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The geodiversity of the Gostynin-Włocławek Landscape Park (Poland) and its buffer zone – an attempt to quantify geotourism potential

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Geodiversity, understood as the diversity of abiotic components (geological structures, landforms, rocks and sediments, and hydroclimatic conditions), underpins geotourism development. We employed a standardized expert assessment to compare the geotourism potential of seven geosites located within the Gostynin-Włocławek Landscape Park and its buffer zone, scoring them for their scientific-educational and tourism values. Six sites: the lakes Gościąż, Rakutowskie, and Lucieńskie; the Goreń Dune; the Włocławek Reservoir; and Zamkowa Hill, show high geotourism potential, whereas the Kresy Nature Reserve (a raised bog) was rated as moderate. The highest scientific-educational scores were achieved by Lake Gościąż, the Włocławek Reservoir, and Zamkowa Hill, reflecting their ability to illustrate Quaternary history, dam-related channel and sedimentary processes, and mass-movement phenomena. Notably, Lake Gościąż and Zamkowa Hill are already listed in the Central Register of Polish Geosites. The results indicate substantial opportunities for geotourism development in the region. To fully realize this potential, targeted actions to improve access, interpretation, and promotion of the geosites are needed.

Key words: evaluation of geotourism potential, Płock Basin, young glacial landscape, geosites.

INTRODUCTION

Geodiversity is a significant factor shaping the development of geotourism (Thomas, 2012; Migoń, 2012; Górska-Zabielska et al., 2024). Broadly, it refers to the diversity of natural abiotic components, including geological rocks and structures, geomorphological features, soils and other sediments, surface water systems, groundwater, and climate conditions, all of which contribute to the ecological hierarchy (Jedicke, 2001). In a more holistic, integrated sense, geodiversity encompasses not only the physical landscape but also its relations to biodiversity and to humans and human culture (Kostrzewski, 1998; Stanley, 2004; Górska-Zabielska and Zabielski, 2017b).

A geodiversity evaluation conducted by Alexandrowicz et al. (2004) found that young glacial landscapes demonstrate moderate to low geodiversity. However, a number of researchers (Kot and Sobiech, 2013; Kot, 2014; Najwer et al., 2016; Górska-Zabielska and Kamieńska, 2017a) have contended that such young glacial landscapes in Poland are nevertheless more diverse and interesting than previously suggested. While flat surfaces such as moraine plateaus, outwash plains, and meltwater erosion plains, along with valley floors and lake depressions, do typically show lower geodiversity, regions characterized by more varied topography, such as ice sheet marginal zones, slopes, and hilly areas of different origins, tend to display higher levels of geodiversity (Kot and Sobiech, 2013; Kot, 2015, 2017; Najwer et al., 2016).

Even so, despite this landscape diversity, these regions are often assessed as having only moderate geotourism potential. This was re-stated by Górska-Zabielska and Kamieńska (2017a) in their study of the proposed geopark "The Post-Glacial Land of the Drawa and Dębnica River Valleys." Nevertheless, Górska-Zabielska and Kamieńska (2017a) noted that the addition of cultural heritage sites can enhance the geotourism appeal of a given geosystem. Migoń (2012) similarly observed that national parks located in the Polish Lowlands tend to have low geotourism attractiveness. On the other hand, Ratajczak-Szczerba (2013) argued that even seemingly uniform lowland landscapes offer valuable features such as landforms, erratics, and exposed geological formations, which can be of interest to geotourists.

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The geodiversity of the Płock Basin, particularly those parts falling within the boundaries of the Gostynin-Włocławek Landscape Park (GWLP), has not yet been thoroughly evaluated. However, some aspects of its diversity have been explored in a methodological study that focused on the potential application of landscape metrics to evaluate geodiversity in the eastern and central parts of the park (Malinowska and Szumacher, 2013). Their findings indicate that moraine plateaus, relative to the valley floor of the Vistula, are both more structurally complex and more functionally capable: they support multiple geo-ecological functions, encompass a wider spectrum of geomorphic processes and landforms, and maintain higher habitat diversity and connectivity. This observation aligns with conclusions drawn from studies conducted in other parts of the Vistula River (Kot, 2015, 2017). Through the analysis of morphology, hypsometry, and lithology, four distinct types of natural landscape have been identified within the GWLP: (i) flat, erosional-accumulative terraces either devoid of dunes or (ii) covered by scattered hills and dune ridges (terrace-dune landscape), (iii) densely-set hills and dune ridges on terraces, and (iv) flat biogenic plains (Niewiarowski and Kot, 2011).The development of geotourism typically involves harnessing landscape features by establishing a network of representative geosites, ranging in scale from individual objects to large, geologically and/or geomorphologically diverse areas (Alexandrowicz, 2003).

The aim of this study is to identify and evaluate the key geosites within the Gostynin-Włocławek Landscape Park (GWLP) and its buffer zone, with particular emphasis on their geodiversity and tourism potential. Through a detailed analysis, we seek to determine the scientific, educational, and touristic value of these sites and to demonstrate whether they can contribute to the development of geotourism in the region. The results may serve as a basis for refining geotourism strategies, including infrastructure expansion and targeted promotional efforts.

