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CHANGES IN FOREST HABITAT TYPES IN THE VICINITY OF SULEJÓW RESERVOIR, PILICA RIVER, POLAND

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Abstract. Water reservoirs have a significant impact on the environment, mainly through their impact on groundwater levels. Water is an important soil-forming factor, and its availability and soil fertility determine the development of forest habitats typical of given conditions. However, long-term changes in water regimes result in habitat changes. We examined changes in forest habitats that occurred in the vicinity of the Sulejów Reservoir in the zone up to 750 m from the bank and with a difference in height from the water level of up to +5 m. Detailed research covered a total area of ~710 ha. We used data from periodic forest inventories. We found changes in forest habitats, mainly involving an increase in their humidity. Fertility also increased in part of the area, which we attribute to moisture improving the availability of elements important for the development of vegetation. Habitat changes occur mainly in the north-western parts of the study area. The penetration of water into the surroundings of the reservoir is most pronounced in the areas of several tributaries, because when the level of damming is high, their role changes – instead of supplying water to the reservoir, they cause its outflow.

Key words: water reservoir, forest sites changes, Pilica River valley, GIS

Introduction

In Poland, a detailed inventory of the forests is carried out every ten years. The collected and analysed data constitute the basis for preparing a forest management plan, which is a quantitative and qualitative description of the condition of the forest and the economic activities planned to be carried out in the next period. The smallest spatial unit for which detailed descriptions and plans for future cultivation activities are made is the survey unit which, broadly speaking, should be understood as a fragment of the forest that is characterised by specific features and will require specific maintenance activities in subsequent periods. A very important part of the forest management plan is the inventory, which contains detailed data on the forest stand and habitat. The description of the tree stand includes, among others: basic data on species composition, spatial structure and dendrometric values determining the average dimensions of trees (Breast-Height Diameter, BHD and Height) and the growing stock, i.e. the volume of thick wood per 1 ha. The description of the habitat provides concise information about the terrain (topography, exposure, slope, altitude), plant cover and soil. The rules for preparing a forest management plan, including a detailed description of the tree stand and habitat, are included in the relevant instructions, the most important of which are the Forest Management Instruction (*Instrukcja*…2012) and the Forest Management Rules (*Zasady*…2023). In the forest classification of habitats currently in force, they are grouped according to their suitability for forest production, i.e., the "forest habitat types" (Sikorska 1992; Grzyb 1999), with the basic criteria being fertility and moisture (Tab. 1).

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Table 1

Variation of habitat types of lowland forests depending on their fertility and moisture level (*Instrukcja*…2012, amended)
The table retains the original abbreviations used in Poland in tree stand valuation: Bs – dry coniferous forest (c.f.), Bśw – fresh c.f., Bw – humid c.f., Bb – marsh c.f., BMśw – fresh mixed c.f., BMw – humid mixed c.f., BMb – marsh mixed c.f., LMśw – fresh mixed deciduous forest (d.f.), LMw – humid mixed d.f., LMb – marsh mixed d.f., Lśw – fresh d.f., Lw – humid d.f., Ol – alder carr, Olj(Lł) – forest on land liable to temporal inundation

Fertility gradient → Humidity gradient ↓	Coniferous forest	Mixed coniferous forest	Mixed deciduous forest	Deciduous forest
Dry	Bs	-	-	-
Fresh	Bśw	BMśw	LMśw	Lśw
Humid	Bw	BMw	LMw	Lw
Marsh	Bb	BMb	LMb	Ol
Inundated	-	-	-	Olj (Lł)

Water is one of the most important soil-forming factors, which also include the bedrock (its mineral, chemical and mechanical composition), climate, living organisms, relief, time and human activity (Rutkowski 1974; Czępińska-Kamińska 1995). Water fertility is determined by the arrangement and mechanical composition of geological layers, both those located in the subsoil of the habitat and those nearby (Grzyb 1995). An increase in soil moisture may contribute to increasing the fertility of the habitat (Czępińska-Kamińska 1995), which is clearly visible in the increase in tree growth (Rutkowski 1974; Kamiński *et al*. 1992; Frydel 2008; Kostuch, Maślanka 2013; Czyżyk, Porter 2018; Czyżyk 2021). Groundwater, especially in sandy soils, is one of the most important habitat factors, and its movement in the soil profile is particularly important. In certain conditions "the depth of groundwater is more important than the soil content", as Włoczewski stated (as cited in Bielak 1992).

"The location of groundwater is the basic factor shaping forest habitats and ecosystems. This factor is particularly important for humid, marsh, and alder forest habitat types" (Malzahn *et al*. 2014). The typical depth of groundwater and its variability ranges were determined for individual forest habitat types (Tab. 2).

