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Forest reservoirs in southeastern Poland as habitats of diatom species new to Poland

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ABSTRACT

The aim of this work was to characterize morphologically and ecologically 4 new species of diatoms to Poland (*Aulacoseira tenella*, *Eunotia galica*, *Pinnularia subfalaiseana*, and *Psammothidium scoticum*) together with the location of their occurrence in the Janowskie Forests and Turzański Forest in southeastern Poland. The research material from Turzański Forest were collected in the spring and autumn of 2023 in a forest pond and a small stream flowing out of this pond, while in the Janowskie Forests always in the spring season of 2023 and 2024. The results showed that the samples were characterized by an acidic or weakly acidic pH (4.0–6.4) and low electrolytic conductivity values (40–134 µS/cm). Studies conducted in forest water ponds and streams flowing from them have confirmed that such places are habitats of diatoms new to Poland, often known only from a few locations in Europe.

Keywords: *Aulacoseira tenella*, *Eunotia galica*, *Pinnularia subfalaiseana*, *Psammothidium scoticum,* morphology, ecology, Turzański Forest, Janowskie Forests.

INTRODUCTION

Wetlands are defined as areas where the water level is close to the ground level (peat bogs, marshes, and periodically flooded areas). Due to the number of functions they perform in the environment, as well as the increased disappearance of such areas resulting from human pressure and climate change, they are particularly valuable habitats in the natural environment (Krawczyk, 2023). The peat bog areas, as a result of unplanned exploitation, have often been degraded, and the water reservoirs that formed in their place were considered abandoned. However, these reservoirs have high natural value: they are important habitats for aquatic and wetland organisms, contribute to maintaining the stability of ecosystems, and enrich biodiversity. The data from 1968 indicate that peat bogs in Poland covered 3,502 km², of which peat excavations occupied 1,751 km², which constituted 14.5% of their area. Currently, small water reservoirs in such places in Poland cover approximately 500 km² (Kaczan, 1968; Kucharski, 1996; Łachacz, 1997; Ilnicki, 2002).

In southeastern Poland, small water reservoirs are found in forest ecosystems, both in the 'Lasy Janowskie' landscape park and in the area of the Głogów Forest District. The 'Lasy Janowskie' landscape park mainly covers continuous forest complexes intersected by numerous valleys of small, meandering streams. There are 3 nature reserves in the Park, including the 'Imielty Ług' Reserve, protecting one of the largest peat bogs in this area. Reserve protection aims to preserve the diversity of aquatic, marsh, and forest biotopes along with the populations of protected animal and plant species living there (Buczyski and Łabędzki, 2012; Skubisz and Noga, 2023). The water marsh ecosystems of the Głogów Forest District are primarily fragments of reed, alder, peat bog, and heavily waterlogged riparian vegetation in natural depressions. They usually occupy small forest-internal areas of local marshes,

which are extremely important from the point of view of water retention. These areas represent a valuable component of forest ecosystems, as they contribute to the preservation of local biodiversity and enhance the ecosystem's capacity for water retention (Murdza, 2020).

The peatlands and wetlands of southeastern Poland are still relatively poorly known in terms of algological research. Few studies have shown that they are habitats of interesting, often rare, endangered, or previously unrecorded species for Poland. So far, only fragmentary studies of algae have been carried out in the Roztocze National Park (Szczurowska, 2003, 2006, 2009), while diatom communities have been studied in more detail, taking into account rare and endangered species in the 'Międzyrzeki' Reserve (Noga et al., 2014a,b; Noga, 2019). In the Wołosate peatland in the Bieszczady Mountains, the diversity of diatom communities was studied (Rybak et al., 2018) and other algae, mainly euglenas (Wołowski, 2011). Fragmentary studies on diatoms were also conducted in a peat bog in the reserve 'Bagno Przecławskie' (Pajączek et al., 2014). Preliminary studies were conducted in recent years in three nature reserves 'Imielty Ług', 'Broduszurki' and 'Źródła Tanwi' (Noga et al., 2022, 2024; Skubisz and Noga, 2023).

The aim of this work was to characterize morphologically and ecologically 4 new species of diatoms for Poland (*Aulacoseira tenella*, *Eunotia galica*, *Pinnularia subfalaiseana*, and *Psammothidium scoticum*) together with the location of their occurrence in Janowskie Forests and Turzański Forest in southeastern Poland.

STUDY AREA

The research was carried out in the Turzański Forest (LT) and the 'Imielty Ług' Nature Reserve (IŁ) situated within the Janowskie Forests region (Figure 1).

