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Impact of beaver dams on surface channel capacity and phytocoenoses diversity of Łąki Soleckie (PLH140055)

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Abstract: The aim of the study was to determine the extent to which created and functioning beaver dams contribute to increasing water retention in the Łąki Soleckie facility (Mała River valley). Changes in the plant cover of meadow habitats within the range of beaver dams were also determined. During the growing periods in 2020–2022, measurements of the periodic levels and water retention of the Mała River and the adjacent ditches (R-27, R-29) were closely related to the activity of beavers and precipitation. The maximum volume of water retained in the Mała riverbed in 2020–2022 was 1,300, 1,700, and 1,200 m^3; the maximum retention of the R-29 ditch was 270, 210, and 200 m^3, respectively. In 2021–2022, the R-27 ditch collected the most water – 270 m^3 and 250 m^3. Starting from June 2022, due to beaver dams D2 and D3, the water level in the river and water retention have stabilised at a high level, despite slight rainfall. The activity of beavers contributed to the transformation of communities of wet habitats located on organic soils (*Calthion*) into communities of periodically wet habitats (*Caricetum gracilis*). In places where natural habitat 6510 occurs, the coverage of species of the *Festuca* genus has increased, and the value of the biodiversity index has increased by an average of 9%. High stability in the community of expansive species (*Deschampsia caespitosa* and *Veronica longifolia*) and their increasing cover may make it difficult to maintain the proper condition of natural habitat 6510.

Keywords: beaver, biodiversity, organic soils, phytocoenoses, river valley, water retention

INTRODUCTION

Historically, peatlands were drained mainly for agricultural purposes, reducing the moisture of their upper layers by lowering the water table using a network of drainage ditches and underground drainage pipelines (Bykowski, 2021). After drainage, these areas were transformed into organic soils of high agricultural usefulness. The high water table on these soils favours meadow use. The yields of agricultural crops grown on organic soils are sometimes several times higher than those grown on mineral soils (Mocek, 2015). However, the drainage of peat soils triggers many unfavourable physical and chemical processes that threaten the condition of these soils. The most important ones include soil shrinkage and compaction due to loss of moisture. Increased air access causes their mineralisation, nitrification and denitrification at the lower water table level (Handzel *et al.*, 2017; Turetsky *et al.*, 2020; Łachacz *et al.*, 2023). These processes contribute to the degradation and deterioration of the properties of dehydrated organic soils, and the consequence of these phenomena is surface subsidence, resulting in their disappearance from the environment (Ilnicki (ed.), 2012; Oleszczuk, Zając and Urbański, 2020). The use of drained peat soils in meadows requires proper water management, which generates additional costs for the agricultural operations of these areas. The decline in the cattle population is related to a lack of interest in agricultural production on drained peatlands, which results in the lack of any water management (Ilnicki, Górecki and Szczepański, 2017). These areas are subject to a succession of scrub and bush vegetation and reduced biodiversity (Pawluśkiewicz, 2015; Ignar, Szporak-Wasilewska and Gregorczyk, 2023). The deterioration of the basic physical and chemical properties of these soils results from the increased evapotranspiration of bushy vegetation, the occurrence of atmospheric and soil droughts, and the drying of the surface layers (Kundzewicz, Hov and Okruszko (eds.), 2017; Oleszczuk, Zając and Urbański, 2020; Łachacz *et al.*, 2023). The basic goal of peat soil restoration is to increase their moisture content. This is achieved by preventing the outflow in streams and ditches using damming devices (weirs, gates) and consequently raising the groundwater level.

In recent decades, in areas not used for agriculture, beavers have been damming water in canals and drainage ditches. Beaver dams in stream beds slow down the water flow, enhance bed and underground retention and contribute to the meandering of riverbeds (Boczoń, Wróbel and Syniaiev, 2009; Karran *et al.*, 2017; Brandyk, Oleszczuk and Urbański, 2020). This takes place in river valley areas where there are drained peatlands with systems of drainage ditches (Naiman, Johnston and Kelley, 1988; Piętka and Misiukiewicz, 2022). As a result of blocking the outflow of water in ditches, the groundwater level increases, causing an increase in the soil moisture of adjacent peat soils. Vegetation also undergoes transformation and evolves towards marsh species (Ilnicki, Górecki and Lewandowski, 2016).

With a water deficit in peat soils, the amount of available forms of nitrogen, phosphorus and other elements decreases (Kalvite *et al.*, 2021). This leads to the impoverishment of habitats and their gradual degradation (Janicka, Pawluśkiewicz and Dąbrowski, 2016), and consequently to the cessation of agricultural production in these areas and their abandonment. Such changes also occur in areas protected by the Habitats Directive 92/43/EEC (Directive, 1992). A satisfactory state of protection of peat bogs and wetlands within the Natura 2000 network was found on only 20% of the area of this category of natural habitats (Dyrekcja Generalna ds. Środowiska (Komisja Europejska), 2015).