Table 2

Approximate spring groundwater level in various groups and variants of moisture in forest habitats (without taking into account rainwater) (*Instrukcja*…2012, amended)

Habitat moisture group	Variant of habitat moisture	Groundwater level [m]
Dry		< 2.5
Fresh	Fresh	< 2.5
	Highly fresh	< 1.8
Humid	Dehydrated	< 1.8
	Humid	0.8–1.8
	Highly humid	0.5–0.8
Marsh	Highly dehydrated	< 1.8
	Dehydrated	0.5–1.8
	Wet	0.2–0.5
	Highly wet	0.0–0.2
Liable to periodic inundation	Non-flooded	Periodically, at least once per year, above the level of terrain
	Flooded	
	Flooded and inundated	

The problem of groundwater levels is approached differently in the literature. According to Krajewski (1978a), the recommended level of groundwater in humid and marsh habitats at the beginning of the growing season, i.e. when it is the highest in our climatic conditions, should be as follows: 10–20 cm for alder forest (Ol), 20–30 cm for humid mixed coniferous forest (BMw), 20–40 cm for humid coniferous forest (Bw), 40–50 cm for marsh coniferous forest (Bb). Typical average levels of groundwater below ground level in the Białowieża Forest (1985–2001) were as follows (Malzahn *et al*. 2014): 280 cm in a fresh habitat, 130 cm in a humid habitat, 24 cm in a marsh habitat. It is also indicated that vegetation is more affected by the extent of capillary seepage than by the groundwater level (Mąkosa 1977).

Forest habitat types are not static. Changes are observed over large areas, the causes of which are believed to be global climate change and the impact of anthropogenic air pollution. Climate change affects water conditions, and air pollution affects the fertility of habitats (Brzeziecki 1999; Paluch 2001), with the dominant increase observed throughout the country – according to data from forest management plans in State Forests, the area of poor habitats is clearly decreasing and increasing medium-fertility and rich habitats (Paluch 2002). Locally, in the case of significant pollution in areas with strong industrial impact, contamination and negative changes in the habitat occur and the growth of tree stands is weakened (Tyszka 1995).

Due to the growing demand for water for industry, agriculture and domestic purposes, as well as to control and improve river flows, large water reservoirs were built in the basins of the main Polish rivers, i.e., the Vistula and the Odra. Until the end of the 1980s, there was a paradigm in forestry of the need to increase the production capacity of forests, among others, using water drainage, i.e., by removing excess water (Krajewski 1985; Babiński *et al*. 1989). Currently, it has completely changed, and wider, mainly environmental, benefits resulting from maintaining water in forests in marsh and humid habitats have been noticed. "The basic principle of water management in forests is to maintain it, among others, in a condition close to natural, springs, water reservoirs, watercourses, swamps and peat bogs" (*Zasady*...2023). For many years, the State Forests have been implementing projects in the field of "small water retention", which consists of restoring old forest reservoirs or building new small ones, for the purpose of, of course, retaining water in the forests, but also to improve the amount of runoff in periods of shortage, improve soil water conditions, enrich biocenoses, provide water for animals, fire protection and other purposes (Mioduszewski 2008; Pierzgalski 2008; Rutkowski, Śmigielska-Wojtyniak 2008; Zabrocka-Kostrubiec 2008; Jagiełka *et al*. 2011).

Both large facilities and those with "low retention" have an impact on the surrounding environment, which has been documented in many technical and scientific studies. The impact of water reservoirs consists of creating a local microclimate (increase in air humidity, accumulation of thermal energy) and changing the level of groundwater. This is referred to as the direct impact, while the indirect impact consists of activating, for example, recreational and communication development processes as a result of having increased the attractiveness of these areas (Kostuch, Maślanka 2005), though this aspect is beyond the scope of our study. Water conditions are shaped by the supply of groundwater, geological structure, and the state of surface and rainwater. Most often, we are dealing with an increase in the level of the local water table in areas above a damming structure, sometimes leading to local, extensive flooding (Mularz 1991). It is also possible to reduce water table in some areas due to the draining effect of the devices accompanying these reservoirs, which drain depressions and polders (Krajewski 1978a, 1997; Chalfen, Czamara 2007). The reservoir in Włocławek (Perek 1978), in the central region of Poland, i.e., with a natural shore (left side of the reservoir), has an impact on groundwater at a distance of up to ~2.25 m, which consists in raising their level (near the reservoir) by ~0.5–1.4 m and significantly reducing the amplitude of annual fluctuations of the water table (to ~0.8 m) compared with amplitudes ~2.0–3.5 m registered before the reservoir was created. In the depression area, near the side dam, the groundwater level rose by 2.0–2.5 m above the lowest level observed in 1960–1968, before the damming. In the same area, the annual amplitude of fluctuations decreased to 0.06–0.40 m, from 0.30–0.80 m in 1971–1976. The analyses performed also allowed the author to state that the groundwater level in the Vistula Valley, on the section from Warsaw to the reservoir in Włocławek, responds strongly to changes in the water level in the river, even at a considerable distance from its bed. Szupryczyński (1981) writes that the development of water conditions was largely influenced by drainage features, including the main canal running along the reservoir (which flows into the Vistula below the dam), whose task is to drain excess seepage water and protect against flooding. These features, made before filling the reservoir, led to a reduction in the water level by 1.0–3.0 m, even excessively. After the damming, the water level rose, but in many places, it did not reach the level it was at before the damming. It was also found that the impact of the reservoir on groundwater is visible in the zone up to 1.5 km from the coastline.