GEOLOGICAL SETTING AND GEOMORPHOLOGIC-HYDROLOGICAL BACKGROUND OF THE STUDY AREA

The GWLP is located in the central part of the Płock Basin mesoregion, bordered by the Kujawy Lakeland and the Inowrocław Plain to the west, and by the Dobrzyń Lakeland to the east (Solon et al., 2018; Rychling et al., 2021). The Płock Basin is one of the largest widenings of the Vistula River valley system, spanning up to 20 km in width. It is a polygenetic landform shaped by successive ding processes of glacial, fluvioglacial and fluvial erosion and accumulation operating during the Vistulian Glaciation (Roman, 2010, 2012; Fig. 1). However, most studies dealing with the morphogenesis of the Płock Basin (see e.g., Skompski, 1969; Mojski, 1970; Roman, 2003; Rychel and Lisicki, 2019) highlight its older provenance, traceable back to at least the Middle Polish Glaciation (Odranian and Wartanian). The Płock Basin is surrounded by moraine plateaus, primarily composed of glacial till and locally covered by sand-gravel fluvioglacial deposits. The surfaces of these plateaus occur at elevations of ~90–135 m a.s.l. to the south of the Płock Basin and ~90–110 m a.s.l. to the north.

The landscape of the Płock Basin is dominated by extensive morphological levels occurring at elevations of 98–95 m, 92–90 m and 82–80 m a.s.l., all related to the drainage and partial damming of meltwater flow from the retreating ice sheet between the Poznań and the Pomeranian glacial phases. Below the levels of the ice-marginal valley, a system of river terraces is visible, with elevations descending along the river course down to the recent floodplain, currently covered by the waters of the Włocławek Reservoir.

Both the ice-marginal valley levels and the river terraces are incised by tunnel valleys, which are a distinctive geomorphological feature of the GWLP. These valleys form a number of extensive systems, exceeding 20 km in length (Fig. 1). Despite their significant length, these valleys are nevertheless relatively narrow – with average widths ranging from 300 to 500 m – while their depths, relative to ice-marginal valley levels and river terraces, can reach up to 50 m. In the Płock Basin, these landforms were created during the Poznań glacial phase by erosion from channelized meltwater flows under hydrostatic pressure. Immediately after incision, the valleys were infilled with dead ice blocks, over which meltwaters and river waters flowed, forming the ice-marginal valley terraces. Subsequent melting of dead ice, primarily occurring during the Bølling-Allerød interstadial (14700 to 12700 cal. years BP) exposed the tunnel valleys, leading to the formation of lakes within them (Błaszkiewicz, 2007).

The Gostynin-Włocławek Lakeland's location within a large ice-marginal valley is an exceptional feature on the Great European Plain, given that most lakelands were formed on moraine plateaus or outwash plains (Roman, 2010). The presence of tunnel valleys on the ice-marginal valley terraces of the Płock Basin is an important geomorphological feature, indicating both the preservation of such glacial landforms by dead ice blocks and the older origins of this part of the Vistula River ice-marginal valley.

The terraces are characterized by numerous sand dunes (Urbaniak, 1967; Rychel et al., 2018; Kruczkowska et al., 2020). The first aeolian phase in this area appeared in the Oldest Dryas stadial (i.e., prior to 14,700 cal. years BP), when periglacial conditions, along with persistent permafrost, generated aeolian sand plains with numerous ventifacts. However, the main dune-forming phase in the Płock Basin took place during the Younger Dryas (between 12,700 and 11,700 cal. years BP). During that period, large dunes, up to 20 m tall, were formed under shrub tundra conditions but with less extensive permafrost, which was conducive to a greater availability of sand. These dunes usually form large fields where parabolic, transverse and irregular varieties can be observed (Fig. 1).

The erosional-accumulative activity of fluvioglacial waters led to the infilling of the Płock Basin with sands and gravels. In most of the area, these deposits now host a single groundwater body with an average thickness of 40–45 m (Skompski, 1969; Glazik, 1992). The hydrographic systems of the Płock Basin are supplied by lateral groundwater flows and surface runoff from moraine plateaus, as well as by ascent from Miocene-Pliocene groundwater bodies and by meteoric waters infiltrating the highly permeable basin floor. In the northern part of the basin, both groundwaters and surface flows are locally recharged by infiltration from the Włocławek Reservoir (Gierszewski, 2000).

The GWLP is drained by three main river systems and the Main Canal. The largest is the 48.5 km-long Skrwa Lewa River, with a 400.4 km^2 catchment (150 km^2 within the park); it flows through the Lucieńskie and Białe lakes, is impounded at Soczewka (0.46 km^2 reservoir), and empties into the Włocławek Reservoir (Brykała, 2009). In the south, the 38 km-long Rakutówka River (260 km^2 catchment, 99 km^2 in the GWLP) flows parallel to the Kujawy Plateau before joining the Lubieńka – a tributary of the Zgłowiączka and, ultimately, the Vistula below the dam. Several ~10 km streams (Ruda, Zuzanka, Ryb-

