survey conducted in 2022. The actual processing of the obtained data took place in 2021-2022.

A Brief Summary of the Methodology

– The areas of interest were delimited as a cadastral district belonging to the middle part of the Elbe River basin in the vicinity of Lysá nad Labem in an area typical for growing vegetables, so that both the landscape in the immediate vicinity of the Elbe River and the landscape further away from it were represented. As a result of this division, the researched area is spread over an altitude range of 172-252 m above sea level.
– The cadastral districts were located to form a continuous area around the Elbe River in a third-order basin 1-04-07 (the Elbe River from the Výrovka River to the Jizera River). Since the borders of the cadastral districts do not correspond to the basin borders, a small part of the researched area is located in a third-order basin 1-05-03 (the Jizera River up to its confluence with the Klenice River).
– Archival maps of the Stable Cadastre *(Franziszeischer Kataster)* and the current orthophoto map of the Czech Republic were used as the main sources. Archival maps of the Stable Cadastre were georeferenced and then vectorized.
– Spatial changes were detected using analysis in a GIS environment using the Symmetrical Difference and Intersection tools. The result is a categorization of wetlands into continuous, disappeared, and new segments.
– Furthermore, the trajectories of wetland changes were described for their individual categories.

Delimitation of the Area

The area was delimited using the borders of the current cadastral districts. A total of 12 cadastral districts with a total area of 117,899 km^2 were selected (Fig. 1). The delimited area lies almost entirely in the Elbe River basin from the Výrovka River to the River (third-order basin 1-04-07); a small part is located in the Jizera River basin up to its confluence with the Klenice River (third-order basin 1-05-03) [12]. The area is located in the agriculturally intensively used landscape of the Polabská nížina (Labe Lowlands). In the northern part it is a slightly undulating, partially wooded landscape (Fig. 1), where part of the cadastral district of Milovice nad Labem lies in the former military area

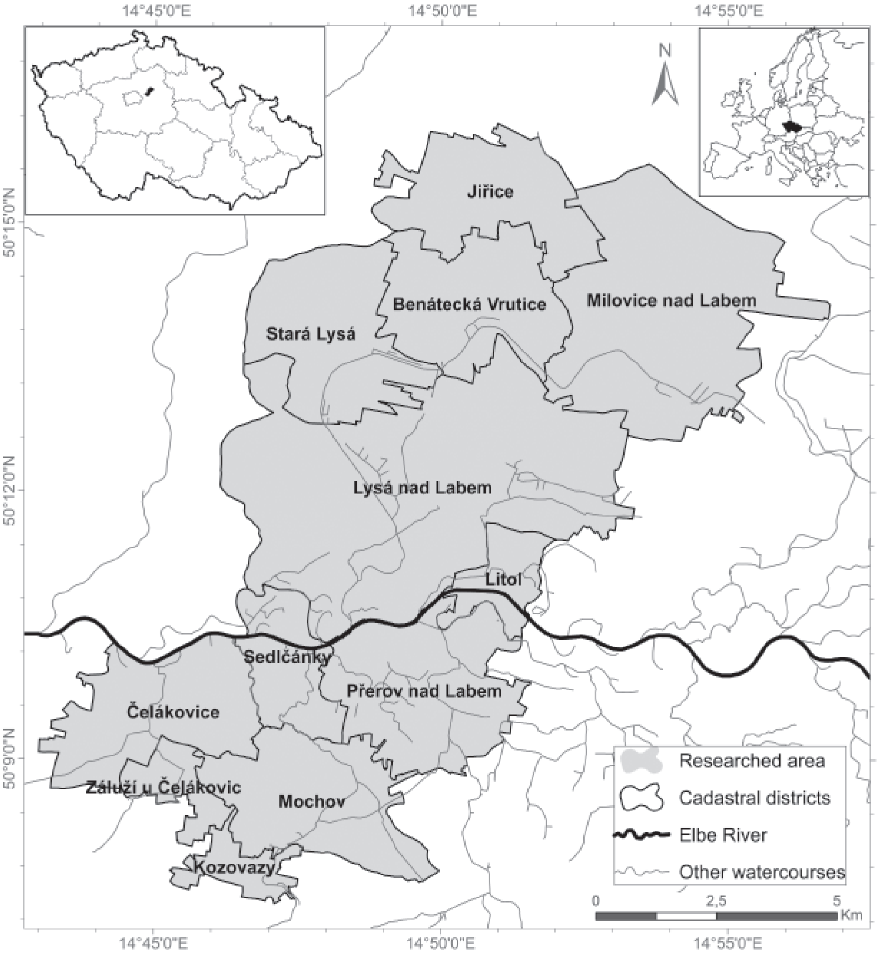

Fig. 1. Location of the researched area within the current borders of the cadastral districts and within the Czech Republic and Europe.

of Mladá. According to the functional types of the landscape, the majority of the research area is a field landscape, and in the northern part a field landscape with heterogeneous agricultural areas. According to the framework type of natural landscape, the entire area is a warm landscape of the lowlands [13]. The dominant soil types are fluvisol, cambisol, pararendzina, and phaeozem [14]. This part of the Polabská nížina was chosen for the fact that the landscape has undergone intensive changes, where wetlands have mostly been transformed into other types of landscape use. At the same time, wetlands are largely absent in this landscape, and their restoration would be significant due to the improvement of the water regime in the landscape, especially mitigating the effects of floods and prolonged dry periods.

The researched area consists of the following cadastral districts: Benátecká Vrutice, Čelákovice, Jiřice, Kozovazy, Litol, Lysá nad Labem, Milovice nad Labem, Mochov, Přerov nad Labem, Sedlčánky, Stará Lysá, Záluží u Čelákovic. During the monitored period, the administrative division changed. While in the middle of the 19th century the monitored area belonged partly to the Kouřim and Mladá Boleslav regions, at present it belongs entirely to the Central Bohemia region, partly to the Nymburk and Prague-East districts [15].