Forests that have grown for several decades in specific conditions of environmental humidity generally react very negatively to large and long-term changes in water level – both its excessive rise (there are many examples of forest dieback due to flooding caused by beavers) and its lowering are harmful, e.g., due to a decrease in the level of the river bottom (Cieśla 2008). Trees react by reducing their growth (decrease in productivity), deteriorating in health, and even dying (Krajewski 1978b). The expected range of impact of water reservoirs on forests depends mainly on the arrangement of geological layers and the topography of the area, or more precisely, its elevation above the reservoir damming level. It is important whether the changes occur in the zone where trees build their root systems. For example, when assessing the impact of the Siemianówka reservoir, located on the Narew River, it was estimated that it would be visible in areas with a relative height of up to 2.0 m above the water table (Krajewski 1978a). Similarly, the impact range of the Folusz reservoir (around Żnin) was determined to be 1.0–2.5 m above the damming level (Krajewski 1978b). The same effect is expected in the area of the Domaniów reservoir – after a short period of its operation (since 2001), clear changes were observed in the appearance and species composition of the surrounding pine stands (dry forest), consisting in the enrichment of the floristic composition of the soil cover, as well as the layer of shrubs and the emergence of more demanding woody species (Kostuch, Maślanka 2005). Small retention facilities have a much smaller but noticeable impact on the magnitude of changes in groundwater levels and their spatial extent (Korytowski 2006). When the groundwater level is low, and there is no effective seepage, the moisture content of the top layers of soil (1.0 m) depends only on monthly rainfall and average monthly temperatures (Liberacki *et al*. 2006).

The aim of our study is to present changes in forest habitats that are taking place in the vicinity of the Sulejów Reservoir – a large water reservoir built almost 50 years ago on the Pilica River. The geoinformation analysis carried out allows for the assessment of changes in quantitative and qualitative terms. Factors that influenced the spatial distribution of the observed changes were identified.

The Sulejów Reservoir and its vicinity

The Sulejów Reservoir (approximate geometric centre: 51.449198° N, 19.949840° E) (Fig. 1) was created in 1973 by damming the Pilica River at the 139th km of the river. The damming raised the water level in the area by ~10 meters – the former village of Swolszewice Błota was located on the bank of the former Pilica at an altitude of about 156.0 m a.s.l. Today's normal water damming level is 166.6 m a.s.l. (Kobalczyk 2023).

The main purpose of building the artificial lake was to provide the inhabitants of the city of Łódź with drinking water through an intake in the village of Bronisławów. An additional function is the production of electricity using the power plant located on the dam. Currently, the facility also serves as a recreational facility. Sulejów Reservoir is the second largest water reservoir in the Łódź Voivodeship. Its area is 2.38 ha, maximum length 25.0 km, average width 1.5 km and average depth 3.3 metres (Ambrożewski 2013).

In terms of surface geological deposits, the studied area is composed mainly of Quaternary sand and gravel sediments. Their thickness decreases from west to east. In Barkowice Mokre, it reaches up to 40 m, in Swolszewice Duże up to 25 m, and in Zarzęcin up to 15 m, which is caused by the increasing elevation of the chalk ceiling (Brzeziński 1992). Locally, in the form of small patches from the Odranian glaciation period, poorly sorted upper boulder clays are deposited on the middle fluvioglacial sands and gravels. They are visible, among others, around the town of Karolinów. In the area under consideration, there are also Aeolian sands, which form both dunes and lie horizontally, mainly on the sands of river terraces above the floodplain, without taking on any characteristic surface forms (Brzeziński 1992). Under the Quaternary sediments, there are sediments dating back to the Cretaceous period, both Lower and Upper (Brzeziński 1992). These are most often marly-sandy mudstones, which in the vicinity of Smardzewice constitute outcrops narrowing the Pilica valley and forming

