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Abstract: During an interdisciplinary study of the mire "Pod Małym Śnieżnikiem", a very old specimen of the Norway spruce (*Picea abies* L.) was encountered. The aim of the present work was to perform a detailed examination of this tree, to compare it to other spruce trees on the mire, and to provide support for establishing protection for this tree stand. Tree-ring cores were sampled at 1.3 m above ground using Pressler borer, in two field campaigns: in June and July 2023, the latter campaign aiming to find the oldest trees. A total of 46 trees were sampled, yielding 84 measuring radii. Tree ring widths were measured down to 0.01 mm under a stereomicroscope. The oldest sampled tree yielded a total of 370 tree rings in the two radii, representing the period 1653–2022. The average tree ring width for TM15 equals 0.33 mm/year, and shows low values (on average 0.19 mm/year) for the period 1742–1943, i.e., during the Little Ice Age cooling. TM15 does not stand out from other trees from the population with respect to height or trunk diameter. A comparison of the age of this tree to the oldest spruce trees in Poland indicates that it is one of the longest living specimens of this species. Considering the natural character of the stand, the remaining flora and the peat-forming processes taking place within the mire "Pod Małym Śnieżnikiem", we argue that the mire should become protected by the law as soon as possible in order to preserve this valuable high-mountain habitat.

Keywords: Norway spruce (*Picea abies* L.), tree-ring width; age of the tree; mountain peat bog; Sudetes mountains; Śnieżnik Massif

1. Introduction

In 2022 and 2023, geological/geobotanical and chronostratigraphic studies were undertaken to reconstruct the development of selected ombrogenic peat bogs and transitional mires located within the Śnieżnik Massif in the Eastern Sudetes. The goal of the first phase of this research was to determine the origin of the studied mires, and to identify the onset of their development, based on radiocarbon dating of the base of organic matter resting on a mineral substratum. Reconstructions of paleoclimatic and paleoenvironmental changes based on the sampled peat bog profiles are also planned, especially with regard to human impact. In 2023, the scope of research was expanded to include a dendrochronological examination of trees growing within and adjacent to the mires, in order to gain insight into the age of the tree stands, and to reconstruct climatic and environmental changes taking place in recent years, also because of unfavourable changes taking place from the onset of forest exploitation in this area to the present day. The research is conducted in collaboration with scientists from the Czech Republic, and covers the entire Śnieżnik Massif. To date, the team has taken and examined peat profiles with thicknesses ranging from 40 to 180 cm, acquired GPR and gouge auger profiles, and collected water samples from the mires. Also, phytosociological relevés were taken, and an analysis of modern flora was performed. Four radiocarbon dates were obtained from the nearby mire "Sadzonki". The oldest one, from the base (1745 ± 30 BP, Poz-163144) indicates that the onset of peat sedentation was associated with the first significant climate cooling of the AD era, correlated with the fall of the Roman Empire, freezing of the Black Sea and the Nile [1,2]. Subsequent dates are: 1490 ± 30 BP (Poz-163144) – from 130 cm below ground level; and 1405 ± 30 BP (Poz-162794) – obtained from 126 cm below ground level. These datums indicate a clear change in biogenic sedimentation *sensu lato* and paleoenvironmental coinditions, and 102.55 ± 0.3 BP (Poz-163141) at 6 cm below ground level. For the mire „Torfowisko pod Małym Śnieżnikiem", the onset of peat accumulation is dated at 1150 ± 30 BP (GdA-7493) – at about 60 cm below ground level. The following datums were obtained at 40 cm below ground level: 320 ± 35 BP (GdA-7490.2) and 550 ± 35 BP (GdA-7490.1). At 20 cm below ground level, within the uppermost layer of peat, an age of 135 ± 25 BP (GdA-7491) was obtained (Figure 2). These datums unambiguously show a relatively young age of the mires located within the Śnieżnik Massif, relative to other mires in the Sudetes [3]. Further radiocarbon dating is planned for future phases of the study, in order to refine the chronology for the remaining mires. Also detailed geochemical, isotopic, paleobotanical and palynological analyses are planned, in order to obtain data for reconstructing paleoclimatic and paleoenvironmental changes, especially in the context of the ongoing discussion on whether distinguishing the Anthropocene as a new chronostratigraphic/geochronological unit is justified [4].