The entire third-order basin 1-04-07, the Elbe from the Výrovka River to the Jizera River, has an area of 604,825 km^2 (the researched area therefore makes up about a fifth of the area of the basin) and is adjacent to the following third-order basin in the upper and middle Elbe River basin: 1-04-05 the Elbe River from the Mrlina River to the Výrovka River; 1-04-06 the Výrovka River; 1-05-02 the Jizera River from the Kamenice River to the Klenice River; 1-05-03 the Jizera River up to its confluence with the Klenice River; 1-05-04 the Elbe River from the Jizera River to the Vltava River. In the Lower Vltava River basin, the neighbouring third-order basins are: 1-09-03 the Sázava River up to its confluence with the Želivka River; 1-12-01 the Vltava River from the Berounka River to the Rokytka River [12].

Materials for Data Processing

Historical Condition of the Landscape and Wetlands

For mapping the historical condition of the landscape and wetlands in the middle of the 19th century, Mandatory Imperial copies *(Kaiserpflichtexemplar)* of the Stable Cadastre *(Franziszeischer Kataster)* were used; if these were not available, the original Indication Sketches of the Stable Cadastre were used, both in 1:2,880 scale. These documents are divided according to the then borders of the cadastral districts. They were mapped in 1841 (Kouřim Region) and 1842 (Mladá Boleslav Region). They are available on the website of the Central Archive of Surveying and Cadastre [15]. The individual map sheets were combined into units according to their affiliation to the historical cadastral district in Adobe Photoshop CS5.v12. In the event that the boundaries of the historical and new cadastral district were not identical and part of the new cadastral district was missing, the relevant part of the neighbouring historical area was also processed.

The documents were then georeferenced using the Georeferencing tool in the GIS environment, specifically in the ArcMAP 10.7.1 program. As reference layers for georeferencing, layers of the Basic Map of the Czech Republic at a scale of 1:10,000, the current borders of cadastral districts, and the current orthophoto map were used. All the mentioned documents were connected using the WMS service, which is available on the CUZK (Czech Office for Surveying, Mapping and Cadastre) Geoportal [16].

The monitored wetland categories are based on the legend of the Stable Cadastre maps and were defined so that it was possible to follow the development of identical categories both on the historical maps of the Stable Cadastre and in the present. These are the basic historical categories of wet meadows, wet meadows with woody vegetation, and swamps and marshes. As an alternative category of wetlands, ponds were also included; however, from water management and partially a landscape-ecological point of view, they are also classified as water bodies. The other (non-wetland) land use/cover categories were similarly classified. These were arable land, forestland, non-forest woody vegetation, grassland, orchards, urban areas, transportation routes, other water bodies (without ponds), and watercourses (Table 1).

Current Condition of the Landscape and Wetlands

Land use/cover types of the current landscape and existing wetland types were identified by the method of manual visual interpretation using a combination of several different types of materials. The main source of data was the current coordinate-connected (WMS) orthophoto map, which is available on the CUZK Geoportal [16]. The following additional documents were used to verify the information obtained from the orthophoto map:

– LPIS for determining the type of agricultural land. A vector layer is available on the Public Land Registry website [17].

Table 1. Monitored Land use/cover categories, including wetland categories

Land use/cover		Description
No wetlands	Urban areas	Town/village residential area except for major streets and roads and major green areas, scattered buildings
	Transportation routes	Any roads, lanes, cycle paths, railway tracks, sidings
	Arable land	Periodically managed arable land
	Forest land	Woody vegetation classified as forest land (ÚHÚL)
	Non-forest woody vegetation	Woody vegetation not classified as forests (e.g. river bank vegetation, parks etc.) (ÚHÚL).
	Grasslands	Meadows, pastures, agriculturally unused grasslands (also linear grassland along roads)
	Other water bodies	Ponds, lakes, dams, water reservoirs and swimming pools
	Watercourses	Rivers, brooks, raceways, canals
	Orchards	Orchards and gardens
Wetlands	Swamps and marshes	Sites permanently saturated with stagnant water or waterlogged for the predominant part of the year, with a reed or cattail stand or similar hygrophytes; scattered woody plants with reed undergrowth or growing in a wetland biotope.
	Wet meadows	Periodically mowed meadows with various hygrophyte vegetation, swamped for the predominant part of the year; swamped meadows that are irregularly mowed/used; unused wet or waterlogged meadows with no woody vegetation.
	Wet meadows with woody vegetation	Wet or waterlogged meadows with woody vegetation not categorised as forests, also with broad-leaf; unused wet or waterlogged meadows with starting woody vegetation or with reed undergrowth or growing in a wetland biotope.
Ponds		Typ of water bodies, especially for fish farming. They have a relatively small area and are no longer deep. They are also classified as wetlands.

– Boundaries of topsoil to differentiate forest stands from non-forest woody vegetation. The WMS service is available on the Forest Management Institute (FMI) Geoportal [18]; the layer of topsoil boundaries is taken from Regional Forest Development Plans.
– ZABAGED® for the initial identification of current wetlands on the basis of the marshs and swamps layer [19]. Available as a WMS service on the CUZK Geoportal [16].
– DIBAVOD to check the location of watercourses and water reservoirs, and to determine current ponds, the layers of watercourses and water reservoirs were used, which are available on the website of the Digital Water Management Database [20].

Programs Used and Data Processing

Georeferencing of archival map sheets of the Imperial compulsory imprints of the Stable Cadastre, connection of current documents using the WMS service, and subsequent creation of a polygon layer in the *.shp* format took place in the GIS environment, specifically in the ArcMAP 10.7.1 program in the ETRS89/UTM zone 33N coordinate system. Each polygon was defined by its identification number, the type of wetland, and the year in which it occurred in the area. All landscape segments were interpreted as polygons, regardless of whether they are enclaves or corridors in the landscape [21], due to the necessity of creating exclusively the polygon layer for subsequent GIS spatial analyses. Spatial analysis of wetland changes at the landscape level was carried out in a GIS environment using the Symmetrical Difference tool for the creation of new feature classes and the transfer of attributes based on combinations of two overlapping feature classes and the Intersection tool. The result of the analysis was the categorization of wetlands according to their spatio-temporal dynamics, into continuous, disappeared, and new segments. The category of continuous wetlands means the occurrence in the same location, both on Stable Cadastre maps and at current documents (according to DIBAVOD [20], ZABAGED® [16, 19], and the orthophoto map [16]). When verifying the data according to the field survey disappeared wetlands are recorded only on Stable Cadastre maps, whereas the new wetlands are recorded only on current documents. The initial data processing took place in a GIS environment; it involved calculating the area of polygons. The resulting values were exported and interpreted in the form of tables in Microsoft Excel 2016. As part of the processing of these map and tabular outputs, the results showing the change in area and location of individual types of wetlands are presented.