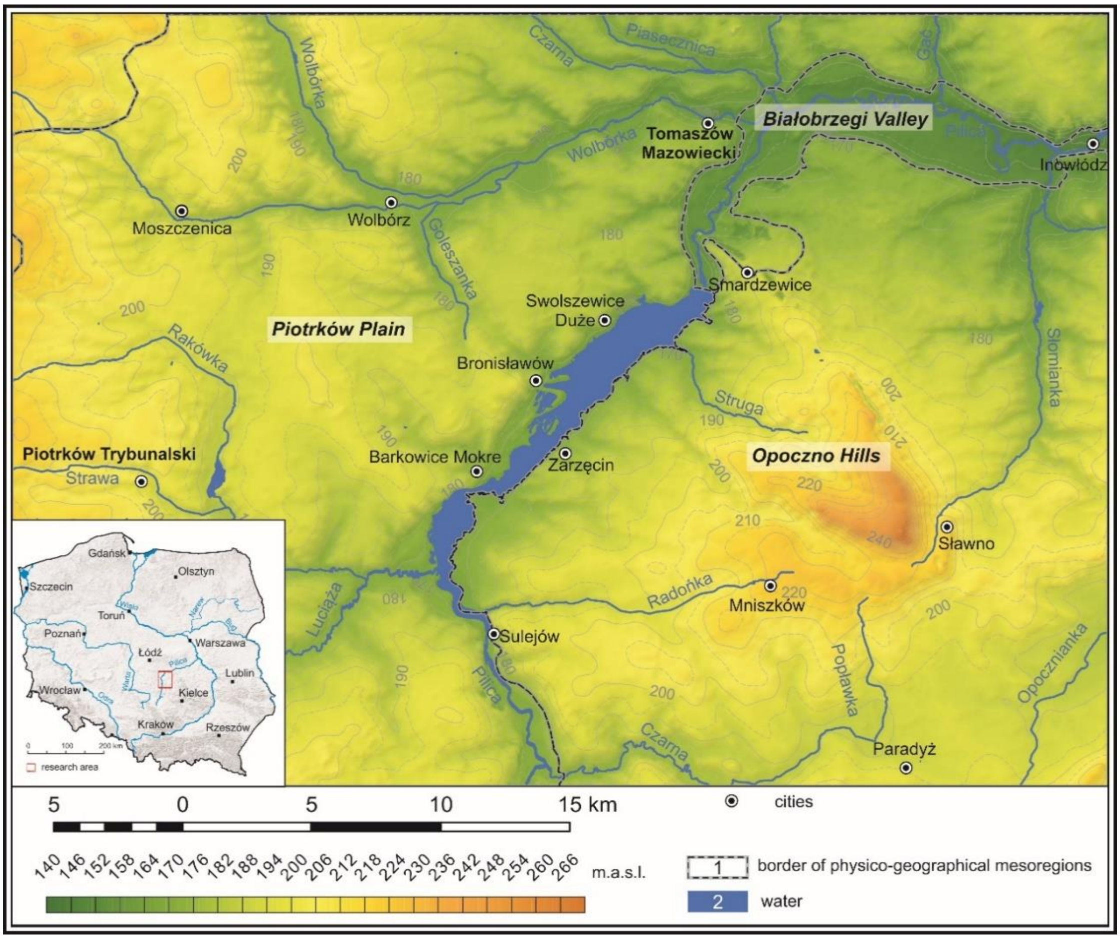

Fig. 1. Location of the Sulejów Reservoir (based on GUGiK data)

Fig. 2. Lining a part of the lake bottom with foil during its construction (*photo by: A. Kobalczyk's archive*)

the site of the dam's foundation. The relatively good permeability of the sediments at the bottom of the reservoir is the reason for the seepage of its waters. To partially prevent this, the bottom of the Sulejów Reservoir near the dam was lined with foil during construction (Fig. 2) (Ambrożewski 2013).

Fig. 3. A floodplain at the mouth of an unnamed stream into the Sulejów Reservoir, Misiowa Bay (*photo by S. Kołyszko 2021*)

The reservoir is fed by the Pilica River, which provides ~80% of the water supply. The next largest watercourse feeding the reservoir is the Luciąża River, a left tributary of the Pilica. The area of the reservoir itself is also irrigated by seven tributaries: two left-bank streams near Lubiaszów and Adamów and five right-bank ones: the Radońka, the Struga and three unnamed streams near the towns of Tresta, Piaski and Zarzęcin Mały. These streams, after filling the reservoir with water, as a result of raising the erosion base, created floodplains in many places (Fig. 3).

Methods

In order to determine the changes that occurred in forest habitats during over 40 years of the Sulejów Reservoir's existence, the research procedure described below was used. All work was carried out using ArcMap 10.4.1 by ESRII.

In the first stage, a vector database of forest divisions, along with the types of habitats assigned to them as of 2015, was downloaded from the Forest Database (BDL) provided by the Office of Forest Management and Forest Geodesy. Then, the coastline of the Sulejów Reservoir was vectorised, and a buffer of 750 m from the shore was designated, which had its BDL data trimmed. Owing to this, a modern division into forest sections with the types of habitats assigned to them was achieved, and the scope of the research area was limited according to the criterion of distance from the shoreline of the reservoir (Fig. 4).

The next step was to develop archival materials in the form of an overview map of tree stands in the Nagórzyce forest district (as of October 1, 1969) and the Opoczno forest district, Błogie district (as of January 1, 1986).

The acquired analogue maps were scanned and then georeferenced, registering them in the PUWG 92 projection. Thanks to this, it was possible to vectorise archival data – forest divisions and subdivisions from 1969–1986 (Madej 2016). In the newly created layer, an attribute table was designed and filled with data based on the forest assessment description as of January 1, 1969, and January 1, 1986, volume II. In the next step, the boundaries of forest divisions and subdivisions for the study area for 2015 were trimmed, and the attribute table was unified. As a result of this work, two vector layers were created – – archival data and contemporary data of the same areas with comparable attribute tables. After assigning symbols and labels to the boundaries of forest divisions and subdivisions, forest habitats, towns and roads, the maps were exported and then compiled in the Corel X3 graphic program, obtaining a visualisation of forest habitats in the period before the creation of the Sulejów Reservoir – in 1969 and 1986 (Fig. 5).