During fieldwork and sample collection from spruce trees growing at the mire "Pod Małym Śnieżnikiem", a very old specimen was encountered that became the subject of the present paper. This study aims to: (i) identify, describe and perform a dendrochronological dating of the oldest tree, (ii) compare the oldest tree to the other trees from the studied population, (iii) provide justification for the attempts to expand the existing nature reserve "Śnieżnik Kłodzki", to cover – among others – also the area of the mire.

2. Materials and Methods

2.1. Study Area

The Śnieżnik Massif, with its highest peak, 1,425 m a.s.l., is located in the eastern part of the Sudetes, a mountain range running along the border of southwestern Poland and the northeastern part of the Czech Republic. It forms one of the highest parts of the Sudetes, distinguished by its partial elevation above the upper forest line. The massif is formed by several flattened ridges, separated by deep valleys, radiating from the centrally located Śnieżnik peak. The massif has a meridional extent of approximately 20 km and a latitudinal extent of approximately 30 km. Human activity has made a significant impact on the local ecosystem [5], for instance by deforestation (for the needs of agriculture and grazing), local industry, and mining in the nearby areas of the Sudetes. It lasted at least since the late Middle Ages when most Sudeten villages existed. Human impact has peaked in the mid-19th century, with the maximum population in the area. An "open landscape" was developed with settlements, arable fields and pastures reaching 800 and locally up to 1,000 m above sea level [6]. Settlement pressure and overpopulation decreased from the end of the 19th century [7]. Another process of deep depopulation took place after World War II when a complete population exchange took place in this area. The research area is a small mire, called "Pod Małym Śnieżnikiem" (50º11′47″N, 16º49′17″E). The mire covers a flat summit surface, located at an altitude of ~1,245 m a.s.l, approximately 600 m ENE from the culmination of Mt Mały Śnieżnik (1,326 m). The mire is situated in the basin of the Nysa Kłodzka, which flows into the Odra River. Still, it is very close to the European watershed and the catchment area of the Morawa River, a tributary to the Danube. The development of the mire was favoured by the local climate, relatively cold and humid. Just 100 years ago (1851–1930), the average annual temperature at Mt Śnieżnik was 2.4°C [8]. Today, no direct meteorological measurements are carried out at this site, but these values are likely to have increased significantly, considering the regional warming trend of 0.3–0.4°C per decade [9]. The average rainfall sum is 1182 mm. The duration of snow cover decreases from year to year. Mountain ridges are also affected by strong winds [10].

The studied tree, and the upper mountain spruce forest, are located within the Śnieżnik Landscape Park, and the Natura 2000 protected area PLH020016 "Góry Bialskie i Grupa Śnieżnika". This area belongs to the Forest Inspectorate Międzylesie, Forest District Jawornica, division 251b. Along with its surrounding, this area is distinguished by the occurrence of valuable plant assemblages, unique fauna, and springs. For this reason, the Międzylesie Forest Inspectorate is lobbying for the inclusion of the discussed area into the Nature Reserve "Śnieżnik Kłodzki". As part of the FSC certification, the stand is included in the representative tree stand list, and no planned forestry is performed within its limits.

2.2. Geology and Geomorphology

The research area is located within the Sudetic Block, in the eastern part of the Orlica-Śnieżnik Dome (OSD), a geological unit representing a gneiss dome surrounded by Neoproterozoic and Late Cambrian–Ordovician supracrustal metasedimentary rocks of the Stronie Formation [11,12]. During the Late Cretaceous, recurrent marine transgressions resulted in the formation of a >3 km thick sedimentary cover, subsequently removed during the Late Cretaceous-Cenozoic tectonic exhumation [13]. Late Cretaceous-Cenozoic tectonic activity resulted in bedrock jointing and faulting under compressional WNW–ESE conditions [14]. During the Paleogene, after the tectonic movements ceased, a regional peneplaine evolved, characterised by a generally flat and hilly landscape. Since the mid-Miocene (15±1.5 Ma) the Sudetes area has been gradually uplifted, resulting in mountainous topography (formation typical for the Śnieżnik Massif [15].