In accordance with the assumptions of the European Union (EU) biodiversity strategy 2030, the European Commission has developed a proposal for a new act on the restoration of natural resources. The Regulation of the European Parliament and of the Council of Europe on nature restoration of 22 June 2022 (Proposal, 2022), in Articles 7 and 9, indicates that Member States will be obliged to rebuild the natural connections of rivers and the natural functions of river valleys, as well as to restore and hydrate drained organic soils used for agriculture. This will help achieve biodiversity, significantly reduce greenhouse gas emissions and contribute to landscape diversity. It is assumed that financial measures will be implemented to rebuild natural resources and restore organic soil retention, by at least 30% by 2030, 50% by 2040 and 70% by 2050.

The results of research presented in the literature (Čiuldienė *et al.*, 2020; Orazi *et al.*, 2022; Połeć *et al.*, 2022) indicate that the activity of beavers may support the increase in soil retention. The European beaver (Stefen, Habersetzer and Witzel, 2016) is protected in the European Union under the Habitats Directive 92/43/EEC (Directive, 1992), and it is a partially protected species in Poland (Rozporządzenie, 2004; Ustawa, 2009).

The construction of beaver dams increases the water level in streams, canals and drainage ditches, which affects the physical and chemical properties of water, biodiversity and landscape forms (Čiuldienė *et al.*, 2020). Beaver activities can have both positive and negative impacts on the human economy and ecosystem services (Gore and Baker, 1989; Crawford *et al.*, 2008; Grygoruk and Nowak, 2014; Pietrek *et al.*, 2016; Jones *et al.*, 2020). Flooding of agricultural areas and tree stands causes economic losses. Increasing retention contributes to improving the preservation of natural habitats. The activity of beavers, with their increasingly numerous population (Smith and Jenkins, 1997; Crawford *et al.*, 2008; Tape *et al.*, 2018), brings us closer to achieving the status required by the Regulation of June 22, 2022 (Proposal, 2022). At the same time, this activity is sometimes a "necessary evil" for farmers and land users in drained areas especially in periods with heavy rainfall. Economic and social changes are increasingly causing agriculture to withdraw from certain areas, especially those located near large cities. Maintenance work of the drainage system is no longer carried out in these areas, while beavers are increasingly active.

The specific aims of the research were:

- determining the impact of beaver dams in the Mała River on the water table in its bed and in the R-27 and R-29 ditches connected to the river;
- determining the amount of water retention in the Mała riverbed and in the R-27 and R-29 ditches;
- determining changes in the plant cover of meadow habitats within the range of beaver dams.

STUDY MATERIALS AND METHODS

STUDY SITE

The article describes the extent to which created and functioning beaver dams contribute to increasing water retention in a drained meadow protected by the Habitats Directive 92/43/EEC (Directive, 1992) – Łąki Soleckie, where the objects of protection are natural and semi-natural grassland formations with codes 6410 (*Molinion caeruleae*), and 6510 (*Alopecurus pratensis*, *Sanguisorba officinalis*), defined in Annex 1 of this Directive.

The Łąki Soleckie facility with an area of 220 ha is located in central Poland, the Mazowieckie Voivodship, in the Piaseczno district, the municipality of Góra Kalwaria and is part of the Chojnów Landscape Park, approx. 30 km south-east of Warsaw. The object selected for research is located on organic soils in the Mała River valley. This is a Natura 2000 habitat protection area (PLH140055) Łąki Soleckie, established by the Order of the Regional Director for Environmental Protection in Warsaw of December 21, 2017 on the establishment of a plan of protective tasks for the Natura 2000 area Łąki Soleckie PLH140055 (Zarządzenie, 2017). The catchment area of the Mała River, which is a right tributary of the Jeziorka River is 72.8 km^2 (Lenartowicz, 2007).

According to the hydrographic division, the research facility is located in the partial catchment of the Mała River, from the tributary from near Wólka Dworska (right tributary) to the tributary from Kawęczynek (right tributary). The botanical composition of the peatland includes sedge and sedge-reed peats with a medium degree of decomposition. In the peatland area, in the early 1970s, 62 drainage and irrigation ditches were made, part of the seepage irrigation system (Brandyk *et al.*, 2020) – Figure 1a. Currently, this system is not used for irrigation (Urbański, Oleszczuk and Gąsowska, 2015; Urbański *et al.*, 2018) and no agricultural production is carried out there. In recent years, increased activity of beavers has been observed in this area, consisting of dam-building in the riverbed and adjacent drainage ditches.