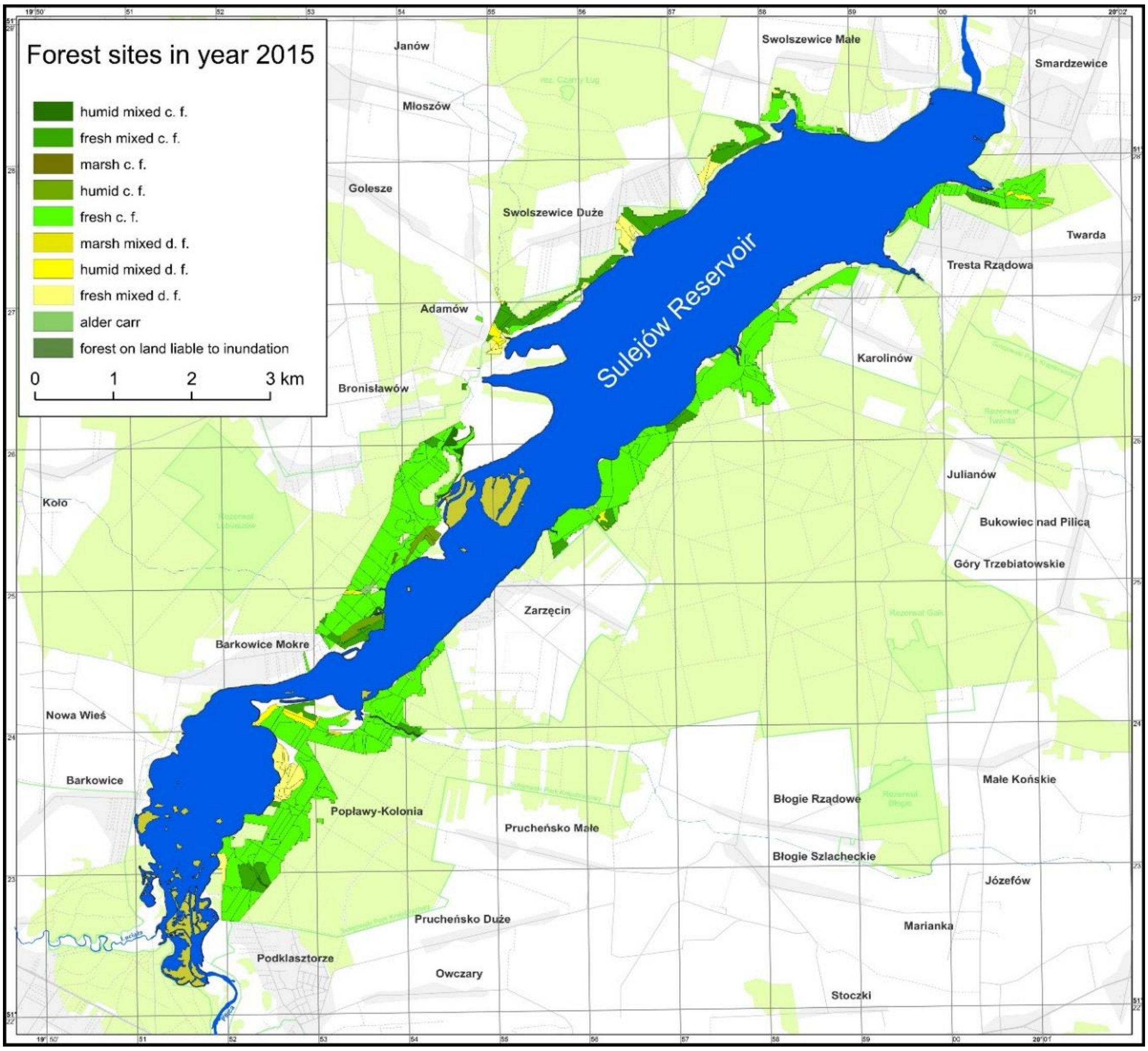

Fig. 4. Types of forest habitats in the vicinity of the Sulejów Reservoir in 2015

In order to investigate how the Sulejów Reservoir, created in 1973, and its waters influenced the surrounding forests, the research area was narrowed down to forest sections that are located at an elevation not exceeding 5 metres above the water surface, dammed up to a level of 166.6 m a.s.l. For this purpose, areas meeting this condition were marked out based on DTM and then intersected with the historical and current layers. As a result, the analysed area was narrowed down to 710 ha of forest. The results were presented in a table and then visualised on maps. The cartographic studies show areas whose condition in terms of fertility and humidity has deteriorated and areas where trophicity and humidity increased by one category (small increase) or at least two categories (large increase). In one of the places (Fig. 6) where both the fertility and humidity of the examined habitat increased, a field inspection was carried out in April 2024.

Results and discussion

In the studied area, changes in the fertility (Fig. 7) and humidity (Fig. 8) of the habitats are clearly visible, especially on the north-western shore of the reservoir. On the south-eastern shore, the area rises quite steeply to higher levels, and for this reason, it did not meet the height assumption in the research procedure, and there was no change in forest habitat types.

There are some differences in the forest habitat classification systems used in the past and present (Tab. 3). Transitional habitats Bśw/Bs and swamps (marsh) were formerly distinguished,