The bedrock outcrops in the peat bog area are represented by laminated gneiss and aplite, mica schist, paragneiss, graphite schist, and quartzite [16] (Figure 1). The study area „Pod Małym Śnieżnikiem" mire was formed on the paragneiss and biotite schist outcrops of the Stronie Formation, within a flattened broad ridge spur (Figure 1d).

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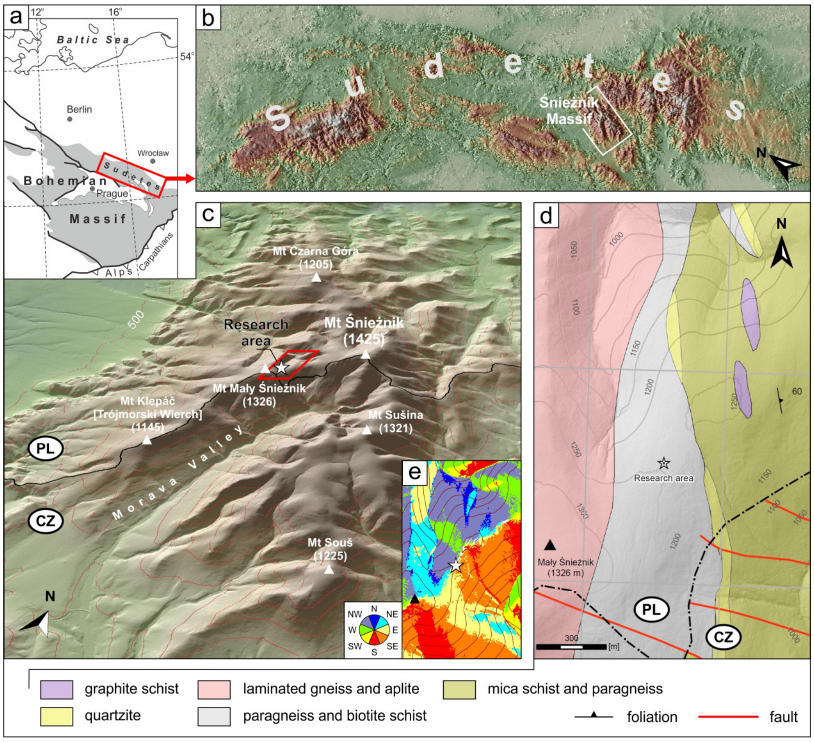

Figure 1. Research area: a – the Sudetes as part of the Bohemian Massif; b – location of the Śnieżnik Massif among other massifs of the Sudetes; c – topography of the Śnieżnik Massif (the area shown on maps d and e is marked with a frame); d – geology of the research site (modified from Don et al. [16]); e – aspect map.

The slopes of the Śnieżnik Massif are covered with a coarse-grained weathering mantle resulting from processes operating under periglacial conditions, traditionally linked with the Pleistocene epoch [17–20]. There are numerous gneiss bedrock outcrops, and blockfields are common, whereas on the highest peaks above the tree line, affected by winter snow blown in near-surface frost, segregation occurs, resulting in structural ground formation [21]. Despite the proximity (ca. 20-30 km) of the Scandinavian Ice Sheet (SIS) during the Elsterian (MIS 12) and Saalian (MIS 8) continental glaciations, there is no clear evidence that mountain glaciers have developed in any of the valleys of the Śnieżnik Massif [22].

At the top, but also in the middle of the slope, there are numerous flattened areas that favoured the formation of peat bogs. The maximum observed thickness of peat covers at the pass below the Mały Śnieżnik peak is lower than 75 cm, and most frequently reaches about 50-60 cm. The contact between the peat deposit and the bedrock is rugged, which is typical of mires in the Sudetes [23]. The reason for this is that the peat rests on highly compacted sediments composed of clay and debris, and locally on blockfields composed of gneiss or schist boulders, which are likely relics of periglacial climatic activity of the Vistulian period [17–19]. The peat layer, resting directly on clay and debris, is composed of strongly decomposed peat, usually of dark brown colour. Gravel, sand, or silt-sized mineral grains, with a high mica proportion (Figure 2), are relatively common within this layer. At the deepest points of the mire, the brown peat is covered by Eriophorum peat, usually very poorly decomposed, up to 30 cm thick (Figure 2). A significant proportion of mineral admixture (often exceeding 20% of dry mass) in strongly decomposed peat may be associated both with the occurrence and decomposition of fallen trees within the mire, and with animal activity (moles, rodents) living in the past within the developing peat soil. The impact of human economic activity, associated with logging, sheep grazing and exploiting metallic resources, also cannot be ruled out. According to Madeyska [24], logging for the construction of settlements or to fuel melting furnaces is reflected in the pollen spectra of pollen-poor plants indicative of human activity. This suggests that trees were not being burned out for agriculture or pastures. The cover of poorly decomposed or not decomposed

Eriophorum peat indicates a change in water relationships within the mire "Pod Małym Śnieżnikiem".