The Verification of Wetland Categories Classification Accuracy

The accuracy check of wetland categories classification was carried out in two steps: The first step of data verification consisted of revision of the available data on the computer. This was performed by using the intersection of all available data recording the current state of wetlands in comparison with the current orthophoto map. This way,the areas with potential contradictions of data vs. the actual state were distinguished. In the second step, the current state of the sites was verified based on a field survey. Adjustments were made by using map records as well as GPS measurement records. A similar procedure was used, e.g., by COPASS et al [22].

Results

Area of Historical and Current Wetlands

Historical wetlands are formed by the sum of areas of disappeared and continuous wetlands. In the first half of the 19th century, the area of wetlands in the researched area was 1,125.68 ha, which represents 9.55% of the researched area. On the other hand, in 2022, wetlands occupy only 51.04 ha, i.e., only 0.43% of the researched area. The total wetland area has therefore decreased by a factor of almost exactly twenty-two, i.e. the area of current wetlands corresponds to 4.53% of the area of historical wetlands (Table 2).

A substantial part of historical wetlands in the researched area was wet meadows, namely 1093.26 ha (i.e., 97.12% of the area of historical wetlands), followed by swamps and marshes with an area of 26.69 ha (2.37%). The remaining area of historical wetlands, 43.67 ha (0.51%), was wet meadows with woody vegetation (Table 2).

Table 2. Change in area of wetlands in the researched area.

Land use/cover	Area [ha]		Area [%]		Situation against 1841/42 [%]
	1841/42	2022	1841/42	2022	
Wet meadows	1,093.26	2.87	97.12	5.62	0.26
Wet meadows with woody vegetation	5.73	4.50	0.51	8.82	78.50
Swamps and marshes	26.69	43.67	2.37	85.56	163.63
Σ	1,125.68	51.04	100	100	4.53

Current wetlands are formed by the sum of areas of new and continuous wetlands. Currently, swamps and marshes occupy the largest area among wetland types. They cover 43.67 ha (85.56%). The rest of the area of the current wetlands is wet meadows and wet meadows with woody vegetation. They cover 2.87 ha (5.62%) and 4.50 ha (8.82%), respectively (Table 2).

In the entire researched area, covering a total of 117,899 km^2 (12 cadastral districts), disappeared wetlands occupy an area of 1,094.64 ha, which is 97.25% of the area of historical wetlands, and continuous wetlands cover an area of 31.04 ha (2.75% of the area of historical wetlands). New wetlands cover an area of 20 ha, which is approximately 55 times smaller than the area of the disappeared wetlands (Tables 3, 4 and 5). It is clear from these data that the majority of historical wetland area has disappeared from the researched area and this loss has not been compensated by the creation of new wetlands.

Wetland Change Trajectories

The vast majority of wetlands in the researched area have disappeared (1,094.64 ha, i.e., 95.54% of all types of wetlands according to temporal stability) (Table 3); continuous and new wetlands make up only a tiny fraction of the area of all types of wetlands according to temporal stability (Fig. 2). This is 31.04 ha (2.71%)

Table 3. Trajectory of changes in the area of disappeared wetlands in the researched area.

Type of change - extinct wetlands	area [ha]	% typ	% total
Wet meadows >> Arable land	621.49	58.41	56.78
Wet meadows >> Grasslands	114.73	10.78	10.48
Wet meadows >> Forest land	109.30	10.27	9.98
Wet meadows >> Non-forest woody vegetation	90.65	8.52	8.28
Wet meadows >> Urban areas	53.68	5.05	4.90
Wet meadows >> Transportation routes	25.18	2.37	2.30
Wet meadows >> Watercourses	18.87	1.77	1.72
Wet meadows >> Ponds	14.02	1.32	1.28
Wet meadows >> Orchards	8.10	0.76	0.74
Wet meadows >> Other water bodies	8.00	0.75	0.73
∑	1,064.01	100	97.20
Wet meadows with woody vegetation >> Forest land	2.18	42.66	0.20
Wet meadows with woody vegetation >> Non-forest woody vegetation	1.71	33.58	0.16
Wet meadows with woody vegetation >> Arable land	0.87	17.09	0.08
Wet meadows with woody vegetation >> Grasslands	0.34	6.67	0.03
∑	5.10	100	0.47
Swamps and marshes >> Arable land	7.32	28.66	0.67
Swamps and marshes >> Forest land	5.88	23.03	0.54
Swamps and marshes >> Grasslands	5.56	21.76	0.51
Swamps and marshes >> Non-forest woody vegetation	4.25	16.63	0.39
Swamps and marshes >> Urban areas	0.83	3.24	0.08
Swamps and marshes >> Ponds	0.61	2.37	0.06
Swamps and marshes >> Transportation routes	0.53	2.06	0.05
Swamps and marshes >> Watercourses	0.29	1.15	0.03
Swamps and marshes >> Other water bodies	0.21	0.82	0.02
Swamps and marshes >> Orchards	0.07	0.27	0.01
∑	25.53	100	2.33
∑	1,094.64	-	100

for continuous ones and 20 ha (1.75%) for new ones (Tables 4 and 5).

At the site of the disappeared wetlands, arable land is currently the dominant land use, accounting for 57.57% of their original area. A significant share is also occupied by grassland (11.03%), forest land (10.73%), and non-forest woody vegetation (8.84%). Urban areas cover 4.99% of the area of original wetlands. Transportation routes, ponds and other water bodies, orchards and gardens are less represented, and watercourses occupy only an insignificant share of the area of disappeared wetlands.

Of wet meadows, 58.41% changed to arable land, 10.78% to grassland, and 10.27% to forest land. 28.86% of swamps and marshes changed to arable land, 23% to forest land, and 21.76% to grassland. In place of wet meadows with woody vegetation, forest land (42.66%), non-forest woody vegetation (33.58%), and arable land (17.09%) are most common (Table 3).