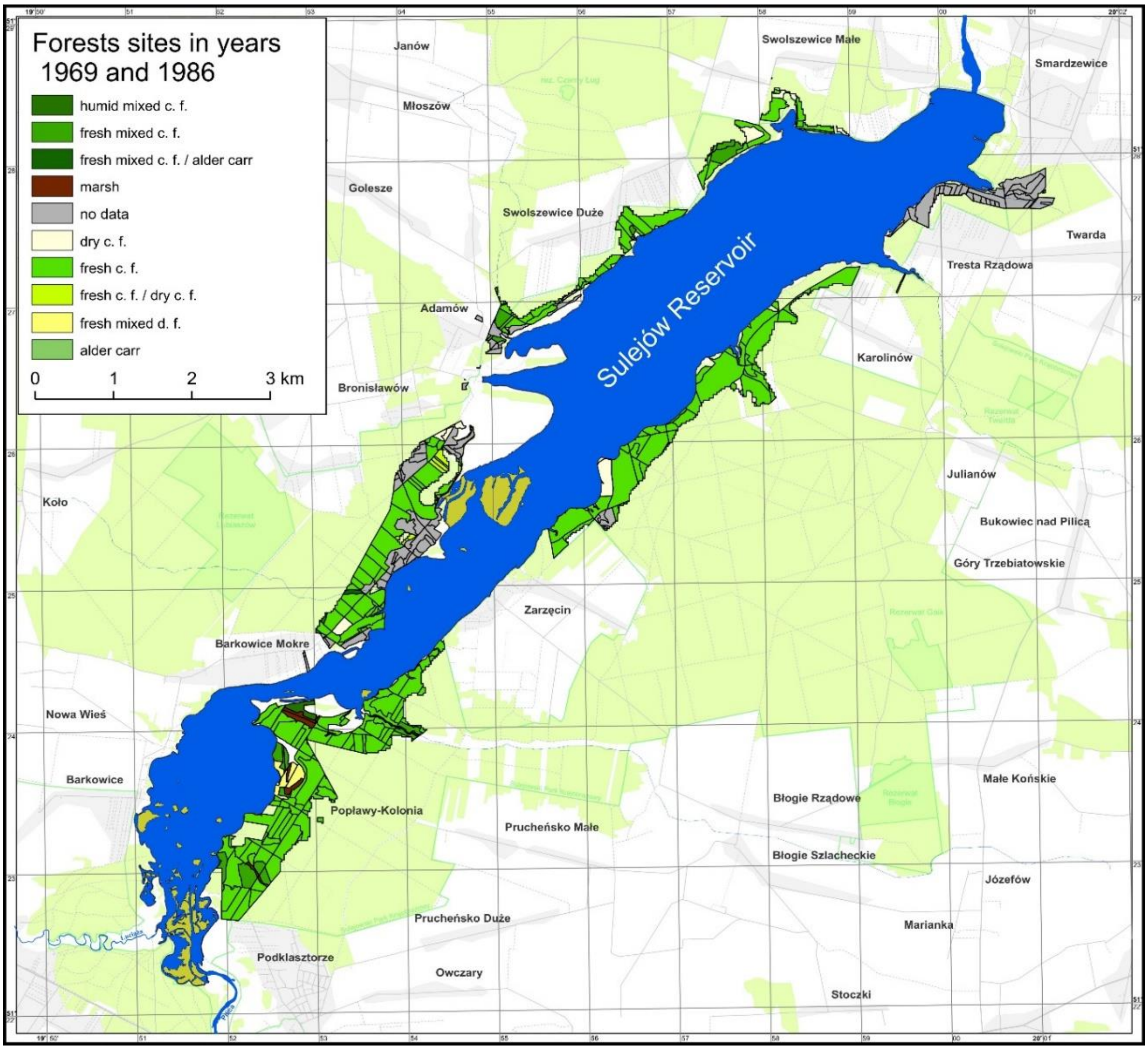

Fig. 5. Historical types of forest habitats (1969, 1986) in the vicinity of the Sulejów Reservoir

Fig. 6. Forest site Bśw – fresh coniferous forest (1969) transformed into a more humid c.f. (2015) as a result of a significant increase in the groundwater level (*photo by M. Jaskulski 2024*)