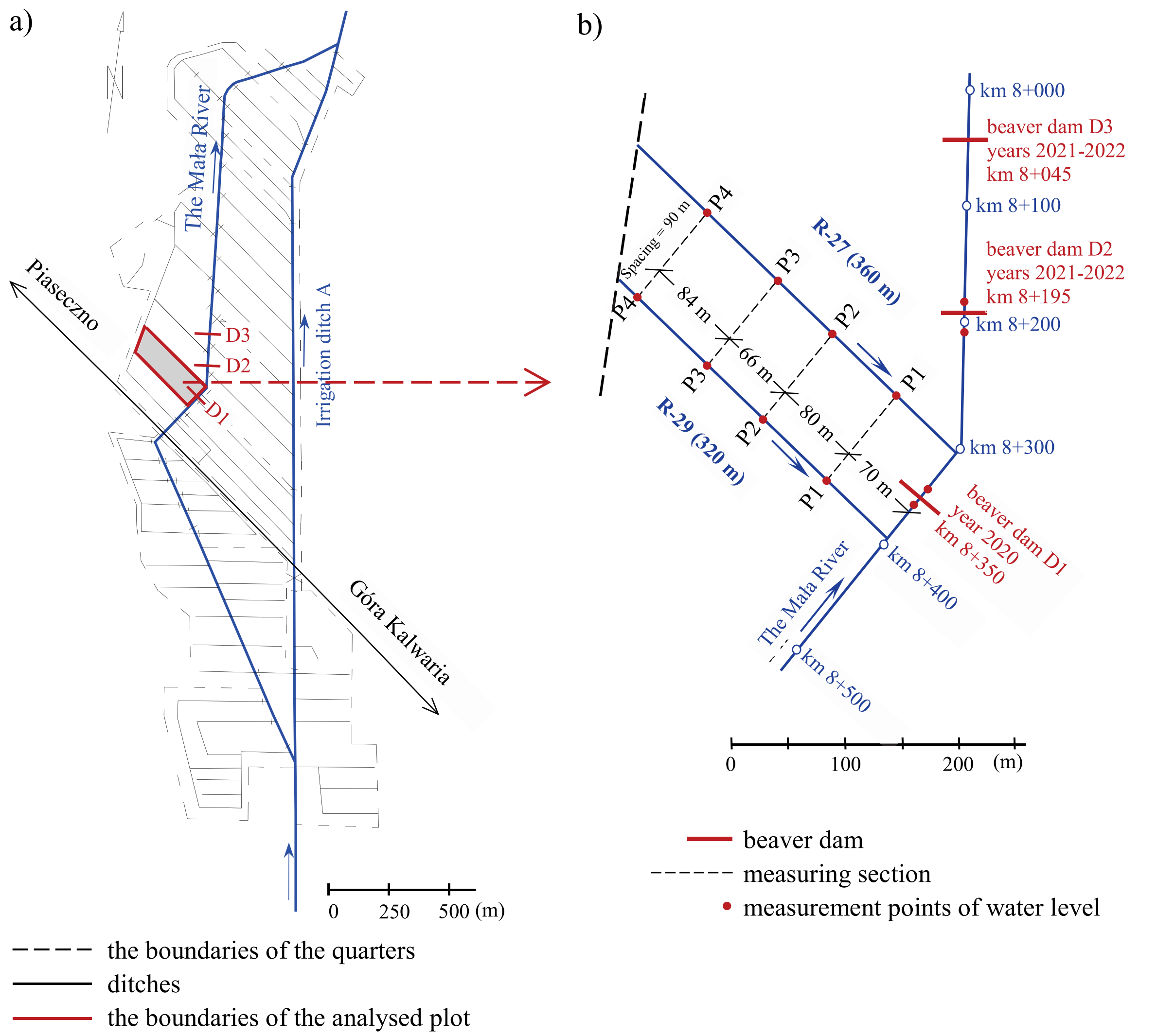

Fig. 1. Scheme of the Łąki Soleckie drainage system: a) with marked study plot, b) with marked beaver dams D1, D2, D3; source: own elaboration

A plot located in the immediate range of three beaver dams was selected for analysis (Fig. 1b). The D1 dam at km 8+350 existed in 2020, and the D2 dams at km 8+195 and D3 at km 8+045 existed in 2021–2022. The periods of occurrence of individual dams D1, D2, D3 are marked in three different colours (Fig. 2). The analysed plot (3.15 ha) is located on the west bank of the Mała River from km 8+305 to km 8+395 and is located between the ditches R-27, 360 m long, and R-29, 320 m long. The spacing of the ditches is 90 m.

In the upper part of the plot, above the P4 section, there is mineral soil (Oleszczuk *et al.*, 2022). In the remaining part of the plot, at cross-sections P1, P2 and P3, there is dewatered peat in the ground to a depth of 0.45 m, and sand below.

RESEARCH METHODS

Four cross-sections P1, P2, P3 and P4 were marked on the study plot, perpendicular to the axis of the ditches, covering the channels of the R-27 and R-29 ditches (Fig. 1b). In the period 2020–2022, from April 1 to October 31, measurements were made of the position of the water table in the Mała riverbed near the D1 dam (2020) and the D2 dam (2021–2022) and in the R-27 and R-29 ditches, in individual measurement sections P1, P2, P3 and P4. Water level gauges were used to measure the water level in the river and ditches.

The bed retention in the Mała River, resulting from damming with beaver dams, was calculated taking into account bed fillings greater than 30 cm. The calculations of water retention in ditches R-27 and R-29 took into account the volume of their beds and the results of measurements of water levels in their outlet sections and the position of the water table in sections P1, P2, P3 and P4.