The Turzański Forest covers most of the macroregion of the Sandomierz Basin (managed by the Głogów Forest District). It occupies a fragment of the Kolbuszowa Plateau with an agricultural forest landscape type. Turzański Forest falls within the Sokołowsko-Wilczowolski Protected Landscape Area. It contains mixed coniferous forests, fragments of oak-hornbeam (*Tilio-Carpinetum*) forests and Carpathian beech forests; in local depressions of the terrain, it can be found alder swamps and raised bogs, and over the streams there are riparian forests and bulrush-reed beds (Murdza, 2020).

Two research sites were designated in the area of the Turzański Forest. The first site was an oligotrophic peat hole with an area of approximately 1600 m^2, resembling the shape of the letter L. It was located in the central part of the forest and was characterized by brown water, and the smell of rotten eggs was noticeable in the surrounding. The sphagnum mosses grew at the edge of the reservoir. Site 2 is a reservoir used for water retention in the forest with an area of approximately 3,000 m^2. The Sokołów forest nursery is located approximately 100 m from the reservoir, to the south-west. The bottom of the reservoir is sandy, and the eastern bank has been concreted. A device was installed in the reservoir to collect water to irrigate the nursery.

The 'Imielty Ług' Nature Reserve is located on the border of the Lublin and Podkarpackie voivodeships. It is part of a contagious forest complex that grows in the Sandomierz Basin within the limits of the 'Lasy Janowskie' landscape park. The reserve includes aquatic, reed, peat bog, and forest ecosystems. Among the non-forest communities, extremely valuable and rare on a national scale, and at the same time very endangered, are raised bogs of the *Oxycocco-Sphagnetea* class and transitional bogs of the *Scheuchzerio-Caricetea nigrae* class. Peat bogs of this size are unique in south-eastern Poland, located in interdune depressions. The reserve plays a significant role in the protection of valuable species of peat bog bryophytes, including those of the genus Sphagnum. It is the largest and best preserved reserve in terms of nature in the Janowskie Forests (Fijakowski et al., 1992; Skubisz and Noga, 2023).

In the 'Imielty Ług' Reserve, research was carried out at two sites: in the 'Imielty Ług' Pond (site 3) and in a small unnamed stream that flows from this pond (site 4). The water in the pond was brown in color, and the banks of the pond were covered in places with mosses of the genus *Sphagnum*.

METHODS

The research material was collected in small water reservoirs in the Turzański Forest (2 sites) in 2023 in spring and autumn and in a forest pond (1 site) and in a small stream flowing out of the

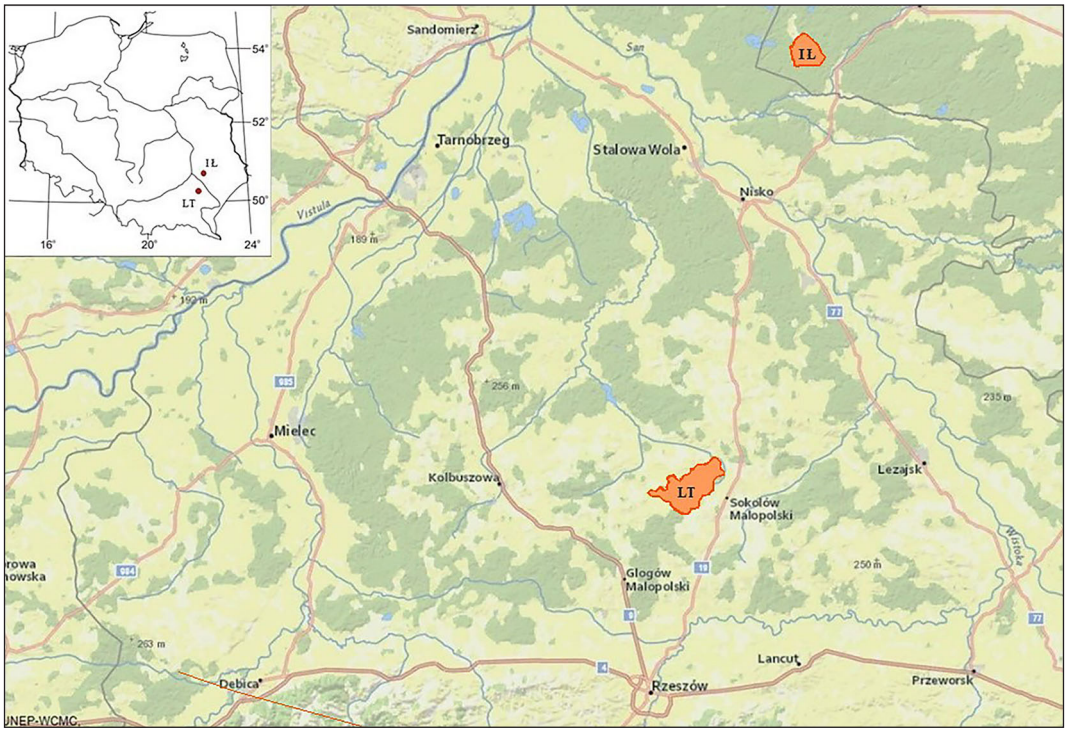

Figure 1. Location of the research area: IŁ – Imielty Ług, LT – Turzański Forest

pond (1 site) in the Janowskie Forests in 2023 and 2024, always in the spring season.