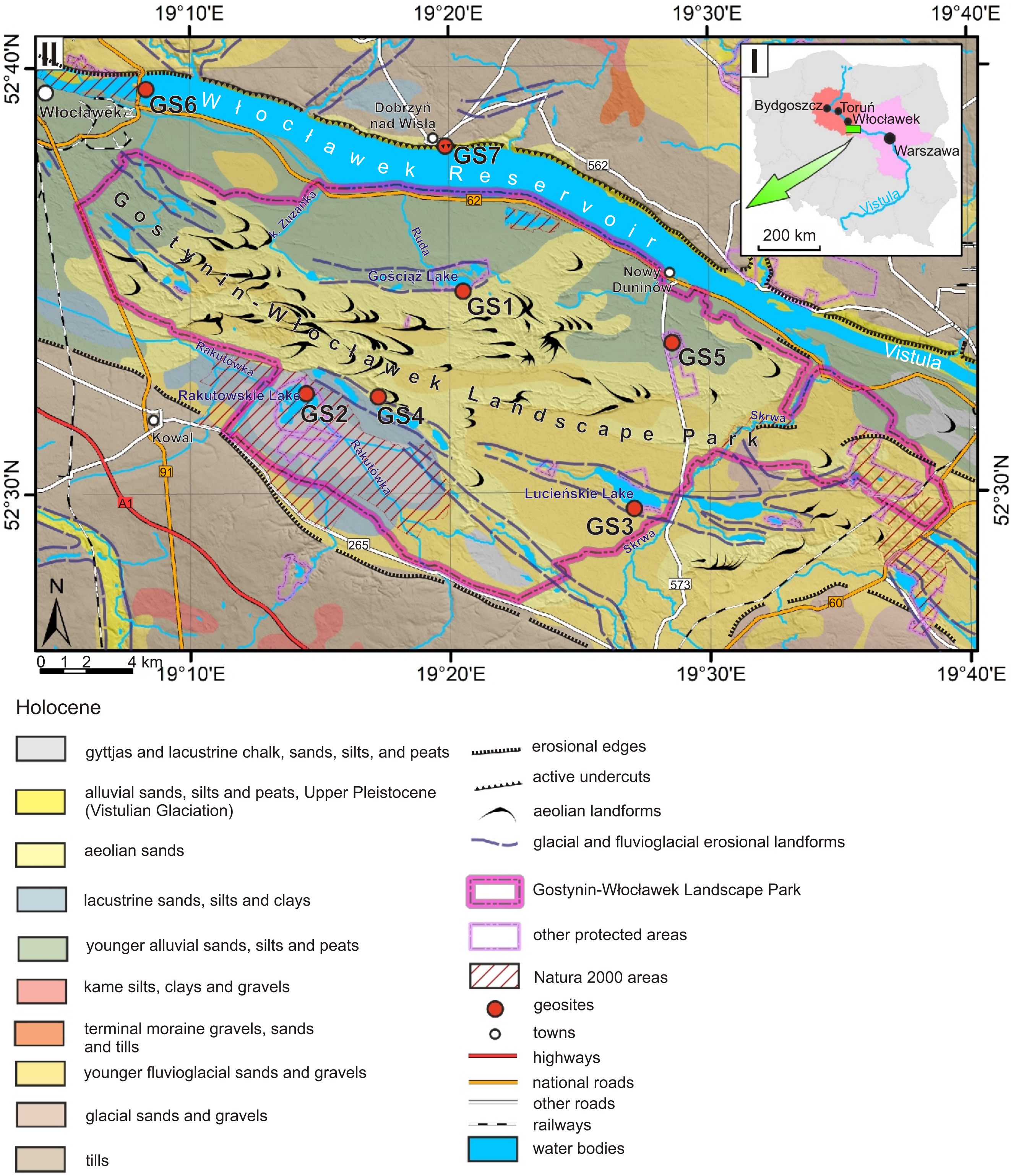

Fig. 1. Location of geosites referred to the geological setting and main landforms of the Płock Basin (lithology and stratigraphy after Marks, 2022)

nica) drain the central dune fields into the Włocławek Reservoir. The Main Canal (built 1963–67) diverts plateau and valley water into the reservoir and regulates its infiltration (Gierszewski, 2000).

Lakes are a key feature of the GWLP's hydrography. There are 51 lakes covering surface areas larger than 1 hectare, arranged in two rows: northern and southern. The southern row splits into two branches near Skrzyneckie Lake. Most of the lakes (45) are small (covering up to 50 ha) and shallow (with 31 lakes being <5 m deep). The largest – Rakutowskie Lake – covered 3.51 km^2 back in the 1920s (Lencewicz, 1929), but this shallow body of maximum depth 2 m has shrunk by 70% over the decades, now covering just 1 km^2 (Bartczak et al., 2019). Other larger lakes include Lucieńskie Lake (2.03 km^2) and Białe Lake (1.5 km^2), the latter being the deepest in the GWLP, at 31 m. The second deepest is Gościąż Lake (24 m), followed by the Lucień Lake (20 m).

METHODS

To assess the geotourism potential of the Gostynin-Włocławek Landscape Park (GWLP), seven geosites (GS1–GS7) were selected. Five of them are located within the park boundaries (Lake Gościąż, Lake Rakutowskie, Lake Lucieńskie, the dune in Goreń, and the Kresy raised bog), while two – Zamkowa Hill in Dobrzyń nad Wisłą and the Włocławek dam with its reservoir – are situated in the park's buffer zone (Fig. 1).

The locations selected represent key elements of the young-glacial and postglacial landscape typical of the region, including ribbon lakes, dune hills, and biogenic plains (Rychel et al., 2014). Their selection was based on scientific, landscape, educational, and cognitive criteria. These sites provide opportunities to present glacial and postglacial processes, as well as subsequent transformations of the abiotic environment, such as aeolian, fluvial and biogenic activity.

A particularly important role is played by the Włocławek dam and its reservoir, which represent an example of anthropogenic transformation of a river system. This location allows for the discussion of issues related to the modification of the hydrological regime, changes in river channel morphology, and sedimentation processes in a dammed environment. The reservoir also serves an educational function in terms of illustrating the impact of large hydrotechnical structures on the geological and geomorphological environment.

Zamkowa Hill in Dobrzyń nad Wisłą, on the other hand, is a topographic feature that provides insight into the geological structure of the region, exposing both Quaternary and older Mio-Pliocene deposits. This site is of significant stratigraphic and cognitive value and additionally represents the effects of contemporary geodynamic processes, such as landslides, slumps, and wave-induced abrasion. The combination of scientific value with landscape and cultural-historical qualities makes this location particularly valuable for educational geotourism.