The phytosociological characteristics of the communities were performed according to the method of Braun-Blanquet (1964). The research was carried out in 2014 before the

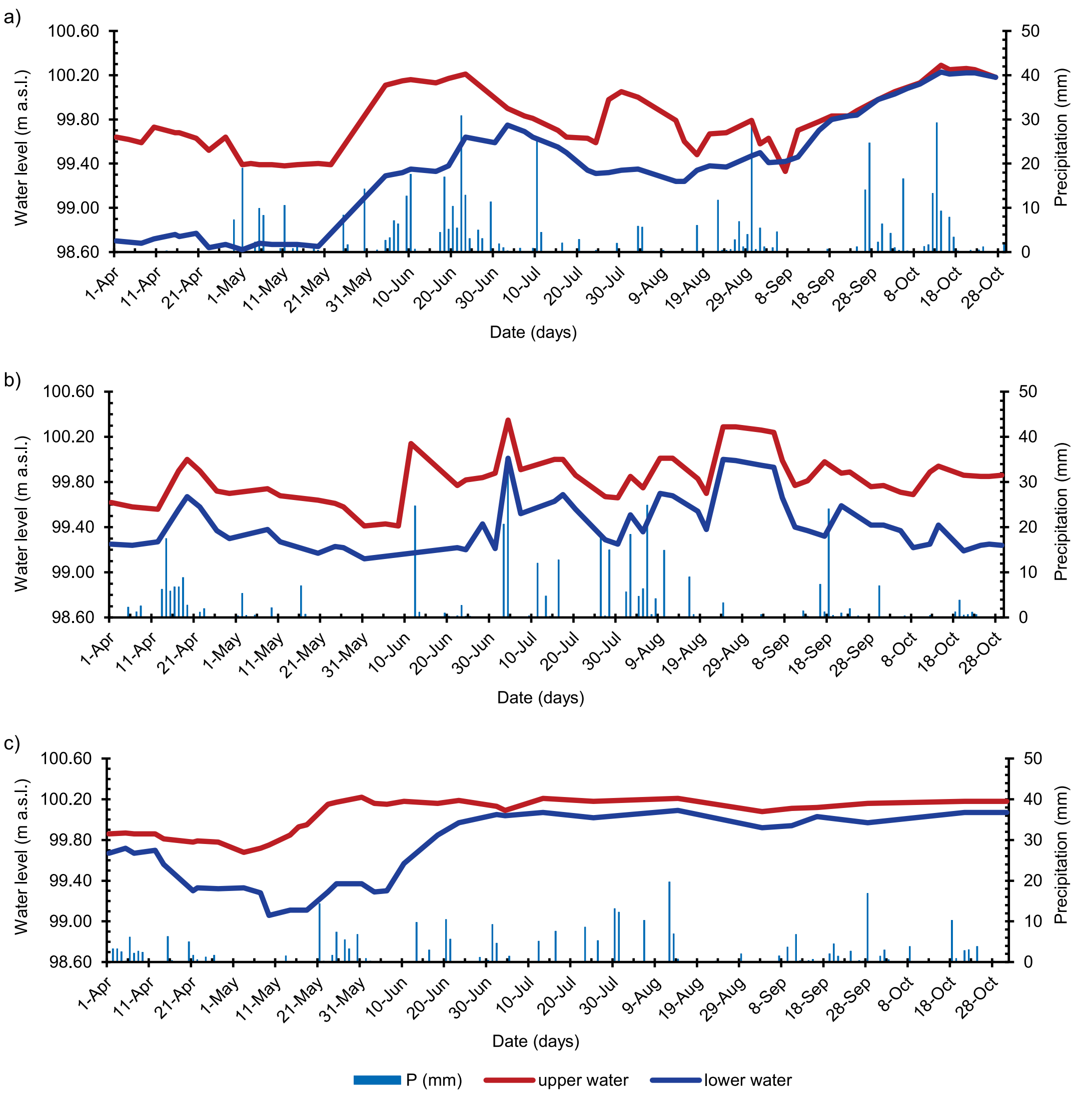

Fig. 2. Water levels above (red) and below (blue) the dams in the Mała River during the growing periods against the background of precipitation (*P*) and beaver dams D1, D2 and D3 in: a) year 2020, b) year 2021, c) year 2022; source: own study

construction of the beaver dams and in 2023 after they had been occurring at the facility for several years. The transect of measurement points was established in the axis of the plot in sections P1, P2, P3 and P4 and on its extension on the other side of the river. The Shannon–Wiener biodiversity coefficient (H') was calculated for the distinguished communities (Shannon, 1948; Wiener, 1948).

RESULTS AND DISCUSSION

WATER LEVEL AND BEAVER DAMS

In 2020, at the beginning of the research period, there was one beaver dam (D1) in the Mała River bed. It was located halfway across the width of the analysed section at km 8+350, between the mouths of the R-29 and R-27 ditches (Fig. 1b). In the period from April 1 to May 21, 2020, this dam raised the water level in the Mała riverbed to a height of 70–80 cm in relation to the downstream water (Fig. 2a). After May 21, 2020, the water table in the Mała River gradually rose as a result of the dam being raised by beavers and intense rainfall in the period from May 21 to June 30, 2020. At the end of May 2020, the water level above the dam was 100.2 m a.s.l., and below it 99.3 m a.s.l. Over the next three weeks, the upstream water table remained at 100.2 m a.s.l. On June 26, 2020, the D1 dam was removed by users of adjacent areas. After its demolition, the water in the riverbed gradually decreased. After a month, on July 25, 2020, the re-appearance of the D1 beaver dam was noticed in the same location. It caused the upstream water to rise to a height of 50–55 cm in relation to the downstream water level (Fig. 2a). The next dam removal took place on August 10, 2020, but after two days the beavers started rebuilding it again. The rebuilt beaver dam during heavy rainfall resulted in a slight increase in the upstream water table in the Mała riverbed, to a height of approximately 30 cm in relation to the lower water level. On September 5, 2020, the dam was removed once again and rebuilt by beavers two days later. Subsequently, as a result of long-term and intense rainfall, a gradual increase in water levels in the riverbed was observed (Fig. 2a). The dam was effective until September 22, 2020, when it was removed once again. In the same period, i.e. on September 10, 2020, another beaver dam (D2) appeared, located on the lower section of the Mała River at km 8+195 (Fig. 1b). The impact of the D2 dam resulted in the measured elevations of the upstream and downstream water tables of the observed upper dam D1 being the same in the later period (Fig. 2a).