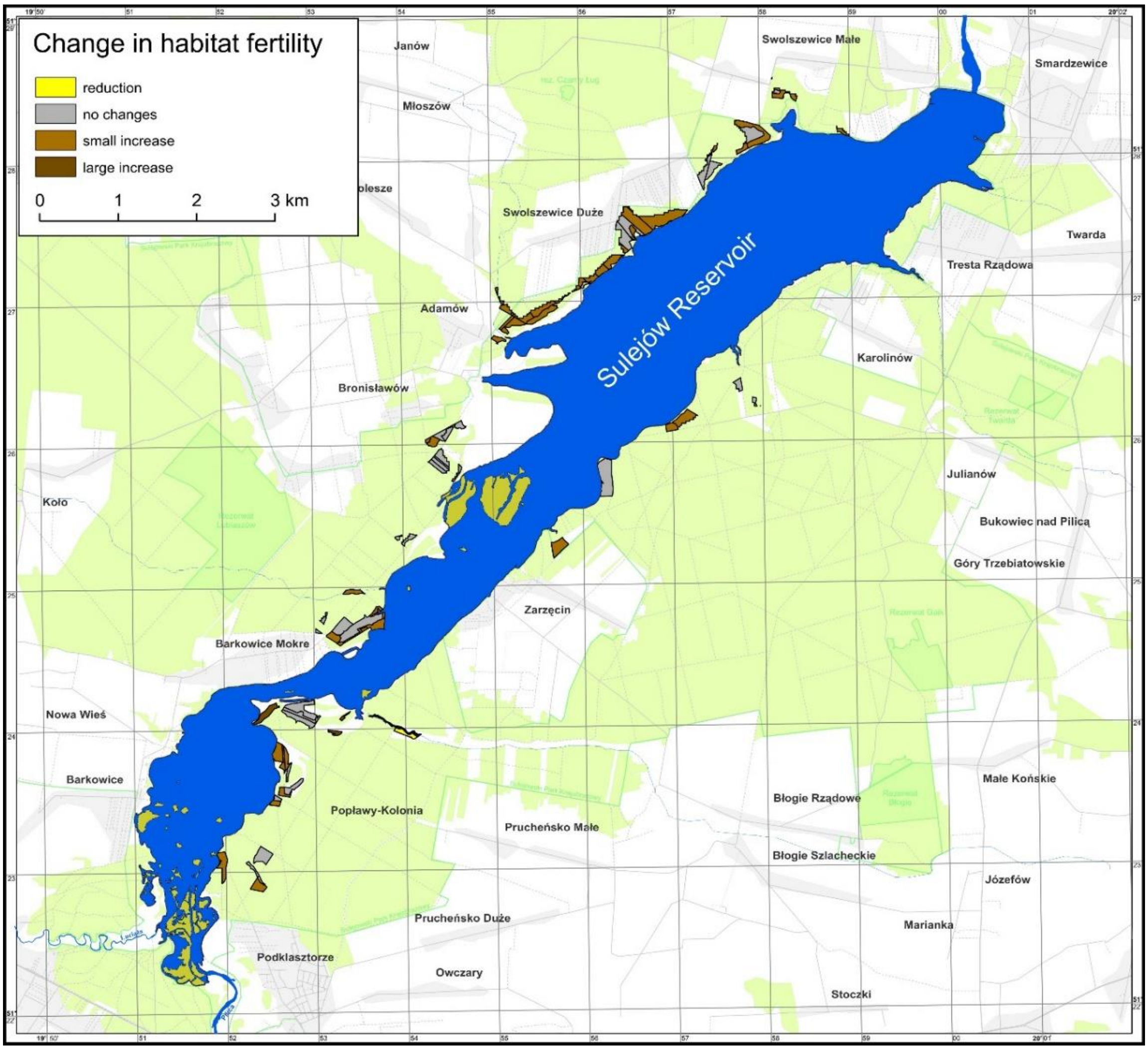

Fig. 7. Changes in the fertility of forest habitats

while now a habitat marked as mixed marsh forest (LMb) has appeared. Moreover, some lands did not have a designated habitat type in older documentation. Some of the land belonging to the State Forests and originally used for agriculture has been afforested. Ultimately, it was possible to perform change analyses for an area of 710 ha.

We found that the dry coniferous forest habitat (Bs), which occupied over 21 ha in the period before the damming, had completely disappeared. Areas of this habitat are currently classified as fresh coniferous forest, c.f. (Bśw) or fresh mixed c.f. (BMśw), i.e., wetter and more fertile. A similar process is also clearly visible in the case of the fresh c.f. habitat (Bśw), a significant part of which (15.3%) is currently described as clearly wetter (transition to marsh c.f. – Bw) or wetter and more fertile, which means the transition to fresh mixed c.f. (BMśw), humid mixed c.f. (BMw), fresh mixed deciduous forest (LMśw), and humid mixed deciduous forest (LMw). Major changes in water conditions may be evidenced by the appearance of a mixed swamp (marsh) forest (LMb) in the new habitat division. According to the newest inventory, the fresh mixed c.f. (BMśw) was classified partly into more fertile and wetter habitat variants (transition to fresh mixed deciduous forest – LMśw and to humid mixed d.f. – LMw, a total of 30.7%), and partly (4.0%) to fresh c.f. (Bśw), i.e. a habitat slightly less abundant in water. The opposite process, i.e., the transition to habitats with lower water abundance, is clearly visible in the case of the humid mixed c.f. (BMw) habitat, 92.8% of the area of which has "shifted" by one degree, i.e. to fresh mixed c.f. (BMśw). A certain fragment of fresh mixed c.f. – BMśw (0.2417 ha, or 4.8% of the original area) is now classified as fresh c.f. (Bśw), which means a significant change in moisture content. In this case, the change can be interpreted as a result of the replacement of the forest