All geosites selected are characterized by good landform exposure, accessibility, and high potential for geotourism interpretation. They enable the integration of geological heritage with other forms of cognitive tourism, which aligns with the principles of sustainable development in protected areas.

The geotourism potential of selected geosites within the GWLP and its buffer zone was evaluated using the ranking method developed by Chrobak-Žuffová (2023). This method was derived from a critical review of 60 geosite evaluation approaches, and integrates modified criteria from Pereira and Pereira (2010) and Fassoulas et al. (2012). In this framework, scientific-educational (VE) and tourism (VT) scores are combined into an overall geosite value index (VK) following Warszyńska (1970). However, it must be noted that this type of evaluation has the potential shortcoming of being highly subjective (Chrobak, 2021). This limitation can be mitigated by methods such as expert triangulation (Flick, 2011). As such, the three authors of the present paper, each with different specializations in the geosciences (geology, geomorphology, hydrology), independently conducted three evaluation procedures using the same methodology. The averages of the values obtained by each investigator was taken as the final VK index values for each geosite.

CHARACTERIZATION OF SELECTED GEOSITES

Of the seven sites selected for the assessment of geotourism potential, two (Zamkowa Hill and Lake Gościąż) are already listed in the Central Register of Polish Geosites (https://geologia.pgi.gov.pl/geostanowiska). Zamkowa Hill, catalogued as KDG 395, is a remnant of the moraine plateau in the Vistula River Valley, while Gościąż Lake is registered under KDG 3322 and its associated nature reserve as KDG 4318. In this study, Gościąż Lake is treated as part of the nature reserve. Additionally, the lake is included in the Catalogue of Geosites within the Abiotic Nature Monuments and Reserves (Bartuś et al., 2012).

Both Zamkowa Hill and Gościąż Lake have been proposed for inclusion in the European Geosites Network, which is part of the IUGS Global GEOSITES project managed by the European Association for the Conservation of Geological Heritage (ProGEO) (Alexandrowicz, 2003). The selection of the Włocławek Dam and Reservoir as geosites was based on their geoeducational significance. These structures offer valuable insights into the interaction between humans and the environment, particularly in understanding the impact of hydrotechnical constructions on river systems. Visitors can also observe natural morphodynamic processes, such as sedimentation (alluvial and lacustrine), erosion, and abrasion, which are influenced by the dam and reservoir.

The inclusion of a river dam as a geosite is not unusual, as seen with the Pilchowice Dam on the Bóbr River, which is also part of Poland's Central Register of Geosites, and other notable dams, such as those on the Kwisa River (Łodziński et al., 2009) and the El-Abid River in Morocco (Rais et al., 2021).

GS1 – Gościąż Lake. Gościąż Lake occupies a part of a tunnel valley, cut into the terrace of the ice-marginal valley near the village of Dobiegniewo in the Płock Basin (Fig. 2). The tunnel valley was formed beneath the ice sheet by the erosional force of meltwater under hydrostatic pressure. When the ice sheet receded, the valley was filled with blocks of dead ice covered over by several metres of clastic deposits. During the first significant climate warming, in the Bølling interstadial, a peat bog developed on the surface through a process known as paludification. Shortly thereafter, during the Middle Allerød interstadial (~13,000 cal. years BP), the dead ice melted, causing the peatbog sediments to collapse onto the tunnel valley bottom, forming as thin (5 cm) basal peat layer. Subsequently, this layer was covered by the sediments of a newly formed lake in the tunnel valley (Więckowski, 1993).

Today Gościąż Lake covers an area of 41.7 ha and its maximum depth reaches 24 m (Ralska-Jasiewiczowa et al., 1998). It forms part of the hydrological system of the Ruda River, which connects several smaller lakes before flowing into the Włocławek Reservoir. However, during dry seasons, these connections between lakes intermittently disappear. Gościąż Lake is recharged primarily by groundwater migrating from the south-

Fig. 2. Gościąż Lake (photo P. Twardowski)

ern part of the ice-marginal valley towards the Vistula River channel. Groundwater outflows are visible as descending, subslope springs of stratified-erosional type along the southern shore of the lake, where ~50 outflows have been identified. Some of these springs originate on the slope of the tunnel valley, where small edge-headwater niches have also been observed (see Mazurek, 2010; Fig. 3).

In the early 1990s, the total discharge from these springs along the southern shore of Gościąż Lake was estimated at ~25 l/s (Gierszewski, 2000), but by 2004 this had decreased to <9 l/s (the authors' unpublished data). Recent monitoring of two springs, carried out from 2017 to 2022, revealed average discharges of 1.0 and 0.15 l/s, with no significant interannual variation (the authors' unpublished data). Chemical analysis of the spring water indicated a low-alkaline pH (7.8), relatively low TDS (285 mg/l) and HCO_3–Ca hydrochemical composition (Gierszewski, 2000).

Fig. 3. Spring niche in the slope of the subglacial tunnel valley of the Gościąż-Mielec lakes system (photo M. Fojutowski)

Gościąż Lake rose to scientific prominence in the 1980s, when K. Więckowski of the Polish Academy of Sciences discovered its annually laminated lacustrine deposits. These deposits revealed that from the very beginning of the lake's history, i.e., since almost 13,000 cal. years BP, carbonate-diatomaceous gyttjas have been deposited at the bottom, forming macroscopically visible, lighter and darker annual pairs of laminae with an average thickness of 0.8 mm. This lamination resulted from seasonal changes in bioproduction in the lake. In the spring, after the ice cover melted, phytoplankton (mostly diatoms) proliferated, which resulted in mass assimilation of carbon dioxide from the water. This, in turn, triggered precipitation of calcite, which deposited at the bottom forming a lighter lamina. In the autumn, when most organisms living at the lake bottom died off, a darker lamina was deposited, rich in organic matter. This process resulted in the accumulation of a 15-metre-thick succession of perfectly annually laminated deposits in the deepest part of Gościąż Lake (Ralska-Jasiewiczowa et al., 1998).