Newly created wetlands consist mainly of swamps and marshes (15.567 ha). Wet meadows with woody vegetation and wet meadows as new wetlands cover an area of 3.744 ha and 0.689 ha, respectively. New wetlands occur mainly on the site of former

Table 4. Trajectory of changes in the area of new wetlands in the researched area.

Type of change - new wetlands	Area [ha]	% typ	% total
Watercourses >> Swamps and marshes	5.94	38.17	29.71
Grasslands >> Swamps and marshes	4.53	29.13	22.67
Forest land >>Swamps and marshes	2.16	13.89	10.81
Non-forest woody vegetation >>Swamps and marshes	1.46	9.37	7.30
Ponds >> Swamps and marshes	0.81	5.21	4.06
Arable land >> Swamps and marshes	0.51	3.24	2.53
Transportation routes >> Swamps and marshes	0.15	0.99	0.77
∑	15.57	100	77.84
Watercourses >> Wet meadows with woody vegetation	2.69	71.88	13.46
Ponds >> Wet meadows with woody vegetation	0.45	11.94	2.24
Non-forest woody vegetation->>Wet meadows with woody vegetation	0.23	6.01	1.13
Forest land->>Wet meadows with woody vegetation	0.19	5.07	0.95
Transportation routes >> Wet meadows with woody vegetation	0.08	2.11	0.40
Grasslands >> Wet meadows with woody vegetation	0.06	1.55	0.29
Arable land >> Wet meadows with woody vegetation	0.05	1.44	0.27
∑	3.74	100	18.72
Watercourses >> Wet meadows	0.63	91.58	3.16
Ponds >> Wet meadows	0.06	8.42	0.29
∑	0.69	100	3.45
∑	20.00	-	100

Table 5. Trajectory of changes in the area of continuous wetlands in the researched area.

Type of change- continuous wetlands	Area [ha]	% typ	% total
Wet meadows >> Swamps and marshes	26.31	89.14	84.76
Wet meadows >> Wet meadows	2.18	9.10	7.03
Wet meadows >> Wet meadows with woody vegetation	0.76	1.76	2.44
∑	29.25	100	94.22
Swamps and marshes >> Swamps and marshes	1.16	100	3.74
Wet meadows with woody vegetation >> Swamps and marshes	0.63	100	2.04
∑	31.04	-	100

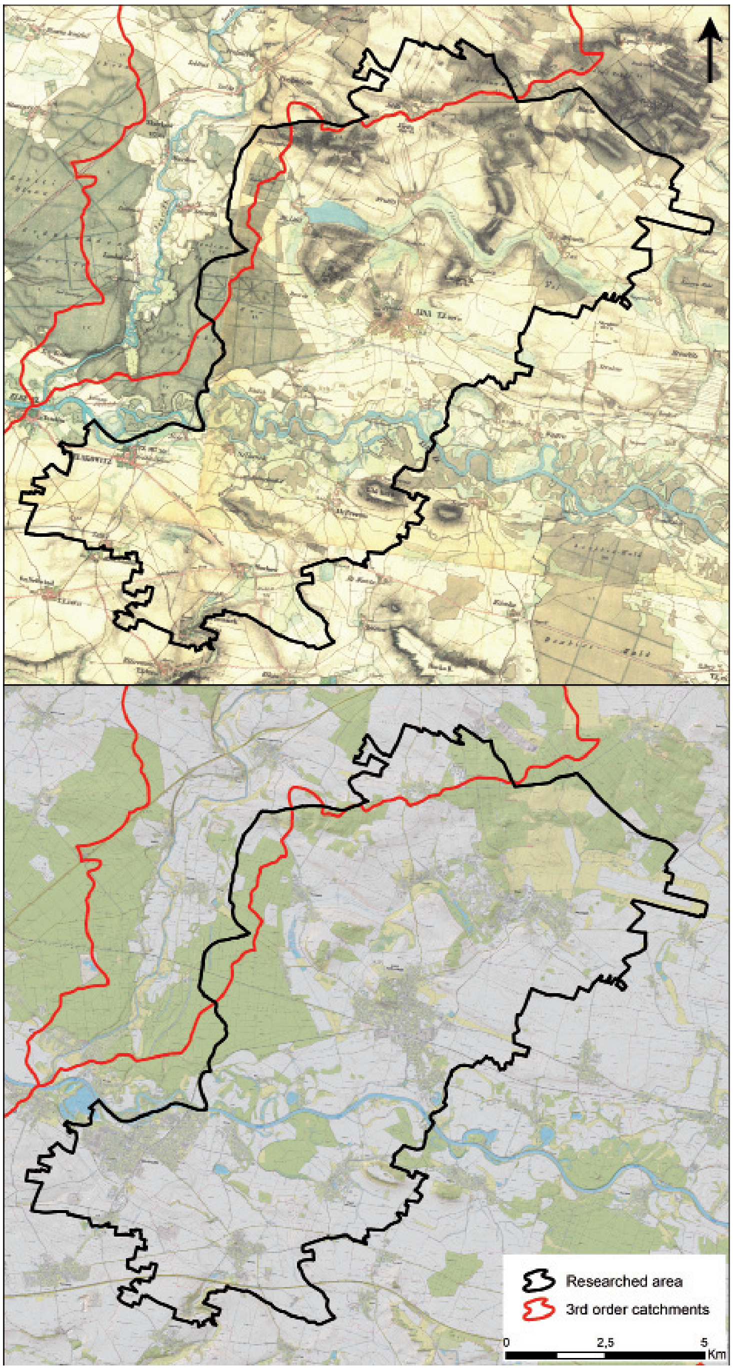

Fig. 2. The research area within the current borders of the third-order basins on the basis of current map of the Czech Republic at a scale of 1:10,000 and the second Austrian military survey (mapped 1836-1852 at a scale of 1:28,800).

watercourses (46.32%) and grassland (22.96%). Forest land (11.76%), non-forest woody vegetation (8.42%), and ponds (6.58%) are also more significantly represented. The representation of arable land and transportation routes is minimal (Table 4).

In the case of continuous wetlands, swamps and marshes currently make up the largest area (28.10 ha). An area of 2.18 ha is occupied by wet meadows. Wet meadows with woody vegetation make up an area of 0.76 ha. All types of continuous wetlands are found mainly on the site of historical wet meadows (Table 5).