Water pH, temperature and electrolytic conductivity were measured directly in the field at all sites. Other analyses of selected water chemical parameters were performed in the laboratory of the University of Rzeszów, using a Thermoscientific DIONEX ICS-5000+DC ion chromatograph.

The collected material was processed in the laboratory according to the methods used by Kawecka (1980) and Noga et al. (2022) to remove protoplasts from cells and organic contaminants. Then, permanent microscopic slides were prepared and mounted in Pleurax synthetic resin.

The diatoms were identified using a Carl Zeiss Axio Imager A2 light microscope equipped with a Nomarski differential interference contrast (DIC) and a 1.4 planapochromatic objective lens at 1000× magnification. Diatom photographs were taken in LM with a Carl Zeiss AxioCam ICc 5 camera and in SEM (Hitachi SU 8010). SEM materials were sputtered with a 20 nm thick gold layer (Quorum Q 150OT ES sputter coater) and viewed at an accelerating voltage of 5 kW.

Diatoms were identified using the specialist literature: Hofmann et al. (2011), Lange Bertalot et al. (2011, 2017), Houk et al. (2017). Detailed characteristics of species new to Poland are presented in the Results and Discussion section. Morphometric data are presented based on 30 measured covers. If a species occurred in the sample rarely or very rarely, all covers in the preparation were measured. The number of counted covers is determined by the number n placed next to each described species.

Diatom counts were obtained by counting all diatom valves in randomly selected fields of view of the microscope slide until a total of at least 300 valves were obtained. The taxa whose percentage share in the sample exceeded 5% were considered dominant.

RESULTS AND DISCUSSION

Studies conducted in 2023 and 2024 in the 'Imielty Ług' nature reserve in the Janowskie Forests and in the Turzański Forest showed that the investigated waters of forest reservoirs were characterized by acidic or weakly acidic pH (4.0–6.4) and low electrolytic conductivity values (40–134 µS/cm). The values of other chemical parameters were low in most locations, often beyond the limit of quantification (especially ammonium nitrogen and phosphates in reservoirs in the Turzański Forest). The water in reservoirs in

the Turzański Forest (site 1 and 2) contained more SO_4^{2-} and Ca^{2+}, while in the 'Imielty Ług' pond in the Janowskie Forests (site 3) a relatively high concentration of PO_4^{3-} was recorded (Table 1).

Aulacoseira tenella (Nygaard) Simonsen (Figure 2: A–AE). Basionym – *Melosira tenella* Nygaard. Synonym – *Aulacoseira distans* var. *tenella* (Nygaard) Ros. Dimensions – diameter: 5.2–7.5 µm, mantle height: 3.0–4.0 µm (n=30). Ecology – the species occurs in acidic, humic lakes (Houk et al., 2017), prefers acidic waters with low trophicity (often oligotrophic) and low nutrient content. It shows a strong tendency to dominate in clean waters, where it can develop in large numbers both in summer and winter. Studies conducted in Chile have shown that it occurs more often in waters with low Si content (Siver and Kling, 1997; Bicudo et al., 2016). Studies conducted in France have shown that *Aulacoseira tenella* is a planktonic species, sensitive to organic pollution and occurring in weakly acidic habitats (Bey and Ector, 2013; Peeters and Ector, 2017). The species has also been found in Japanese lakes, in which the pH was close to neutral (6.2–6.5) and was observed most often in summer (Tuji, 2015). Distribution: The species is known from many locations in Europe, including: Great Britain (Whitton et al., 2003; Pentecost and Haworth, 2021), France (Bey and Ector, 2013; Peeters and Ector, 2017; Roubeix et al., 2021), the Netherlands (Veen et al., 2015; Mertens et al., 2025), and Skandinavia (Eloranta, 1986; Karlson et al., 2018). It is also reported from North America (Siver and Kling, 1997; Kociolek, 2005; Cheng et al., 2022; Griffiths et al., 2024), South America (Bicudo et al., 2016; Heinrich et al., 2019) and Asia – Japan (Tuji, 2015). Comments: *Aulacoseira tenella* was dominant at the sites in the Turzański Forest. It developed massively (81% in autumn and >16% in spring) at site 2 in the reservoir constituting the water intake point and very rarely (in the form of single covers) at site 1 – in a peat pit. It occurred relatively abundantly (<3%) at site 3 in the 'Imielty Ług' Pond in the Janowskie Forests (late spring in June) – however, it was not the dominant species there. Mass development of this species at site 2 was observed in September, at low water level, temperature below 10 °C, acidic pH (4.6) and electrolytic conductivity 134 µS/cm (Table 1). Apart from *A. tenella*, *Achnanthidium minutissimum* was also the dominant species, but its numbers were much lower (approx. 10%). In the spring period, i.e. in May 2023, the water level at site 2 was much higher (due to heavy rainfall in early spring), the water temperature was almost 15 °C, pH>6, while the