One of the most pressing challenges in Earth sciences is understanding global climate change and its impact on the natural environment. However, scientific discussion of these issues must be based on a foundation of reliable knowledge of past climates (palaeoclimate) and environments (palaeoenvironments). High-resolution records of palaeoenvironmental changes from sedimentary environments are therefore invaluable for this purpose. Annually laminated lake deposits are particularly significant, due to their proximity to human habitats. Close analysis of such deposits enables researchers to not only study palaeoclimate changes but also understand the role of human activity in such interactions (Braueret al., 2009). Because the formation and preservation of such laminae require specific conditions, only a few geosites worldwide are known to contain such annual lamination dating back more than 10,000 years (Zolitschka et al., 2015). As such, the nearly 13,000 annual pairs of laminae from Gościąż Lake represent a rare and unique archive of Earth's history. These deposits have been the focus of extensive interdisciplinary re-

Fig. 4. Rakutowskie Lake (photo P. Twardowski)

search, yielding important insights into global climatic and environmental changes in the Late Glacial and Holocene (Ralska-Jasiewiczowa et al., 1998; Müller et al., 2020; Bonk et al., 2021; Płócienniket et al., 2022; Błaszkiewicz et al., 2025).

Access to the geosite is via a compacted dirt road accessible to vehicles, turning off road 62 just before the village of Dobiegniewo, and leading to a forest car park (~6 km). Then, one walks ~2 km along a forest track to the viewpoint by the beach on the south-eastern shore of the lake. At the beach there are two information boards about the lake's origin and its lacustrine deposits. The site lies on the Main Trail of the Płock Basin (Szlak Główny Kotliny Płockiej). A snack bar is located at the turn-off from road 62 onto the dirt road.

GS2 – Rakutowskie Lake. Rakutowskie Lake is situated in the southern portion of the Płock Basin, within Terrace VI of the ice-marginal valley, near the Kujawy Moraine Plateau (Wiśniewski, 1976). The lake covers the central part of a large, somewhat elongated depression, with its morphological axis running parallel to the adjacent moraine plateau (Fig. 4).

The lake basin was most likely formed by the melting of buried dead ice blocks, presumably during the Bølling-Allerød interstadial (14,700–12,700 cal years BP). Another possible contributing factor to its formation may have been the burial of ice in extensive, braided river channels during the formation of Terrace VI. The outer portions of the lake basin are filled with muddy sands, 2–3 m thick, characteristic of shallow, periglacial lakes. In the central area of the lake basin, biogenic plains developed, as the lake gradually became infilled with bottom sediments, mostly carbonate gyttjas followed by a low moor peat bog (Bartczak et al., 2019). Currently, the lake is very shallow (with a maximum depth of only 2.9 m). This shallow depth means that even small differences in seasonal and annual recharge cause significant fluctuations in the lake's surface area, of up to 0.7 km^2. Rakutowskie Lake and its close surrounding are part of an ornithological preserve, serving as a nesting site for many bird species.

Access to the geosite is from the town of Kowal via road 2907C to the village of Dębniaki, then continues on road 190906C to the observation tower in Krzewent, where there is a parking area. Next to the tower there are two information boards about the geosite. The viewpoint lies along the GWLP educational trail "Niecka Kłocieńska".

GS3 – Lucieńskie Lake. Tunnel valleys are characteristic landforms of the Gostynin-Włocławek Lakeland, where they form several systems reaching up to 10 km in length (Fig. 5). The longest of these is the system of the Lubieńskie-Skrzy-

Fig. 5. Lucieńskie Lake (photo L. Urbankiewicz)

Fig. 6. Parabolic dune in the vicinity of Goreń (photo L. Urbankiewicz)

neckie i Goreńskie lakes. Although lengthy, these tunnel valleys are relatively narrow landforms, with average widths of ~400 m, but they are exceptionally deep-reaching depths of up to 50 m relative to the ice-marginal valley terraces they cut through (Roman, 2010).

Like other such landforms in the Płock Basin, the tunnel valley of Lucieńskie Lake was formed during the Poznań Phase of the Last Glacial Period. It resulted from the subglacial erosional activity of meltwaters under hydrostatic pressure. Immediately after the tunnel valley formed, it was filled with blocks of dead ice, over which meltwater continued to flow, eventually creating an ice-marginal valley terrace. Later the melting of the dead ice (presumably in the Allerød Interstadial) uncovered the valley and led to the formation of Lucieńskie Lake. In the Płock Basin, the presence of tunnel valleys incised into an undoubtedly younger terrace of the ice-marginal valley is significant, in that it demonstrates the role of dead ice blocks in preserving these ancient tunnel valleys.

Access to the site from the village of Lucień is by a local road towards Miałkówek, along the southern edge of the tunnel valley. Two parking areas are located next to snack bar. A short walk of several tens of metres leads to the lake shore. The viewpoint is equipped with information boards. A cycle route passes the site.