The Verification of Wetland Categories Classification Accuracy

When verifying the available data, it was found that the error rate of the data was in the units of percent (except office validation accuracy for wet meadows with woody vegetation) in the researched area. In total, the wetlands were classified by office validation and field validation with accuracy over 93% and 96%, respectively (Table 6). Based on the evaluation of the processed data from the orthophoto map along with

Table 6. The verification of wetland categories classification accuracy when including ponds.

Land use/cover	Sample number	Office validation accuracy	Field validation accuracy
Wet meadows	12	91.7	91.7
Wet meadows with woody vegetation	17	88.2	94.1
Swamps and marshes	27	92.6	96.3
Ponds	32	96.9	100
Total	88	93.2	96.6

background data compared to modified data from the field survey, it was found that the available data largely correspond to the actual state and the changes are not so significant, therefore further field visits are not necessary.

Discussion

A certain inaccuracy in the results is caused by the fact that the documents used are partially incompatible, especially in terms of the nature of the map type, scale, and quality. In particular, it concerns the use of Stable Cadastre maps and current orthophoto maps, which are quite different sources. The results are refined by using other current maps.

Comparing historical and current wetland categories will always be imprecise because, even for the same category, wet meadows in the past will never be the same as wet meadows today, especially in terms of the scale of their economic use in the past and almost exclusive affiliation to specially protected areas at present. To make it easier to compare the development of wetlands, the individual categories of historical and current wetlands were labelled with the same terminology, even though they often differed both in their management and appearance as well as integration into the landscape. In the legend of the Stable Cadastre, in addition to ponds, there are four basic representations of wetlands: marshes, marshes with reeds, wet meadows, and peat bogs. During the mapping of the Stable Cadastre, there were various deviations from

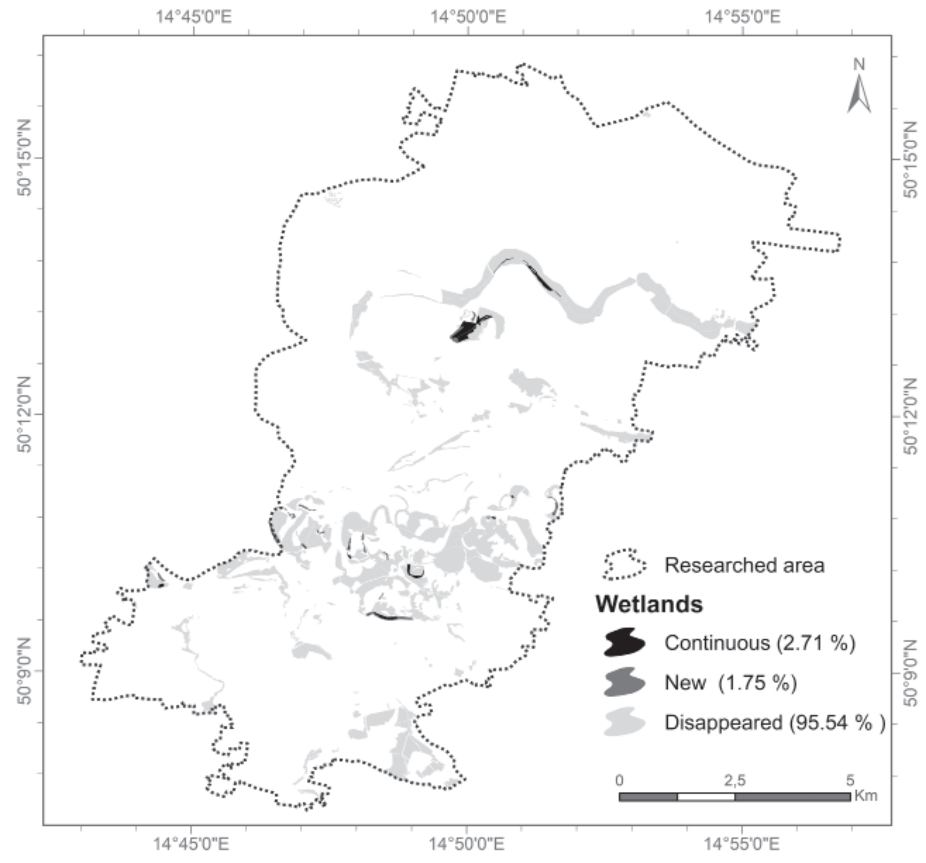

Fig. 3. Spatio-temporal changes of wetlands in the researched area.

the prescribed legend; however, in almost all periods, in addition to the basic depiction of wet meadows, wet meadows with woody vegetation are abundant in the researched area. Mostly it is a symbol of deciduous trees, the same as in the depiction of deciduous forests [15, 23]. These were used to determine the types of wetlands in the researched area; conversely, as part of a clearer distribution of wetland categories, marshes and marshes with reed vegetation were merged into one category. Peat bogs do not occur in this part of the middle Elbe River basin.

This article is written in the form of a case study; it does not map the entire territory of the Czech Republic comprehensively. As the researched area is large enough (12 cadastral districts, area 117,899 km^2), it is assumed that the obtained results will be representative for this type of landscape. Even with regard to the analysis of spatial changes in wetlands (Table 3), where half of the disappeared wetlands were occupied by arable land, the observed changes can be attributed mainly to an increase in agricultural production, which is in line with the trends of land use development in Czechia [24-27].

The results demonstrate a fundamental loss of wetlands in the landscape of the researched area, where only 4.53% of wetlands were preserved from the original area in 1841-42. The change in composition of wetlands is also interesting; while wet meadows dominated in the 19th century (97.12%, compared to 5.62% today), in the current landscape the category of swamps and marshes predominates (85.56%). The reason is clearly the fact that the function of wetlands has changed – in the past wet meadows fulfilled a production function to a large extent and were used for harvesting hay or reeds [9], not only in the Czech Republic, but also in other European countries, such as Sweden [28], Switzerland [29], and Great Britain [30]; at present, wet meadows are no longer being cultivated and have started to overgrow due to succession [9]. However, especially in the middle part of Elbe River basin, where the Elbe River meandered in the past, the natural circulation of surface water and groundwater has been disturbed by human economic activity; as a result, wetlands are most often found in places overgrown with "wild" vegetation, which cannot be cultivated with modern technology without drainage, and so they are overgrown with both woody plants and reeds. The occurrence of swamps and marshes in Polabská nížina was expected, as this is indicated by the results of studies dealing with wetlands in the landscape of the lowlands of the Czech Republic [31-33]; however, such a dominance of this type of current wetland was not expected.