Table 1. The values of physicochemical parameters measured in water reservoirs in the Turzański Forest (sites 1 and 2) in 2023, in the 'Imielty Ług' pond (site 3), and in the stream flowing from the pond (site 4) in the Janowskie Forests in 2023 and 2024, along with the percentage of dominant species (T – temperature, C – conductivity)

Parameter	1	2	3	4
T [ºC]	8.9–14.2	9.7–14.7	20.5–24.0	20.0–21.5
pH	4.0–6.4	4.6–6.1	5.7–5.8	5.6
C [µS/cm]	56–102	50–134	40–48	21–43
Cl^- [mg/l]	3.35–4.89	5.32–6.22	2.51–3.87	3.60–3.80
SO_4^{2-} [mg/l]	10.95–10.99	24.93–26.31	2.84–5.96	1.28–5.90
PO_4^{3-} [mg/l]	<0.001	<0.001	3.39–3.45	<0.001
NO_2^- [mg/l]	<0.001	<0.001	<0.001	<0.001
NO_3^- [mg/l]	<0.001–1.98	2.21–2.62	1.89–1.93	1.84–2.07
NH_4^+ [mg/l]	0.06–0.29	0.05–0.06	0.05–0.11	0.04–0.11
Mg^{2+} [mg/l]	1.02–1.20	1.49–2.01	0.31–0.66	0.55–0.58
Ca^{2+} [mg/l]	6.14–8.08	6.14–6.37	2.91–3.72	3.26–4.48
Dominant taxa	*Eunotia sphagnicola* (10.4–92%) *Pinnularia* sp. (10%) *P. subcapitata* var. *elongata* (5.7–77.5%)	*Achnanthidium minutissimum* (10.3–19.3%) *Eunotia exigua* (11.3%) *Hantzschia calcifuga* (9%) *Nitzschia acidoclinata* (6%)	*Eunotia rhomboidea* (7.9%) *E. juettnere* (7%) *Fragilaria gracilis* (6–20%) *Tabellaria flocculosa* (34–41%) *T. fenestrata* (11–13%)	*Aulacoseira ambigua* (14.5–21.8%) *Staurosira venter* (28.6–29%) *Tabellaria flocculosa* (8–10.6%) *T. fenestrata* (11.9–17.8%)

electrolytic conductivity was much lower compared to the autumn season (50 µS/cm). *Aulacoseira tenella* also dominated in this season, but its share in the community was much lower (>16%). It was one of the five dominant taxa and the share of the most abundant dominant – *Achnanthidium minutissimum* – did not exceed 20% (Table 1). The water was characterized by a slightly brown color, clearly darker in autumn, at low water levels. The observations above are consistent with the information provided by Houk et al. (2017), who described *A. tenella* as a species occurring in acidic, humid lakes. It is also worth emphasizing that the diameter of cells identified at sites 2 and 3 was clearly larger (5.2–7.5 µm), compared to the dimensions reported in the literature: 5.1–5.9 µm (Houk et al., 2017). The information above, i.e. mass development in the diatom community and larger dimensions compared to those presented in the literature, indicate that *A. tenella* finds favorable conditions for development in forest water reservoirs in southeastern Poland.

Eunotia gallica Lange-Bertalot & Witkowski (Figure 3: A–H). Dimensions – length: 125.3–157.9 µm, width: 4.3–5.0 µm, 13–17 striae 10 µm (n=5). Ecology – the ecology of the species is