GS4 – Goreń Dune. An important feature of the GWLP landscape is the presence of extensive dune fields that have formed over the sand terraces. In addition to these fields, individual large dunes also stand out, such as the parabolic Goreń Dune, which rises to a height of ~8 m (Fig. 6). This dune has well-defined arms extending ~465 m to the west, with asymmetrical slopes: a gently sloping proximal side and a steeper distal slope. The Goreń Dune is a classic example of inland aeolian deposition that occurred during cold periods of the Late Glacial, under conditions of intermittent permafrost and sparse tundra vegetation (Rychel et al., 2018).

Access from road 265 in Baruchowo is via local road 2918C towards Kłótno, then continues towards Goreń. Before the village, there is ~200 m walk along a gravel track to the dune exposure at the road cutting. A marked cycle route runs nearby.

GS5 – Kresy Nature Reserve. The Kresy Nature Reserve derives its name from the medieval border between the historical provinces of Cuiavia (*Kujawy*) and Masovia (*Mazowsze*). The reserve's raised bog is situated in the northern region, at the center of a small, shallow depression surrounded by extensive dune fields. Its position and morphology suggest that it originated as a blowout depression, formed by the deflation of fine sand during the Younger Dryas. According to our investigation, after aeolian activity had ceased, a rising groundwater table during the early Holocene led to the formation of a small lake ~7 m deep (our unpublished data). As gyttjas accumulated at the lake bottom, the lake rapidly became shallower, allowing a low-moor peat bog to spread over the lacustrine sediments. With a shift from waterlogged to rain-fed conditions, the area transformed into a transitional peat bog, eventually developing into a raised bog (Fig. 7). This is indicated by the fact that the raised bog is characterized by a slightly dome-shaped surface surrounded by a waterlogged margin. This succession represents a typical example of biogenic sedimentary deposition in shallow lakes.

Access to the site is via road 573 from Nowy Duninów, ~3 km towards Gostynin. The site lies directly by the road; there are no designated parking places, and stopping is only possible at the roadside, with a view of a small pond and the raised-bog dome. Shops and food outlets are available in Nowy Duninów.

GS6 – Włocławek Dam and Reservoir. The Włocławek Dam is a 1,200-metre-long hydrotechnical structure comprising five key components: (i) a weir, (ii) a 160 MW hydroelectric plant, (iii) a lock, (iv) a fish pass and (v) a head dam. It was built between 1963 and 1970 at the 674.8 km mark of the Vistula River's course, as a part of the Lower Vistula Cascade – a planned system of 7–9 dams, which has never been built. The damming of the river by 11.3 m resulted in the creation of a large (75 km^2) water body known as the Włocławek Reservoir or Włocławek Lake (Fig. 8). At normal water levels the reservoir is 57 km long, an average of 1.2 km wide and 5.5 m deep, with a maximum depth of 15 metres. Its current volume is estimated at 370 million cubic metres, making it the second-largest reservoir in Poland (Gierszewski, 2018).

The Włocławek reservoir was designed for multiple purposes: power generation, navigation, flood control, and providing water for agriculture and industry. Today, its primary function is hydroelectricity production, with a secondary recreational function and an only marginal flood control function due to its low usable capacity. The focus on energy generation – particu-

Fig. 7. Kresy Reserve, raised-bog dome (photo L. Urbankiewicz)

larly prior to 2002, when the power plant was operating on a peaking basis – resulted in high variability of daily flow rate dynamics.

The Włocławek Reservoir has caused significant environmental changes in the Vistula River valley. One of the most spectacular impacts in the early years was the reappearance of mass movements and strong abrasion on the high banks. Another key change was in the transport of clastic sediment. The flow rate decreases significantly towards the dam, from 50–70 cm/s upstream of, to 8–6 cm/s near the dam (during average discharge for the Vistula River). This has resulted in the deposition of a mass of sand and gravel in a fan delta at the reservoir's upper end. Sand has also accumulated in shallower parts of the reservoir (up to 6 m depth), where the bottom was above the wave base. Additionally, the reservoir traps 25–70% of suspended material, depending on hydrological conditions. This suspended load settles as dark, silty-clayey sediments in deeper parts of the reservoir, which unfortunately tend to collect hazardous substances including toxic metals, persistent organic pollutants and polycyclic aromatic hydrocarbons. However, due to the relatively low content of clay minerals and organic matter in the sediments, in tandem with the reservoir's strong water mixing, only cadmium has been detected in elevated concentrations in the bottom sediments.

Downstream from the dam, the lack of coarse clastic sediments and the high energy of water discharge have caused severe erosion in the river channel, increasing its depth by 3.5 m near the weir and by 2.1 m along a 10-km stretch downstream. This erosion front is gradually moving towards the Vistula River mouth and is now located between the towns of Toruń and Solec Kujawski (Habel, 2013). Beyond the erosional zone, an accumulation zone forms where material eroded from the riverbed is deposited.

There is a Geosite on the dam with views of the reservoir, its shores, and the Vistula Valley in Włocławek, and information boards at the viewpoint. Access from Włocławek is via road no. 67. Parking is available on the dam crest and by the dam on the right bank of the Vistula.

Fig. 8. The Włocławek Dam and Reservoir (photo L. Urbankiewicz)

Fig. 9. Zamkowa Hill – relic of a moraine plateau in Dobrzyń nad Wisłą (photo L. Urbankiewicz)

GS7 – Zamkowa Hill. Zamkowa Hill is an outlier of the moraine plateau, rising via a steep (50°) slope to 40 m in height. The plateau edge directly contacts the abrasion-accumulation coastal platform of the Włocławek Reservoir (Fig. 9). At the edge zone, Neogene deposits are exposed, mostly Miocene sands and silts intercalated with lignite layers, and Pliocene clays. Above these lie Quaternary deposis consisting of two layers of moraine till, 15 to 30 m thick in total, separated by a 3-m layer of sand and gravel with a glacial pavement. The Quaternary deposits rest relatively horizontally whereas the underlying Neogene strata are glaciotectonically disturbed, with numerous folds oriented almost perpendicular to the shoreline of the Włocławek Reservoir (Banach, 1977; Roman and Żuk, 2019). This geological configuration, combined with significant elevation differences, facilitates the development of landslides at the edge zone of the moraine plateau.