In 2021, from April 1, the D2 beaver dam was present in the Mała riverbed (Fig. 1b). It was located at km 8+195, 105 m below the mouth of the R-27 ditch. The upstream water table in the Mała River (Fig. 2b) was located between 99.6 and 99.8 m a.s.l. The exception was the period from April 11 to 21, 2021, when intense rainfall occurred and the D2 dam raised the upstream water to a height of 30–40 cm in relation to the lower water elevation. On June 8, 2021, an increase in the D2 dam was observed, which resulted in an increase in the elevation of the dammed water table to 100.2 m a.s.l. The downstream water level remained 60 cm below the upstream water level. On August 20, 2021, a simultaneous increase in the elevations of the upstream and downstream water tables by 40 cm was observed. This was caused by the appearance of another beaver dam (D3), located in the lower reaches of the Mała River at km 8+045, 150 m below the D2 dam. The D3 dam was destroyed on September 5, 2021, and a dynamic decrease in the elevations of the upstream and downstream water tables in the river was observed. In October 2021, no further dynamic changes in the position of the water table in the Mała riverbed were observed. The elevations of the upstream and downstream water at the tested D2 dam differed by 40–60 cm during this period (Fig. 2b).

In 2022, beaver dams D2 and D3 existed from April 1 (Fig. 1b). In the first decade of April 2022, the D2 dam raised the upstream water to a height of 20 cm in relation to the downstream water elevation (Fig. 2c). In the following weeks, after the demolition of the D3 dam, the downstream water table gradually lowered in the absence of rainfall. However, from May 5, 2022, there was a slow increase in the elevation of the upstream water table, as a result of the raising of the D2 dam by beavers. On May 21, 2022, the upstream water elevation reached a maximum value of 100.2 m a.s.l. and remained at this level until the end of October 2022. From June 5, 2022, there was also a gradual increase in the downstream water elevation, which finally reached the maximum value of 100.1 m a.s.l. at the beginning of July and remained at this level until the end of October 2022 (Fig. 2c). It should be emphasised that the water level in the river was stable, despite the slight and lowest rainfall in 2022, compared to two previous observation periods. Thanks to the persistent reconstruction of the D3 beaver dam, located 150 m below the D2 dam (Fig. 1b), stable moisture conditions were ensured.

Based on previous observations proposed by Gąsowska *et al*. (2015) and Gąsowska, Oleszczuk and Urbański (2019) of water levels in the Mała River during the vegetation period (April–October) without the occurrence of beaver dams, it was found that the average filling level of the riverbed was approximately 30 cm. However, the ditches adjacent to the river were most often dry in the summer (Oleszczuk *et al*., 2021).

WATER RETENTION

In the Mała riverbed, at the beginning of the observation period in 2020, i.e. from April 1 to May 21, despite the existence of the D1 dam at km 8+350 (Fig. 1b), the retention amount did not exceed 200 m^3 of water (Fig. 3a). In the following days, as a result of the beavers raising the dam and intense rainfall, an increase in the water table in the river and an increase in riverbed retention to 1,000 m^3 was observed. After the dam was dismantled (June 26, 2020), the riverbed retention gradually decreased to 300 m^3 within 30 days. The reconstruction of the D1 dam (July 25, 2020) resulted in the retention in the Mała riverbed increasing again to 700 m^3. As a result of the subsequent removal of the dam (August 10, 2020), the retention decreased to 50 m^3. At the end of the observed period (September 24, 2020), another D2 beaver dam appeared in the Mała River at km 3+195. The impact of this dam and intense precipitation increased retention in October 2020 to a maximum value of 1,300 m^3.