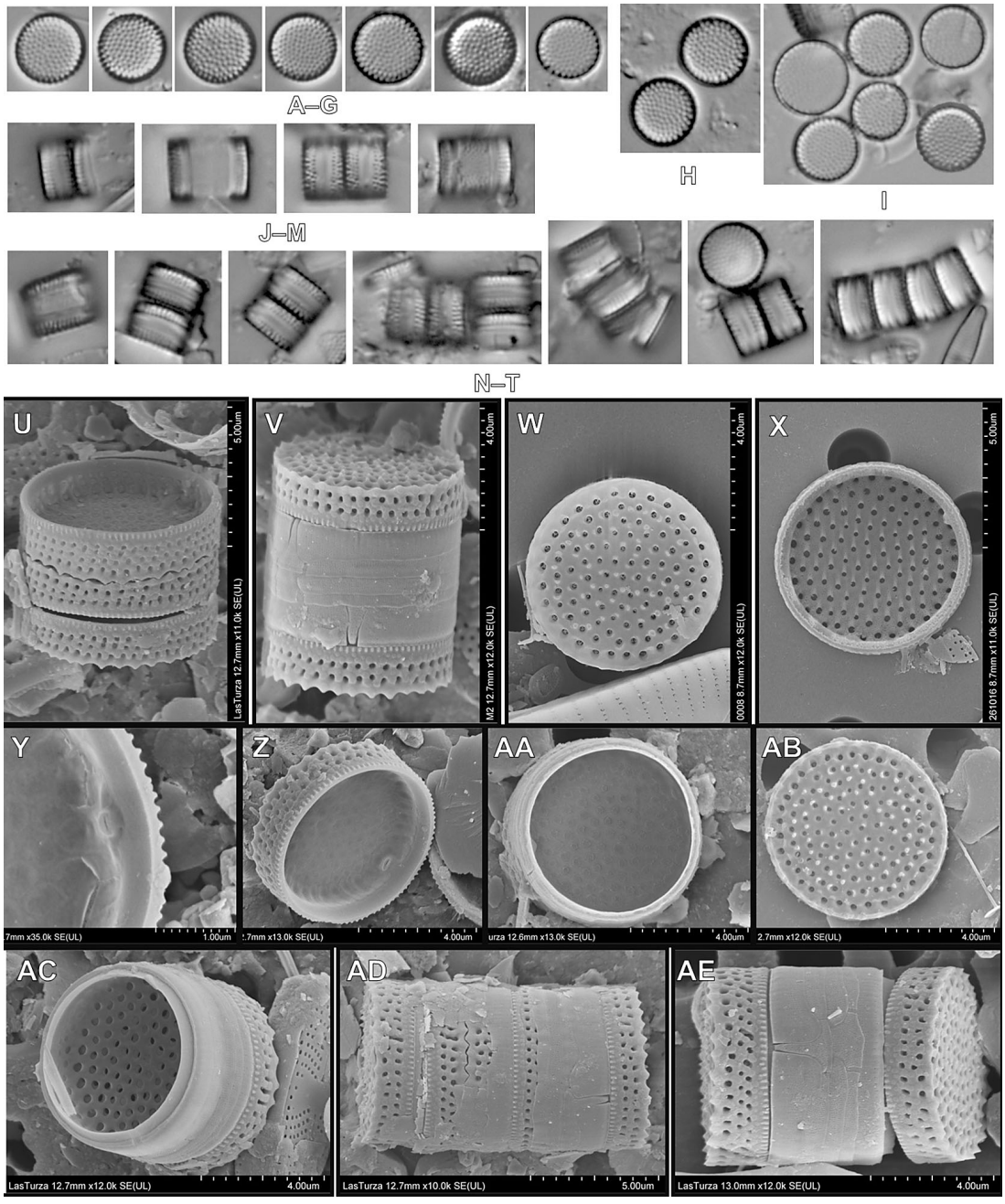

Figure 2. *Aulacoseira tenella* (A–AE): valve view in LM (A–I), girdle view in LM (J–T), SEM images (U–AE)

unclear and poorly known. It has been recorded at an altitude of about 2000 m a.s.l. in the Pyrenees Mountains, in small pools of *Sphagnum* (Lange-Bertalot et al. 2011). Distribution: *Eunotia galica* was described from the eastern Pyrenees, France, and was also recorded in NW France (Calvados) by Lange-Bertalot et al. (2011). The authors consider the occurrence of this species to be uncertain, it is also observed in other places in Europe, but they do not specify where (Lange-Bertalot et al. 2011). Comments – *Eunotia galica* occurred very rarely in the study area – only at site 3 in the 'Imielty Ług', in the Janowskie Forests. Only 1 valve was found in June 2023 and 4 valves in May 2024 in the material collected at the shore of the pond, between mosses of the *Sphagnum* genus. On the basis of the conducted research, little can be said about the ecology and occurrence of this species, as the species occurred sporadically in the material. It is worth emphasizing that in