From the point of view of the temporal stability of wet meadows, the analysis of their trajectories in the researched area shows that they historically belonged to the most widespread wetland category (281.06 ha in 1840). Simultaneously, their representation in the current landscape of the researched area has significantly decreased (12.3 ha). In the category of disappeared wetlands, they are the most common type (Table 4). This fact corresponds to the findings of similar studies in the Czech Republic and abroad [26, 28-34].

An interesting phenomenon was found when comparing the very significant decrease in areas of wet meadows with the increase in areas of swamps and marshes. The wetland type swamps and marshes shows the highest detected dynamics of trajectories towards area increase. Swamps and marshes, which cover 26.69 ha in the Stable Cadastre maps, have increased their area to 43.67 ha by 2022. A possible explanation lies in the historical abandonment of mowing wet meadows and their subsequent overgrowth with reeds or successional trees, but also in the afforestation of less fertile sites, especially the expansion of historical forest sites [24, 25, 35-38]. The change in the water regime of the landscape due to shortening of the Elbe watercourse and the isolation or infilling of remnants of its meanders certainly had an impact as well.

Ponds as a type of wetlands were not considered during the initial processing of the results. Only a habitat with vegetation cover, not an open water surface, was designated as a wetland. From a landscape-ecological and water management point of view, ponds are classified as water bodies. However, they also meet the definition of wetlands [7, 23, 39]. On the maps of the Stable Cadastre, all water bodies in the researched area are also generally classified as ponds; in fact, no other water body type existed at that time. At present, according to maps and the field survey, the situation in the researched area is similar; the ponds are also often created from the former meanders and branches of the Elbe River. However, we can find other types of

Tab. 7. Change in the area of wetlands in the researched area when including ponds.

Land use/cover	Area [ha]		Area [%]		Situation against 1841/42 [%]
	1841/42	2022	1841/42	2022	
Wet meadows	1093.26	2.88	90.81	3.23	0.26
Wet meadows with woody vegetation	5.73	4.50	0.47	5.05	78.50
Swamps and marshes	26.69	43.67	2.22	49.00	163.63
Ponds	78.20	38.07	6.50	42.72	48.69
Σ	1.203.87	89.12	100	100	7.40

water bodies here. If we were to include ponds with wetlands, the area of historical wetlands would increase from the original 1,125.68 ha (9.55% of the researched area) to 1,203.87 ha (10.21%). The area of the current wetlands would then be 89.12 ha (0.76%) instead of 51.04 ha (0.43%). Ponds would occupy 6.5% of the area of historical wetlands, and wet meadows would still be the dominant type of historical wetlands, but instead of the original 97.12%, they would only cover 90.81%. Ponds would also be the absolutely dominant type of new wetlands, along with swamps and marshes, making up 42.72%, and swamps and marshes would have their representation reduced from 85.56% to 49%. Also, the inclusion of ponds among wetlands would cause an increase in the proportion of the area of current wetlands to the area of historical wetlands from 4.53% to 7.40%. In the case of historical wetlands, the inclusion of ponds would not cause significant changes in the results, while in the case of the current ones, the difference would be more significant (Table 7). This is due to the large occurrence of wetlands in the past and their almost complete disappearance. Compared to a similar study in the upper part of the Výrovka basin on the Elbe and Sázava watershed, the results are partly different; here, ponds form the absolutely dominant type of current wetlands, while swamps and marshes are hardly present in the current landscape. This area, however, is largely hilly and is known for its pond farming tradition. In both areas, however, the same result occurred; the dominant type of historical wetlands – wet meadows – had almost completely disappeared from the current landscape [33]. Wet meadows were also the dominant type of historical wetlands during the monitoring of changes in wetlands on the edge of Brdy Mountains. In contrast to the middle part of the Elbe river basin, the ponds here form only a negligible area of wetland habitats, both historical and current, and swamps and marshes do not occur in this area at all [34].

Based on the study of archival maps, it is therefore demonstrable that wetlands were historically a common part of the landscape. This confirms the fact that Europe is marked by a long history of human influence and use of the landscape [40]. In Central Europe, a huge area of wetlands has been converted into agricultural land during the past few centuries [26, 29].

It would be appropriate to use the knowledge gained in landscape planning with regard to the protection and management of wetlands, especially in view of changing climatic conditions. Evaporation in the Czech Republic is growing rapidly; average evaporation between 2001 and 2018 was 18% (519 mm) higher than in 1971-2000 (440 mm), while simulations of future scenarios using regional climate models predict growth of up to 54%. Such an increase would have serious consequences for the availability of surface water and agricultural production in the dry season in the Czech Republic, as was already proven in 2014-2018 [41].

Another possibility of how the results presented here could be used is the development of a basic document for river basin plans to improve the condition of surface water bodies. It is particularly important to improve the ecological status of surface water bodies since, for the most recently evaluated and presented period of 2016-2018, 94.6% of surface water bodies of the "river" category and 86.3% of bodies of the "lake" category in the Czech Republic are in unsatisfactory ecological status/potential [42]. Some components of the evaluation of the ecological status/potential, such as the representation of phytoplankton, macrozoobenthos, fish, macrophytes or phytobenthos, as well as water saturation with oxygen, could be increased by bringing the status of watercourses closer to the original one, i.e. by restoring meanders and adjacent wet meadows suitable for flooding instead of deepened manmade straight ones, often paved channels. It would be appropriate to start a kind of reverse process to that which took place here in the second half of the 20th century (straightening rivers, melioration, removal of copses and wetlands, etc.). If so much effort and so many funds could be devoted to the above-mentioned transformation of our landscape, it would probably be necessary to devote a lot of effort and many funds to the transformation of our landscape closer to its original state, where the landscape fulfilled non-production functions much better, in particular being much more capable of retaining water.