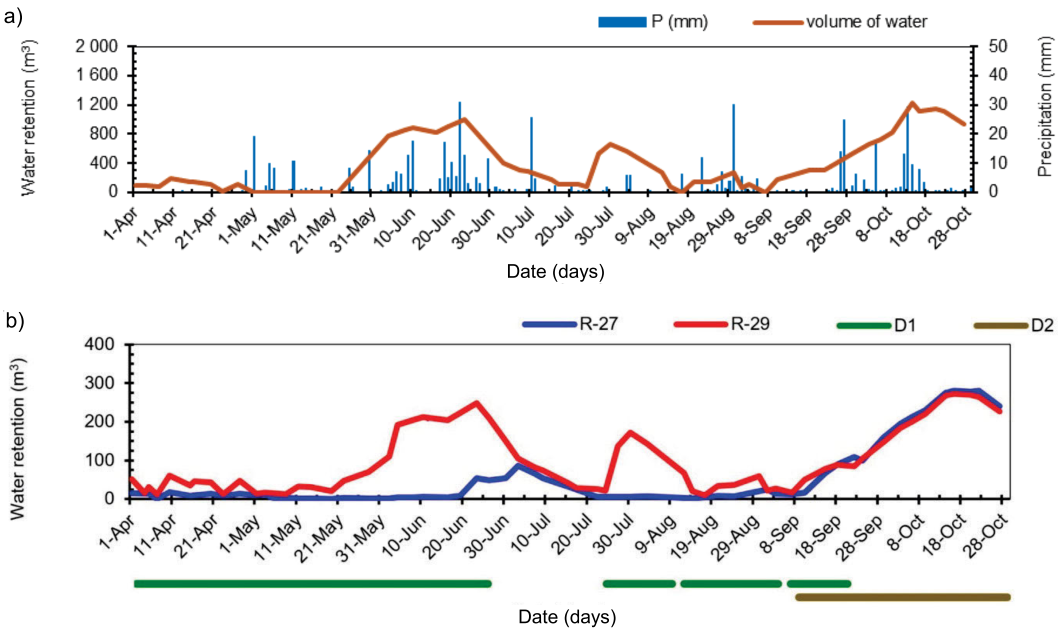

Fig. 3. Water capacity retained in the analysed season April–October in 2020 year: a) in the Mała River, b) in the R-27 and R-29 ditches; *P* = precipitation (mm), D1 and D2 = beaver dams; source: own study

In the R-27 and R-29 ditches, which are direct tributaries of the river, small dynamics of retention changes (Fig. 3b) were correlated with water levels in the river. In 2020, the mouth of the R-27 ditch was located below the D1 beaver dam, and the mouth of the R-29 ditch was above this dam. Water retention in the R-29 ditch ranged from 20 to 270 m^3. The volume of water stored in R-27 was small and amounted to 10–20 m^3, mainly due to the location of its outlet into the Mała River (below the D1 dam). In the period after heavy rainfall that lasted from June 20 to July 12, 2020, the volume of water collected in the R-27 ditch increased to 100 m^3. At the end of the observation period in 2020, the volume of retained water in both observed ditches gradually increased. This increase from September 10, 2020 was caused by the previously existing D1 dam at km 8+350, and from September 22, 2020, by the D2 dam, which was built at km 8+195. During the existence of the D1 dam at km 8+350, changes in retention in the R-29 ditch were closely related to changes in retention in the Mała riverbed (Fig. 3). After the D2 dam was built, the storage volumes of both ditches were closely related with retention in the Mała riverbed.

In 2021, water retention in the Mała riverbed was caused by the D2 beaver dam at km 8+195 (Fig. 1b). Retention increased to 1,000 m^3 after June 10, 2021 as a result of the enlargement of the D2 dam by beavers and rainfall of 26 mm (Fig. 4a). After intense rainfall on July 3 and 4, 2021, amounting to 28 and 34 mm, retention in the river reached its maximum value in the analysed period of 2021, which was 1,700 m^3. On August 20, 2021, another D3 beaver dam appeared in the lower reaches of the Mała River at km 8+045, approximately 150 m below D2. Its periodic impact resulted in an increase in retention to approximately 1,500 m^3. After the destruction of the D3 dam on September 5, 2021, with low rainfall, the volume of river retention decreased, reaching values of 200–300 m^3.

The retention amounts of the R-27 and R-29 ditches in 2021 were influenced by the change in location of the beaver dam from km 8+350 (D1) to km 8+195 (D2). Therefore, the mouths of both ditches into the Mała River were located above the D2 dam (Fig. 1b). The dynamics of retention changes in both ditches were similar, with the tendency to maintain a larger water volume in ditch R-27 by 30–40% compared to ditch R-29 (Fig. 4b). This was a consequence of greater water depths in the R-27 ditch, whose outlet to the Mała River was closer to the D2 dam. Periodic changes in retention in both ditches were closely related to changes in retention in the Mała riverbed (Fig. 4).

In 2022, the retention volumes resulted from the presence of the D2 beaver dam at km 8+195 of the Mała River (Fig. 1b). The year 2022 was characterised by slight but systematic rainfall, except for two periods without rainfall, from April 27 to May 12 and from August 16 to September 6 (Fig. 5). The increase in retention of the Mała River from 200 to 1,200 m^3 caused by the gradual raising of the D2 dam by beavers occurred in the first half of May. In the following months, until the end of the observation period, retention in the Mała River bed remained at a high level of 1,000 to 1,200 m^3. Similar trends in the dynamics and magnitude of retention changes were observed in ditches R-27 and R-29 (Fig. 5b). Larger retention volumes of approximately 50–60 m^3 occurred in the R-27 ditch compared to the R-29 ditch.

Boczoń, Wróbel and Syniaiev (2009) indicated, based on their research conducted in 2007–2008, that beaver dams contributed to raising the water table in beaver ponds by approximately 68 cm in selected areas of the Białowieża Forest. This resulted in a shortening of the period when the water table was located below the surface. Grygoruk and Nowak (2014), based on research carried out in the Krzemianka valley (north-eastern Poland) in 2006–2013, estimated the scope of changes in riverbed water retention caused by beaver activity in the range from 7,000 to 15,000 m^3, which contributed to raising the groundwater table in adjacent areas by approximately 48 cm. Larsen, Larsen and Lane (2021) based on data from 1978–1994, they observed the impact of the beaver dam on increasing the water level in the river by 150 cm, which resulted in an increase in groundwater in the adjacent area by approximately 40 cm.