The central landslide on the Zamkowa Hill slope is an old structure, that was active before the Włocławek Reservoir was constructed in 1969. However, the filling of the reservoir triggered intense undercutting of the lower slopes by wind-driven waves (abrasion; Kaczmarek et al., 2015). This, in turn, distinctly accelerated landslide activity. Over the first 10 years, the landslide progressed at a rate of 3.6 m per year, slowing to 1.0–1.7 m per year more recently. Today, the landslide is ~220 m long, 60–90 m wide, and covers nearly 2 hectares. Morphologically, it is a rotational landslide with a distinct scarp and crown at the top and its main body at the base. The average thickness of the colluvium is ~7 m, with the rupture surface occurring at the contact between the colluvium and the bedrock (Kaczmarek et al., 2015).

Above the landslide lies Zamkowa Hill, separated from the main plateau by a trough formed by denudation. This trough was later utilized by humans and during the stronghold's existence it was converted into a moat-like structure (Andrzejewski, 2000).

Access is via a 250 m walk from Plac Wolności, first along Farna Street, then along a dirt path. Parking is available at Plac Wolności and on Farna Street. Information boards are located along the approach to the site.

GEOSITE VALORIZATION AND DISCUSSION

Evaluation of the seven geosites indicates generally high geotourism potential (Table 1). Lake Gościąż was assigned to Group I (special value), five geosites to Group II (high value),

Table 1

Summary results of geosite valorization

Geositename	Category	VE	VT	VK	Index	Group
GS1 – Gościąż Lake	lake	51.13	59.23	53.56	0.77	I
GS2 – Rakutowskie Lake	lake	40.57	51.97	43.99	0.63	II
GS3 – Lucieńskie Lake	lake	22.83	61.80	34.52	0.49	II
GS4 – Goreń Dune	dune	28.33	50.13	34.87	0.50	II
GS5 – Kresy Nature Reserve	peatbog	22.57	33.27	25.78	0.37	III
GS6 – Włocławek Dam and Reservoir	river	42.03	61.33	47.80	0.68	II
GS7 – Zamkowa Hill	landslide	45.90	56.80	49.17	0.70	II

Table 2

Expert evaluation of geosites according to scientific-educational and tourism values

Geosite name	Valorization according scientific-educational and tourism criteria		
	Expert 1	Expert 2	Expert 3
GS1 – Gościąż Lake	0.70	0.84	0.76
GS2 – RakutowskieLake	0.63	0.65	0.60
GS3 – Lucieńskie Lake	0.49	0.51	0.49
GS4 – Goreń Dune	0.45	0.49	0.56
GS5 – Kresy Nature Reserve	0.30	0.38	0.42
GS6 – Włocławek Dam and Reservoir	0.69	0.68	0.68
GS7 – Zamkowa Hill	0.86	0.53	0.71

and the Kresy Preserve, a peat bog ecosystem, to Group III, reflecting moderate scientific-educational and tourism values. Detailed results are shown in Tables 1 and 2.

The highest ranking, based on the average geosite value index (VK), comparable to that established by Warszyńska (1970), was ascribed to GS1 – Gościąż Lake. Slightly lower scores were assigned to GS6, GS7, and GS4 (Table 1), in a ranking order influenced by two of the three experts (Table 2). One expert, however, awarded the top rank to GS7 (Zamkowa Hill), followed by GS1 and GS6. All three experts agreed that the lowest score went to GS5 (Kresy Peatbog), reflecting its limited potential.

When only the scientific-educational values were considered (as per Chrobak et al., 2020), the rankings of the geosites improved significantly. Gościąż Lake (GS1) was placed in Group I for its exceptional scientific and educational value, scoring over 50 out of 60 points. One expert even awarded it the maximum score, though another noted that a specialized knowledge base is necessary to fully appreciate the geosite. The GWLP has partly addressed this issue by installing educational information boards along the lake's shore (Fig. 10). Gościąż Lake has also earned high rankings in the Central Register of Geosites in Poland for its educational (7/10) and scientific (10/10) appeal. However, in the Catalogue of Geotourism Objects (Bartuś et al., 2012), its cognitive value was rated lower, with only regional significance.

Sites GS6 and GS7, located near the boundary of the GWLP, were ranked in the upper ceiling Group II for their scientific-educational value. One expert rated GS7 (Zamkowa Hill) as the most valuable, awarding it 57.5 out of 60 points. It received a similarly high score (8/10) in the Central Register of Geosites. However, the other two experts pointed out that Zamkowa Hill's scenic value was relatively low and that many similar geosites exist in Poland, leading to a VE index score of 45.9.

This disparity in evaluation stems from differing perspectives on Zamkowa Hill's features. Viewed solely as a landslide or moraine plateau remnant, its similarity to other geosites is apparent. However, when considered holistically – as an outlier of the moraine plateau shaped by mass movements and anthropogenic activity – Zamkowa Hill proves to be quite a unique geosite. Its location on the edge of the Vistula River valley and its distinctive geological structure, with highly glaciotectonically disturbed Neogene strata, make it exceptional in the Polish Lowlands (Brykczyński, 1982; Roman and Żuk, 2015, 2019). Additionally, the combination of Pliocene clays and the valley's hydrogeological conditions drive significant mass movement activity (Banach, 1977; Kaczmarek et al., 2015).