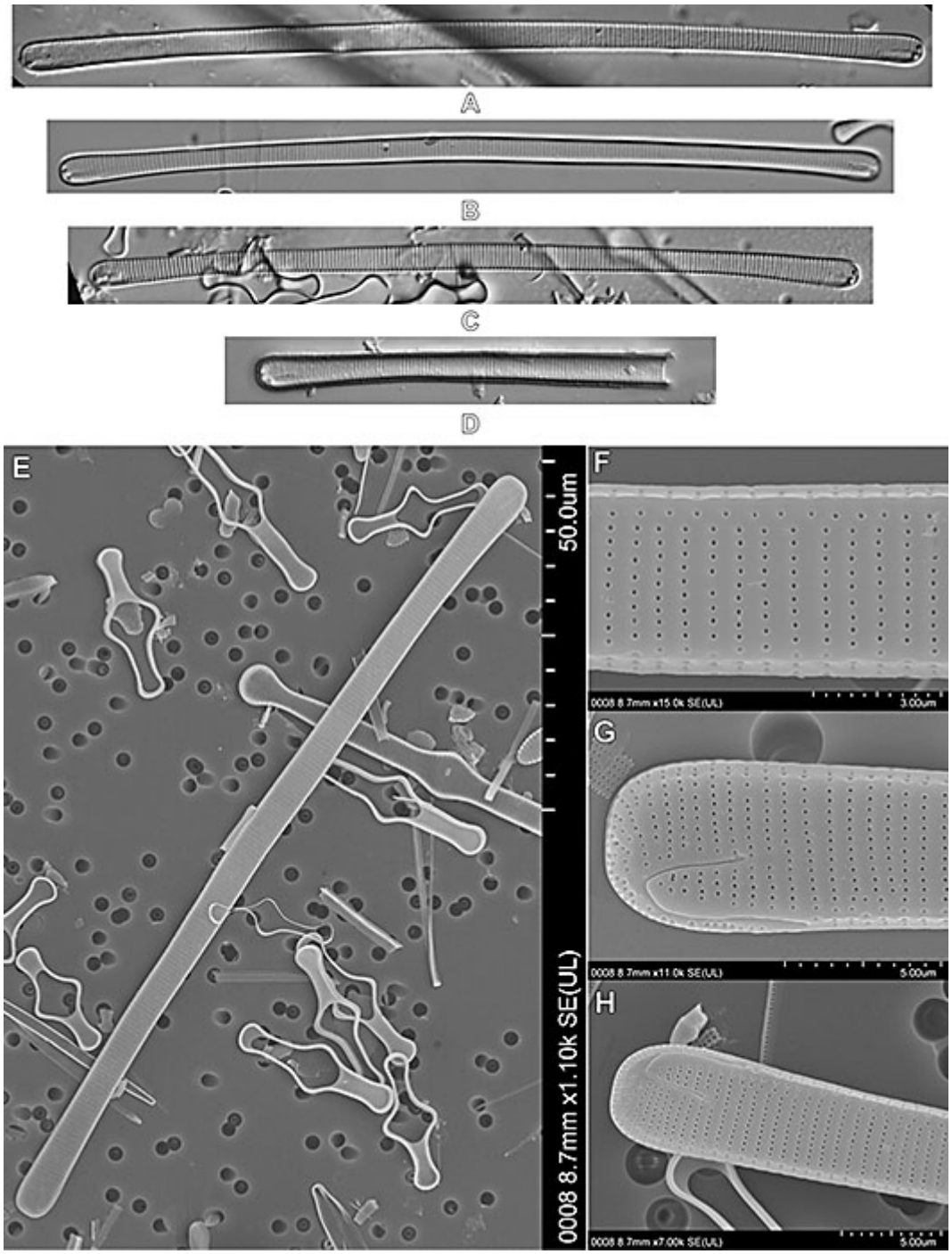

Figure 3. *Eunotia galica* (A–H): valve view in LM (A–D), SEM images (E–H), raphe end (G, H)

the material collected at the shore of the lake, from a sandy habitat, no valves of *Eunotia galica* were found at all. Single valves were identified only in the material squeezed out from between *Sphagnum* mosses. Also in France, this species was found in puddles with *Sphagnum* (Lange-Bertalot et al., 2011).

Pinnularia subfalaiseana Krammer (Figure 4: A–K). Dimensions – length 42.6–55.5 µm, width 8.8–11.2 µm, 11–13 striae in 10 µm (n=10). Ecology – rare species, prefer oligotrophic waters (Krammer, 2000). Distribution – *Pinnularia subfalaiseana* has been described from west Germany, from the Eifel and Venn regions (Krammer, 2000). It is a species known from a very small number of localities, apart from Germany it is reported only from the Netherlands (Veen et al., 2015; Mertens et al., 2025) and Scandinavia (Karlason et al., 2018). Comments – in the study area, *P. subfalaiseana* occurred very rarely, always in the form of single specimens at site 2 in the Turzański Forest and at site 4, in a small, unnamed stream flowing out of the pond of 'Imielty Ług' in the Janowskie Forests.