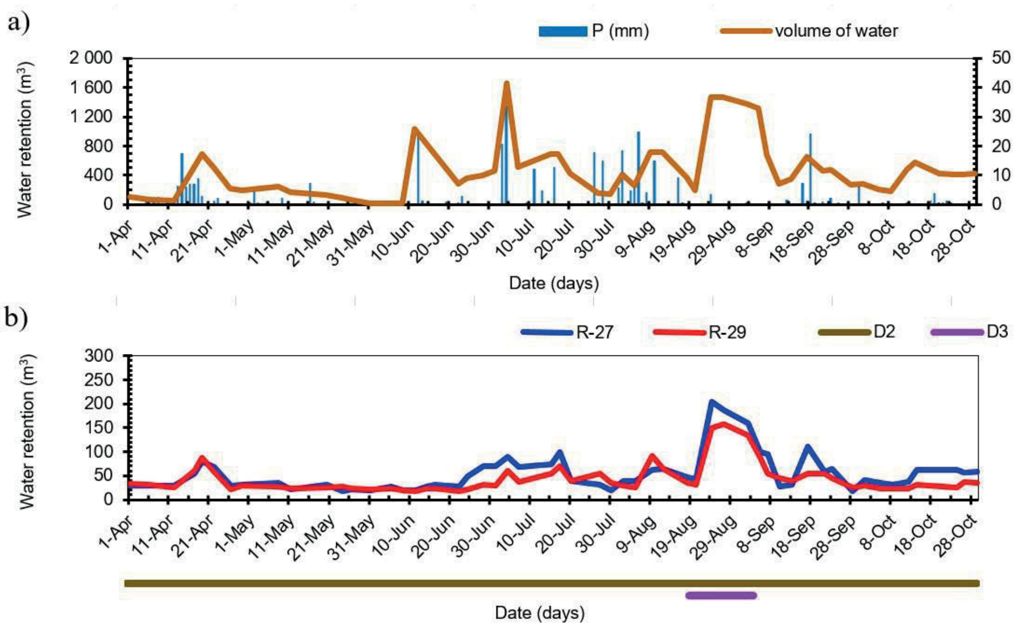

Fig. 4. Water capacity retained in the analysed season April–October in 2021 year: a) in the Mała River, b) in the R-27 and R-29 ditches; *P* = precipitation (mm); D2 and D3 = beaver dams; source: own study

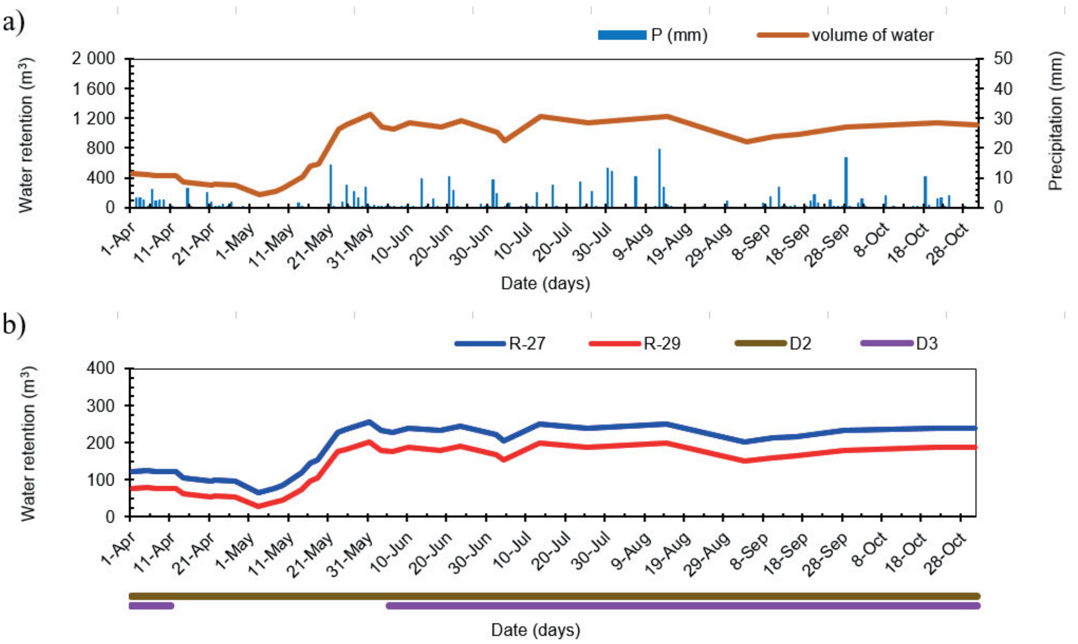

Fig. 5. Water capacity retained in the analysed season April–October in 2022 year: a) in the Mała River, b) in the R-27 and R-29 ditches; *P* = precipitation (mm), D2 and D3 = beaver dams; source: own study

PHYTOCOENOSES OF THE RESEARCH AREA

Before the construction of beaver dams, the phytocoenosis of the studied site was defined as anthropogenic, fertilised, multi-cut meadow communities of humid and wet habitats – *Calthion* aliance, *Molinietalia* order, *Molinion-Arrhenatheratea* class (Gąsowska, 2015). Currently, the plant communities in this plot are more diverse and are not protected by the Habitats Directive (Directive, 1992).