Human activities from the eleventh century to the present, including the construction of an Early Medieval castle at the edge of the moraine plateau and the more recent Włocławek Dam, have further transformed the landscape. The dam altered

Fig. 10. High substantive level of information boards at the Gościąż Lake shore as a good example of direction for the development of geotourism infrastructure (photo L. Urbankiewicz)

hydrogeological conditions and intensified mass movements along the valley scarp, exposing the disturbed Neogene strata and enhancing the geosite's scientific appeal.

All experts agreed on the unique scientific-educational value of the Włocławek Dam (GS6). The Rakutowskie Lake geosite scored almost 52, recognized as a rare lacustrine-peat-bog ecosystem with a water balance highly dependent on both weather conditions and human activity (Bartczak et al., 2019). Lower scientific-educational scores (Group II) were given to Lucieńskie Lake (GS3) and the Goreń Dune (GS4), as similar landforms are common across the Vistulian Glaciation landscapes in Poland. The Kresy Peatbog site (GS5) received the lowest score (Group III), with experts noting that peat bogs are widespread, the landscape is monotonous, and it is the only geosite not discussed in the global scientific literature.

In contrast to scientific-educational values, the ranking of tourism attractiveness (VT index) showed less variation. Most of the geosites examined scored between 50 and 61 out of a maximum of 90 points, with lower scores given to the Goreń Dune (GS4, 50 points) and Kresy Peatbog (GS5, 33 points). Nevertheless, all geosites were classified in Group II for their high tourism value. Experts highlighted the lack of infrastructure (e.g., accommodation and restaurants) and the distance to existing facilities as factors reducing their tourism appeal. Additionally, promotion of some of these geosites is inadequate and most of them are not yet formally recognized as geosites.

The classification based on the VK index (Table 1) reveals a clear gradient of geotourism potential: one flagship site (GS1) is in Group I, most sites in Group II, and one low-scoring site (GS5) is in Group III. This pattern is consistent with quantitative geoheritage assessment frameworks in which core/scientific–educational values (VE) typically drive the upper end of the ranking, whereas tourism values (VT) show less dispersion because they depend more on infrastructure and management conditions than on a site's intrinsic uniqueness (cf. GAM and its modifications; e.g., Fassoulas et al., 2012; Brilha, 2016). Differences in the scores of GS7 (Zamkowa Hill) clearly illustrate a scale effect: at the national scale, comparable landforms are numerous, whereas at the local scale the site is exceptional. The literature emphasizes that scientific value combines rarity, representativeness, integrity, and state of knowledge, and that the spatial frame of reference should be made explicit in reporting because it directly conditions the outcome (Reynard et al., 2016; Brilha, 2016).

The assessment inevitably contains a subjective component (choice of criteria and weights, interpretation of thresholds, frame of reference, differences in expert experience), and some VT indicators reflect current infrastructure and promotion rather than properties inherent to the geosite. In our case, we limited subjectivity to some extent through a short team "calibration" before scoring (independent scoring followed by a consensus meeting) and by checking inter-rater agreement. Another way to reduce arbitrariness would be to complement the assessment with a visitor-preference module (e.g., M-GAM; Tomić and Božić, 2014). However, agreement between expert valuations and visitor preferences can be limited: in the Sub-Tatra case study by Chrobak-Žuffová (2023), the correlation between the synthetic valorization index (VK) and tourists' preferences was moderate (r 0.4), and respondents tended to favor features with strong scenic/experiential appeal. These findings support enriching expert assessment with preference weights in the spirit of M-GAM, which helps align development priorities with user expectations while preserving the primacy of scientific values. At the current stage, aimed at a consistent, regionally comparable expert assessment and classification of geosites the expert approach is, in our view, the optimal solution.

CONCLUSIONS

The geosites studied within and around the Gostynin-Włocławek Landscape Park (GWLP) show significant educational value, offering valuable insights into the region's geomorphology, geology, and palaeogeography. The assessment of their geotourism potential indicates high scientific, educational and tourist values. Consistent with the findings of Kot and Sobiech (2013), the development of geotourism in areas with diverse young glacial landscapes depends not only on individual spectacular sites but also on geodiversity, or the complexity and variation of abiotic environmental components. The results of this study suggest that the scientific and educational value of these geosites could be further enhanced by improving tourism infrastructure and increasing promotion. Górska-Zabielska (2023) emphasized the significant educational potential of lowland geosites in raising public awareness about nature conservation and the impact of human activity on the environment.

The GWLP plays a key role in the wildlife corridor along the Vistula River valley, connecting Kampinos National Park with the Bydgoszcz Forest. In terms of landscape diversity, it shares similarities with the Kampinos National Park, both featuring well-preserved dune fields, old-growth forest remnants, and wetlands within the Vistula River ice-marginal valley. However, the factors that drive tourism in these areas differ significantly. Kampinos National Park benefits from its proximity to Warsaw and its historical and cultural significance, which boost its attractiveness to tourists. Kampinos uniquely combines natural beauty with cultural heritage and history, which enhances its appeal.

To increase the tourism potential of the GWLP, its current recreational and leisure focus could be expanded to include geotourism, capitalizing on the region's natural features. The GWLP's well-established educational programs could be updated to include modern knowledge about its geoenvironmental assets. This would not only attract school groups but also encourage the broader development of geotourism in the region.

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