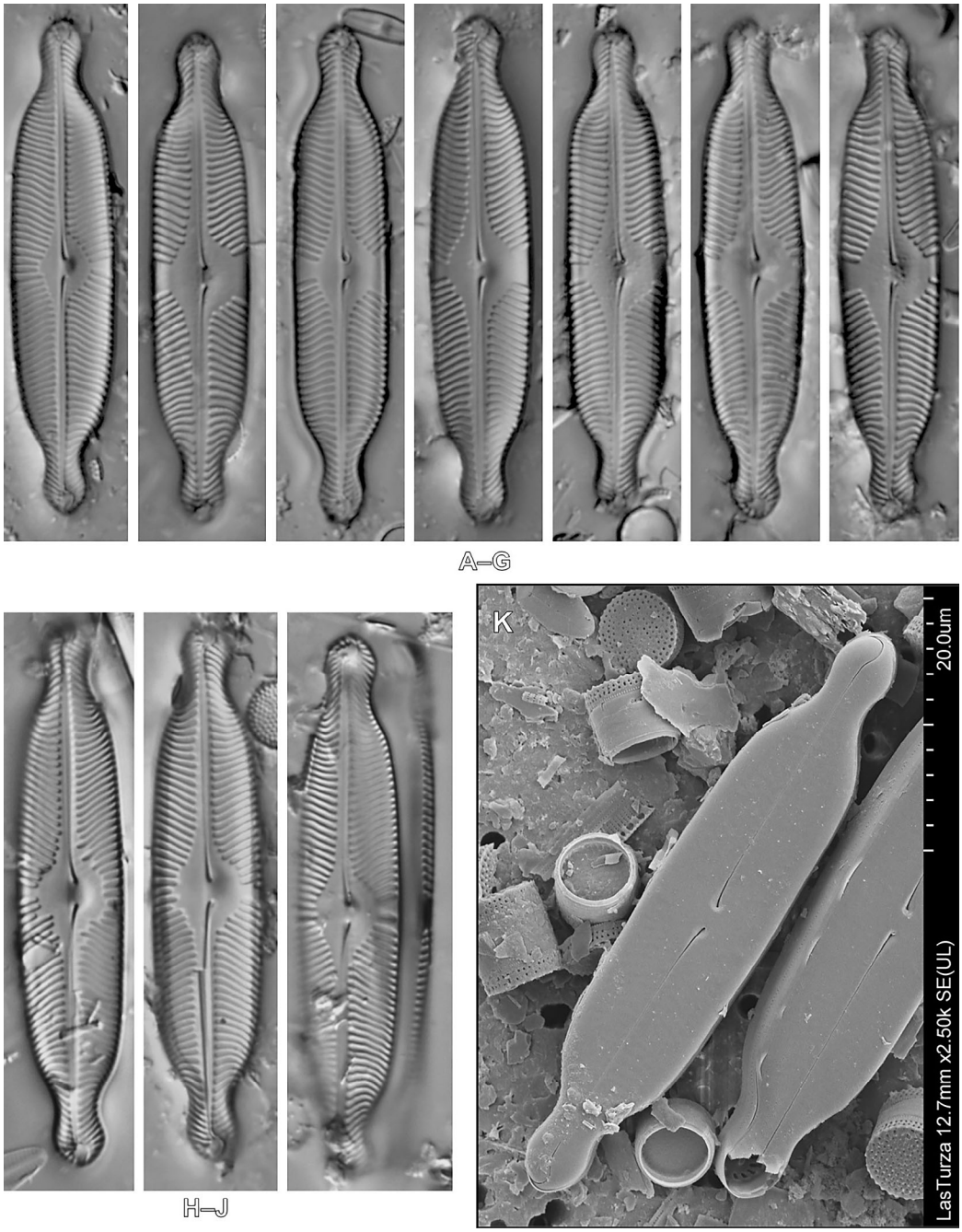

Figure 4. *Pinnularia subfalaiseana* (A–K): valve view in LM (A–J), SEM image (K)