The situation can potentially improve in response to ongoing climate change and associated sustainable agriculture. At the beginning of March 2020, a list of more than 3,600 signatories of a document was published, calling for the EU's Common Agricultural Policy (CAP) to also address sustainability of agriculture [43]. At the same time, an article describing this call and related issues was published. In principle, it was about starting to promote sustainability of agriculture. In the EU, the CAP is failing, especially in terms of biodiversity and land degradation. It calls on the European Parliament, the Council, and the Commission to adopt ten urgent measures to ensure sustainable food production, biodiversity conservation, and climate change mitigation in the CAP [44].

Conclusion

The main results are the description of the development trajectories of wetland habitats in the middle of Elbe river basin and verification of the methodology for monitoring of the wetlands development for use in the entire Elbe river basin. The area of wetlands before the mid-19th century was 1125.68 ha in the researched area, while in 2022 it was only 51.04 ha (i.e. 4.53% of their original area), which means a dramatic decrease of wetlands in the landscape. While the majority of the area of historical wetlands was wet meadows (97.12%), at present the largest area of wetlands is swamps and marshes (85.56%). Disappeared wetlands in this area occupied 1,094.64 ha (95.55% of the area of all wetland types according to stability), continuous wetlands 31.04 ha (2.71%), and new wetlands 20 ha (1.75%). Arable land is currently the most dominant land use/cover type at the site of disappeared wetlands, amounting to 57.57% of their area. Grasslands and forest land occupy a significant share of the area of disappeared wetland habitats, 11.03% and 10.73%, respectively. These facts confirm that wetlands that have disappeared due to landscape management are the most common category in the monitored area and that more than half of the wetlands have been replaced by arable land.

The results presented in this article should form a practical, usable basis for the restoration of disappeared wetlands and, simultaneously, for the viable management of current wetlands. These landscape elements are a solution for adapting to the issues caused by climate change. A varied landscape with a sufficient representation of wetland habitats contributes significantly to retaining water in the landscape and maintaining a stable climate. In the future, we are planning to map the other locations in the Elbe River basin in a similar way.

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Conflict of Interest

The authors declare no conflict of interest.

References

1. ZHAI X.J., CUI L.J., LI W., ZHAO X., ZHANG M., LI C., DOU Z. The definition of wetland biotope and its application in wetland restoration. Acta Ecologica Sinica **19** (42), 7752, **2022**.
2. CRAFT C., VYMAZAL J., KRÖPFELOVÁ L. Carbon sequestration and nutrient accumulation in floodplain and depressional wetlands. Ecological Engineering, **114**, 137, **2018**.
3. MITSCH W.J., GOSSELINK J.G. Wetlands, 5th edition. John Wiley & Sons, New York ISBN 978-1-118-67682-0, **2015**.
4. POKORNÝ J. No wonder it's dry. VTEI - Vodohospodářské technicko-ekonomické informace **59** (4), 59, **2017** [In Czech].
5. WENGUANG Z., WENJUAN W., GUANGLEI H., CHAO G., MING J., XIANGUO L. Cooling effects of different wetlands in semi-arid rural region of Northeast China. Theoretical and Applied Climatology **141**, 31, **2020**.
6. HESSLEROVÁ P., POKORNÝ J., HURYNA H., SEJÁK J., JIRKA V. The impacts of greenery on urban climate and the options for use of thermal data in urban areas. Progress in Planning **159**, 100545, **2022**.
7. ČÍŽKOVÁ H., KVĚT J., VLASÁKOVÁ L. Wetlands: ecology, conservation and sustainable use, 1th edition. University of South Bohemia in České Budějovice ISBN 978-80-7394-658-6, **2017** [In Czech].
8. DAVIDSON N.C. How much wetlands has the world lost? Long-term and recent trends in global wetland area. Marine and Freshwater Research, **65** (10), 936, **2014**.
9. WETLANDS. Wetlands z.s., [on-line]: http://www.mokrady.wbs.cz, cit. 3.12.**2022** [In Czech].
10. MEYER B.K., VANCE R.K., BISHOP G.A., DEOCAMPO D.M. Origin and Dynamics of Nearshore Wetlands: Central Georgia Bight, USA. Wetlands **35**, 247, **2015**.
11. BEDNÁŘ M., ŠARAPATKA B., NETOPIL P., ZEIDLER M., HANOUSEK T., HOMOLOVÁ L. The Use of Spectral Indices to Recognize Waterlogged Agricultural Land in South Moravia, Czech Republic. Agriculture **13** (2), 287, **2023**.
12. HEIS VUV. TGM WRI Hydroecological Information System, [on-line]: http://heis.vuv.cz/lang/eng, cit. 15.10.**2022**.
13. ROMPORTL D., CHUMAN, T., LIPSKÝ Z. Landscape typology of Czechia. Geografie **118** (1), 16, **2013** [In Czech].
14. GEOPORTAL SOWAC GIS. Research Institute for Soil and Water Conservation, [on-line]: https://geoportal.vumop.cz/, cit. 19.3.**2022** [In Czech].
15. STABLE CADASTRE. Land Survey Office, Imperial obligatory prints of the stable cadastre, [on-line]: http://archivnimapy.cuzk.cz/, cit. 23.4. **2022** [In Czech].
16. ČÚZK GEOPORTAL. Land Survey Office, Access to map products and services, [on-line]: http://geoportal.cuzk.cz/, cit. 8.5. **2022**.
17. LPIS. Public Land Register, [online]:https://eagri.cz/public/app/lpisext/lpis/verejny2/plpis/, cit. 25.6. **2022** [In Czech].
18. GEOPORTAL UHUL. Forest Management Institute, [on-line]: https://geoportal.uhul.cz/mapy/mapylho.html, cit. 13.7.**2022** [In Czech].
19. ZABAGED®. Land Survey Office, ZABAGED® katalog, [on-line]: https://geoportal.cuzk.cz/Dokumenty/ZABAGED_katalog/ EN/index.html, cit. 3.8. **2022**.
20. DIBAVOD. Digital Water Management Data Base, [on-line]: http://www.dibavod.cz/, cit. 21.08.**2022** [In Czech].
21. FORMAN R., GODRON M. Landscape Ecology, John Wiley & Sons, New York, **1986**.
22. COPASS C., ANTONOVA N., KENNEDY R. Comparison of Office and Field Techniques for Validating Landscape Change Classification in Pacific Northwest National Parks. Remote Sensing **11** (1), 3, **2019**.
23. RICHTER P. Problematics of archive map data interpretation, specifically the wetland habitats. VTEI - Vodohospodářské technicko-ekonomické informace **63** (5), 32, **2021** [In Czech].
24. LUCC CZECHIA. Land Use Land Cover Change Czechia (1845-2010), Charles University, Faculty of Science, [on-line]: https://www.lucccz.cz/module.Pagesimple/?url=en, cit. 21.8. **2022**.
25. ZELINKA V., ZACHAROVÁ J., SKALOŠ J. Analysis of spatiotemporal changes of agricultural land after the Second World War in Czechia. Scientific Reports **11**, 12655, **2021**.