In the part of the plot located on mineral soil, above cross-section P4, the fresh meadow community of *Arrhenatheretalia* order, *Arrhenathertum elatioris* association, dominates (f_1 – Tab. S1). Apart from *Arrhenatherum elatius*, the community also included large amounts of *Festuca rubra*, *Holcus lanatus* and *Plantago lanceolata*. Species of wet habitats were rare. The most valuable species of this group of plants was *Ranunculus auricomus*.

On the organic soil (in transect P1–P3, Tab. 1), the most abundant community was from the *Phragmitetea* class, *Magnocaricion* association, i.e. the *Caricetum gracilis* community (f_2, f_3). In the structure of this community, depending on the patch, *Juncus effusus* and *Veronica longifolia* occurred. The second characteristic community in the part of the studied plot located on organic soil was the *Caricion nigrae* association, of the order *Caricetalia nigrae*, class *Scheuchzerion-Caricetea nigrae* (f_4). Along the stream on the side of the plot there was *Glyceria maxima* community, accompanied by *Phalaris arundinacea* and *Iris pseudoacorus* (f_5). The value of the Shannon–Wiener index (H') of these communities ranged from 0.20 to 0.52.

In the location of natural habitat 6510 (Tab. 1), in 2023, three plant communities were distinguished. The *Veronica longifolia* community (f_6) was closest to the impact of the beaver dam. In the central part of the plot (up to 100 m from the river), the community of *Deschampsia caespitosa* (f_7–f_8) dominated, and the community of *D. caespitosa* with *Festuca pratensis* (f_9–f_{10}) was found furthest from the impact of the beaver dam. The biological diversity of communities on this side of the river was on average twice as high (H' = 0.45–1.00), and compared to 2014 (f_{11}–f_{16}) only on average 9% higher. A positive aspect of changes in the botanical composition of communities was the reduction in the cover of *Holcus lanatus* (species indicating drying of organic soils) and the increase of *F. pratensis* and *F. rubra*. Three species, i.e., *D. caespitosa*, *Poa trivialis* and *V. longifolia* were characterised by the greatest stability in the communities. It is expected that in the near future, under current habitat conditions and late or no mowing of meadows, the cover of *D. caespitosa* and *V. longifolia* will increase, which will not be beneficial for natural habitat 6510.

An increase in biodiversity as a result of beaver activity was also observed during research conducted by Law *et al.* (2017) in Scotland on a neutral valley fen that was drained in the 1800s to create pasture for livestock. They emphasise that 8–12 years of access for beavers to the studied area is too short to achieve full success in restoring wet habitats. Research results published by Pawluśkiewicz, Janicka and Piekut (2019) and Janicka, Pawluśkiewicz and Gnatowski (2023) indicate that in some situations it is necessary to introduce key species to improve the condition or even restore natural habitats, especially 6510.

CONCLUSIONS

1. The levels and water capacity of the Mała River and adjacent ditches were closely related to the activity of beavers and the rainfall occurring in the area. The maximum volume of retained water in 2020 was periodically 1,300 m^3, in 2021 it was 1,700 m^3, and in 2022 the bed retention of the Mała River was 1,200 m^3.
2. Beavers respond to human activities and adapt recovery of dams to emerging obstacles. The impact of beaver activity on the amount of water retention in the river and ditches was particularly visible in periods when low rainfall was observed, from July 25 to August 10, 2020 and from August 21 to September 10, 2021.

3. The functioning of beaver dams in the Mała riverbed had an impact on the riverbed retention of drainage ditches. In 2020, the maximum retention of the R-29 ditch was 270 m^3. In 2021, 270 m^3 of water accumulated in the R-27 ditch, and 210 m^3 in the R-29 ditch. In 2022, the largest volume of dammed water in the R-27 ditch was 250 m^3 and 200 m^3 in the R-29 ditch.
4. At the beginning of June of the third year of existence of the beaver dams, the water in the river stabilised at the level of 100.1 m. In consequence, retention in the Mała riverbed remained at a high level of 1,000 to 1,200 m^3, as well as stable and high water retention in the ditches despite slight rainfall.
5. In the area where initially there were communities not covered by the Habitats Directive, as a result of the activity of beavers, the *Calhtion* communities were transformed into *Caricetum gracilis*.
6. The occurrence of beaver dams resulted in an increase in the value of the biodiversity index (H') by an average of 9% compared to 2014. The cover of *Holcus lanatus* decreased and the cover of *Festuca pratensis* and *Festuca rubra* increased. High cover of *Deschampsia caespitosa* and *Veronica longifolia* in the current habitat conditions and the late or complete absence of mowing of the meadows may worsen the conservation status of natural habitat 6510.

SUPPLEMENTARY MATERIAL

Supplementary material to this article can be found online at: https://www.jwld.pl/files/Supplementary_material_Oleszczuk.pdf

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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