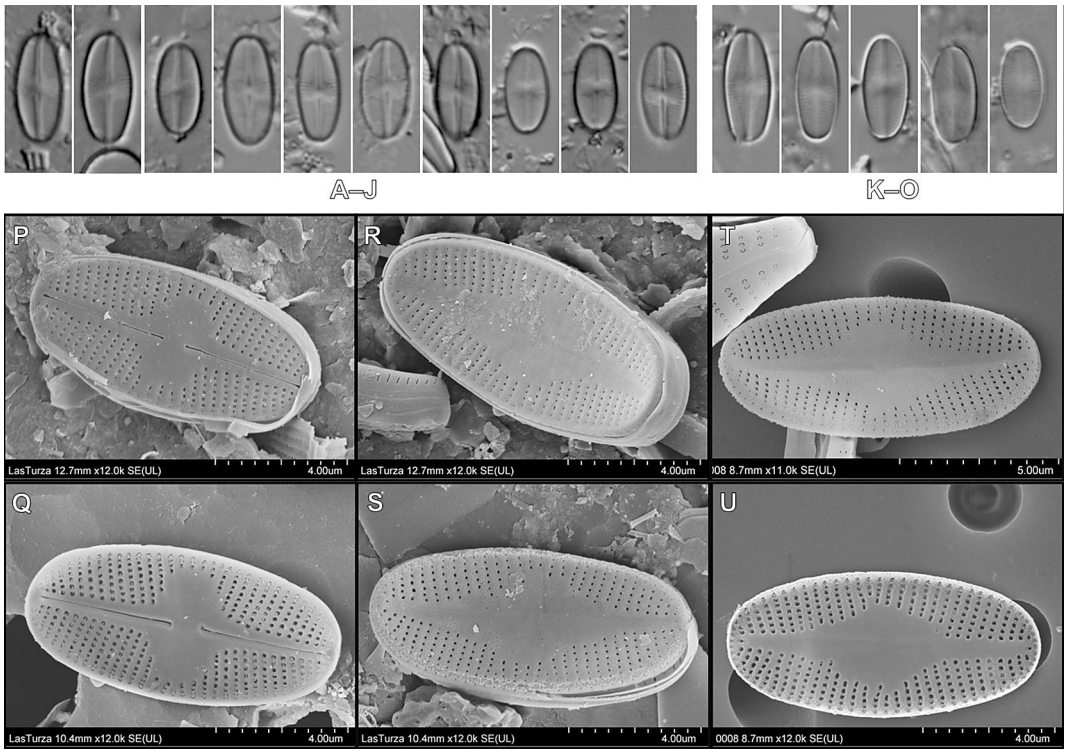

Figure 5. *Psammothidium scoticum* (A–U): valve view with a raphe in LM (A–J), valve view without a raphe in LM (K–O), SEM images (P–U): external view of the raphe valve (P), internal view of the raphe valve (Q), external view of the rapheless valve (R–T), internal view of the rapheless valve (U).

Psammothidium scoticum (Flower & Jones) Bukhtiyarova & Round (Figure 5: A–U). Basionym – *Achnanthes scotica* Flower & Jones. Dimensions – length 8.5–10.7 µm, width 4.2–4.9 µm, 26–28 striae in 10 µm (n=30). Ecology – the species occurs relatively rarely as a dispersed species in oligotrophic, electrolyte-poor and weakly acidic water bodies in the Alps and low mountain ranges (Krammer and Lange-Bertalot, 1991). It has also been found in core sediments from study lakes in the USA, where it was one of the most numerous (22%) dominant species (Enache et al., 2013). It developed very abundantly in mountain lakes in the Retezat Mts., reaching a maximum abundance of 70% (Buczkó, 2016). Distribution – *Psammothidium scoticum* is most often reported from various regions of Europe, including Germany (Ludwig and Schnittler, 1996; Hofmann et al., 2018; Doege et al., 2022), the Netherlands (Veen et al., 2015), Britain and Ireland (Whitton et al., 2003), Scandinavia (Lange-Bertalot and Metzeltin, 1996; Karlason et al., 2018), Belgium (Denys, 2009), Romania (Buczkó, 2016) and from the Arctic areas (Genkal and Vekhov, 2007; Barinova et al., 2023a,b). It is also known from North America (Bahls, 2009; Potapova, 2010; Enache et al., 2013; Bishop et al., 2018) and Asia (Medvedeva and Nikulina, 2014; Potapova, 2014; Luo et al., 2024). Comments – *Psammothidium scoticum* developed single (<1% share in the community) both in the reservoir constituting the water intake point in the Turzański Forest (site 2), and in the pond of the 'Imielty Ług' (site 3) and in the stream flowing out of it (site 4) in the Janowskie Forests.

CONCLUSIONS

Studies carried out in forest water reservoirs (peat pits, ponds and streams flowing from them) have shown that such places are habitats of diatoms new to Poland, often known only from a few locations in Europe, such as *Eunotia galica* and *Pinnularia subfalaiseana* which have found favorable conditions for development in forest water reservoirs in southeastern Poland. *Psammothidium scoticum* occurred in all the studied locations, but only as single specimens. The study confirmed that it is a species of oligotrophic waters with low electrolyte content or do

not have a clearly defined ecology, such as *E. galica*. This study, concerning the occurrence of new diatoms in Poland, confirms the information contained in the literature on ecology, and their occurrence (usually in the form of single specimens) indicates that they deserve the rank of rare species. They should probably be placed in the category of endangered due to their occurrence in unusual habitats, which are currently decreasing in number and are threatened, among others, by drying out. However, if they develop in large numbers, such as *Aulacoseira tenella*, then they can be omitted when identifying them due to their small size or similarity to other taxa with which they co-occur. Moreover, specific habitats such as forest water reservoirs remain poorly researched, especially in south-eastern Poland.

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