26. ŠANTRŮČKOVÁ M., DOSTÁLEK J., DEMKOVÁ K. Assessing long-term spatial changes of natural habitats using old maps and archival sources: a case study from Central Europe. Biodiversity and Conservation **24**, 1899, **2015**.
27. CZECH NATIONAL GEOPORTAL. Map View, [on-line]: https://geoportal.gov.cz/web/guest/map, cit. 15.10.**2022**.
28. IHSE M. Swedish agricultural landscapes e patterns and changes during the last 50 years, studied by aerial photos. Landscape and Urban Planning **31**, 21, **1995**.
29. GIMMI U., LACHAT T., BÜRGI M. Reconstructing the collapse of wetland networks in the Swiss lowlands 1850-2000. Landscape Ecology **26** (8), 1071, **2011**.
30. HUNT R. Rural Britain Then and Now. Octopus Publishing Group Limited ISBN 978-0-753713-63-1, **2004**.
31. SKOKANOVÁ H., FALŤAN V., HAVLÍČEK M. Driving forces of main landscape change processes from past 200 years in Central Europe - differences between old democratic and post-socialist countries. Ekológia **35** (1), 50, **2016**.
32. SKALOŠ J., RICHTER P., KEKEN Z. Changes and trajectories of wetlands in the lowland landscape of the Czech Republic. Ecological Engineering **108**, Part B, 435, **2017**.
33. RICHTER P. The trajectory of wetlands development in the upper part of the Výrovka River basin over the last 180 years. VTEI - Vodohospodářské technicko-ekonomické informace **62** (6), 20, **2020** [In Czech].
34. RICHTER P., SZTYMONOVÁ R. Monitoring changes in the landscape development on the northeastern edge of the Hřebeny Mountains with a focus on wetlands. VTEI - Vodohospodářské technicko-ekonomické informace **64** (2), **2022**.
35. POLENO Z., VACEK S. Theoretical principles of forest cultivation. Lesnická práce, s. r. o., Kostelec nad Černými lesy ISBN 978-80-87154-09-0, **2007**.
36. FOREJT M., SKALOŠ J., PEREPONOVA A., PLIENINGER T., VOJTA J., ŠANTRŮČKOVÁ M. Changes and continuity of wood-pastures in the lowland landscape in Czechia. Applied Geography **79**, 235, **2017**.
37. KADLECOVÁ P., BĚLUNKOVÁ Š., KUMBLE P., SKALOŠ J. Changes in forest and non-forest woody vegetation in Bohemia between mid 19th century and 2015. Fresenius Environmental Bulletin **28** (8), 5836, **2019**.
38. PEREPONOVA A., SKALOŠ J. Spatio-temporal dynamics of wood-pastures in lowland and highland landscapes across Czechia. Regional Environmental Change **19**, 267, **2019**.
39. WETLAND TYPE. Nature and Landscape Protection Agency of the Czech Republic, About wetlands, [on-line]: https://mokrady.ochranaprirody.cz/o-mokradech-typ-mokradu/, cit. 13.2.**2023** [In Czech].
40. KEDDY P.A. Wetland ecology - Principles and conservation. Cambridge University Press, 2nd edition ISBN 978-0521739672, **2010**.
41. MOŽNÝ M., TRNKA M., VLACH V., VIZINA A., POTOPOVA V., ZAHRADNÍČEK, P., ŠTĚPÁNEK P., HÁJKOVÁ L., STAPONITES L., ŽALUD Z. Past (1971-2018) and future (2021-2100) pan evaporation rates in the Czech Republic. Journal of Hydrology **59**, 1253900, **2020**.
42. MIČANÍK T., VYSKOČ P., PRCHALOVÁ H., POLÁŠEK M., NĚMEJCOVÁ D., DURČÁK M., RICHTER P. Surface Water Status Assessment for the Third Cycle River Basin Management Plan of the Czech Republic. VTEI - Vodohospodářské technicko-ekonomické informace **62** (6), 20, **2020**.
43. PE'ER G., BONN A., BRUELHEIDE H., DIEKER P., EISENHAUER N., FEINDT P.H., HAGEDORN G., HANSJÜRGENS B., HERZON I., LOMBA Â., MARQUARD E., MOREIRA F., NITSCH H., OPPERMANN R., PERINO A., RÖDER N., SCHLEYER CH., SCHINDLER S., WOLF CH., ZINNGREBE Y., LAKNER S. Full list of signatories to: Pe'er et al. "Action needed for the EU Common Agricultural Policy to address sustainability challenges" (Preprint version) (Closed list 19.2.2020) [Data set], Zenodo, [on-line]: https://zenodo.org/record/3685632#.X2MxkmgzaUk, 12.1.**2023**.
44. PE'ER G., BONN A., BRUELHEIDE H., DIEKER P., EISENHAUER N., FEINDT P.H., HAGEDORN G., HANSJÜRGENS B., HERZON I., LOMBA Â., MARQUARD E., MOREIRA F., NITSCH H., OPPERMANN R., PERINO A., RÖDER N., SCHLEYER CH., SCHINDLER S., WOLF CH., ZINNGREBE Y., LAKNER S. Action needed for the EU Common Agricultural Policy to address sustainability challenges. People and Nature **2** (2), 305, **2020**.