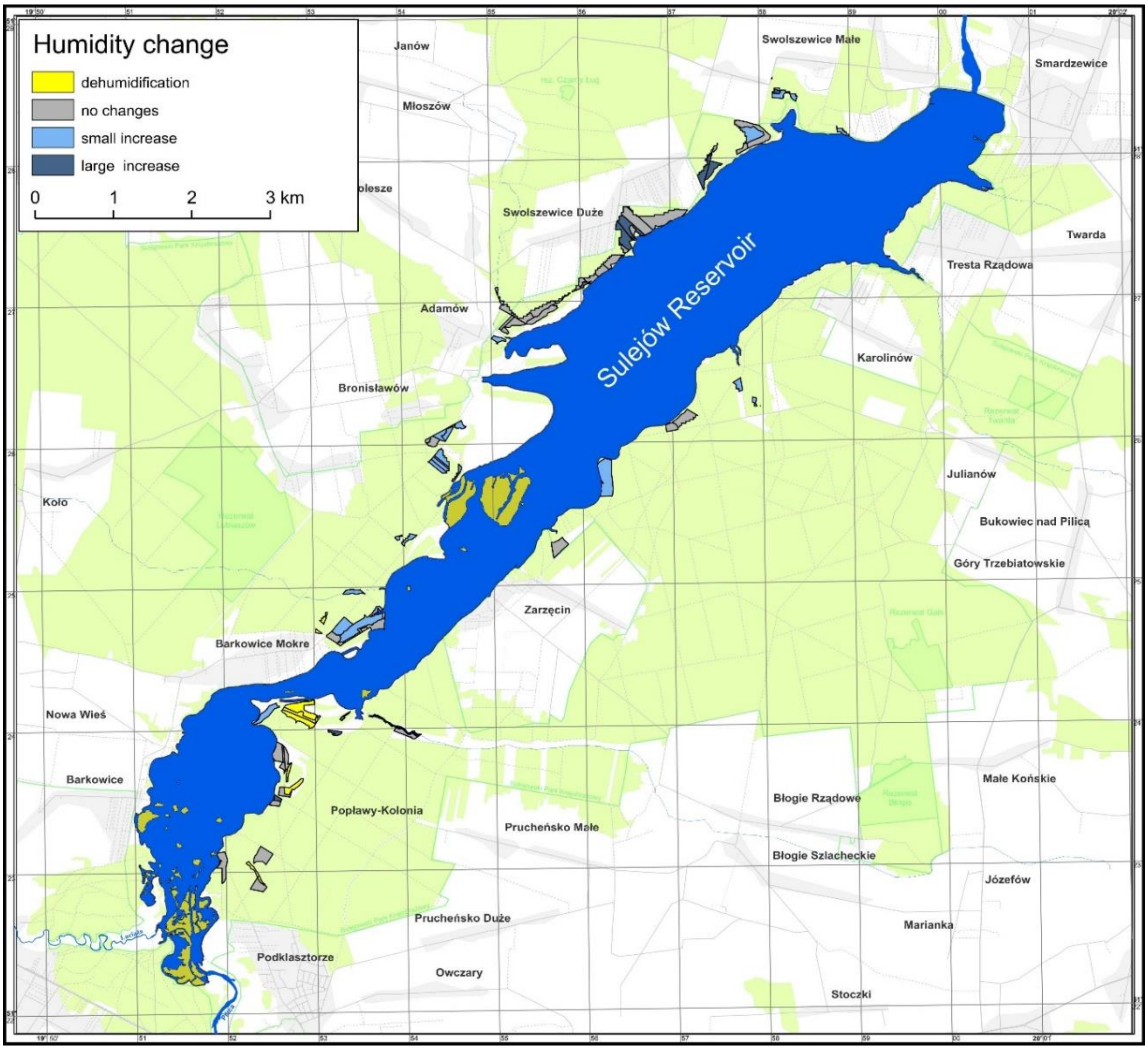

Fig. 8. Changes in the humidity of forest habitats

stand because felling took place between the inventory dates. As a result, a new stand, now ~30 years old and with a high density of young trees, resulted in the depletion of the forest undergrowth, and the area was classified as fresh c.f. (Bśw). Let us also note that alder forests (Ol) are now fully classified as ash–alder forests (Olj), while the habitat previously defined as a swamp (marsh) is now classified as a habitat on the border of mixed coniferous and mixed deciduous habitats (BMśw, BMw, LMśw, LMw). The most important observation from the analysis of the location of changes in forest habitats is that they are concentrated in the areas of tributaries of streams directly supplying the reservoir. Therefore, as a result of rising water levels, these tributaries drain water from the reservoir into the surrounding forest stands.

The picture of the observed changes in forest habitats was undoubtedly influenced by the fact that our reference data regarding the initial condition of the habitats were heterogeneous because, for part of the area (Nagórzyce Forest District), they came from 1969, and for another (Opoczno Forest District) from 1986, i.e., four years before and 13 years after the damming of Sulejów Reservoir, respectively. We believe that, if we had the opportunity to refer to more homogeneous reference data, the observed changes would be even more visible. One should also take into account the very probable human factor consisting of changes in the pragmatics of phytosociological research (Sikorska 1992) or the principles of forest habitat classification used in forest management (Brzeziecki 1999). Another factor that the authors of some works draw attention to is the processes of increasing habitat fertility observed practically throughout the country. Their causes are believed to be the impact of industrial air pollution, namely dust fall (Paluch 2001, 2002), or the change or abandonment of certain forms of forest use, such as grazing of farm animals, harvesting brushwood or leaves (Brzeziecki 1999), as well as warming climate (Kowalski 1993).

Table 3

Changes in the types of forest habitats in the study area
(explanations of the abbreviations of habitat names are given in Table 1)

		Current habitat types											
		Bs	Bśw	Bw	Bb	BMśw	BMw	LMśw	LMw	LMb	Ol	Olj	**Total [ha]**
Historical habitat types	Bs		19.16			2.64							**21.81**
	Bśw		425.06	6.37		52.43	0.71	12.39	3.95	1.09			**502.00**
	Bw												
	Bb												
	BMśw		1.42			23.53		10.11	0.94				**36.00**
	BMw		0.24			4.72	0.12						**5.08**
	LMśw							8.94					**8.94**
	LMw												
	Ol											1.52	**1.52**
	Olj												
	Bśw/Bs		6.30										**6.30**
	Marsh					0.68	0.35	2.28	4.57				**7.87**
	No data		86.07	6.56	0.47	12.34	4.95	2.81	5.85		1.43		**120.47**
	Total [ha]		**538.27**	**12.93**	**0.47**	**96.34**	**6.12**	**36.53**	**15.30**	**1.09**	**1.43**	**1.52**	**710.00**

Long-term changes in groundwater levels lead to profound changes in soils (Czępińska-Kamińska 1995), to which both undergrowth plants and the trees themselves will respond. Further changes may be similar to those described by Kowalski (1993), i.e., the eutrophication of habitats will increase, the vitality of trees will decrease, and coniferous species will disappear and will gradually be replaced by deciduous species. In some areas, tree stands may respond with increased growth, which, in a sense, from the point of view of forest management objectives, may be perceived positively. However, in order to demonstrate such an effect of changes, detailed dendrometric tests are necessary.

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