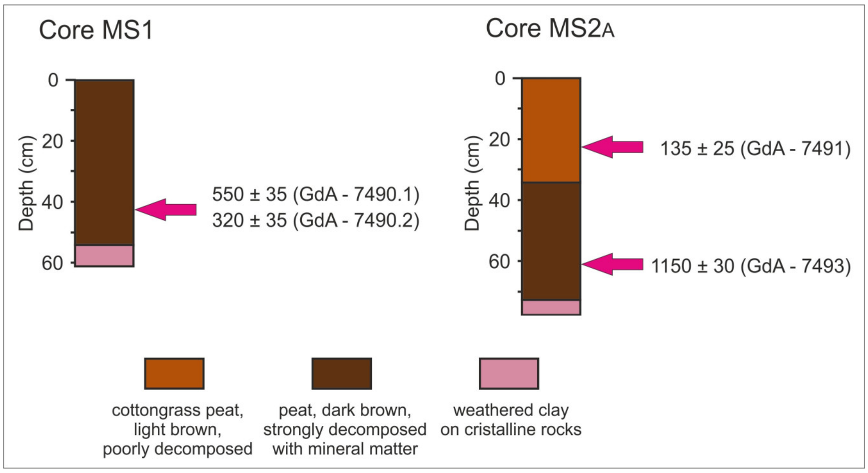

Figure 2. Peat profiles from the "Pod Małym Śnieżnikiem" peat bog. MS1 – peat profile from the lower part of the peat bog; MS2A – peat profile from the top part of the peat bog.

2.3. Plant Cover

The highest parts of the Śnieżnik Massif are covered with a spruce forest of the upper mountain forest zone. The moderately thick stand of such spruce forest is composed exclusively of the Norway spruce (*Picea abies*). These trees are distinctive due to the rather frequent occurrence of many tops caused by abiotic damage, mainly caused by wind and snow caps. A biotic factors also influence the formation of deadwood in the stand, predominantly the feeding of the European spruce bark beetle (*Ips typographus*). Regardless of these, the stand displays relative stability and has high regenerative capacity. Gaps left by fallen and dead trees display the process of natural succession, as evidenced by the formation of spruce biogroups, characteristic of the upper mountain forest zone.

With respect to phytosociology, two assemblages occur at the study site. *Camagrostio villosae-Piceetum typicum* (R. Tx. 1937) Hartm. ex. Schlüter 1936, a typical community of upper mountain Sudetic spruce forest [25] (syn. *Camagrostio villosae-Piceetum abietis* Schlüter 1966 [26] is formed on fresh or moderately humid soils. *Camagrostio villosae-Piceetum sphagnetosum*, a bog subcommunity of the upper mountain Sudetic spruce forest grows in places with obstructed drainage, and around water-filled depressions [25,27]. In such places, the substratum is extremely acidic (pH around 4.00), oligotrophic and fed mostly by rainfall. The upper mountain Sudetic spruce forest is distinguished by a grassy-shrubby undergrowth with the dominant European blueberry *Vaccinium myrtillus* L. and the hairy small-reed *Calamagrostis villosa* (Chaix) J. F. Gmel., which are accompanied by the lingonberry and the Arctic starflower. The bog upper mountain Sudetic spruce forest occupies more humid habitats compared to the former. A flora characteristic for ombrogenic peat bogs, dominated by Sphagnum mosses, especially the Girgensohn's Bog-moss *Sphagnum girgensohnii* and the Russow's Bog-moss *Sphagnum russowii*, accompanied by vascular plants typical for ombrotrophic habitats, such as the cranberry *Vaccinium oxycoccos* L., the bog rosemary *Andromeda polifolia* L., and the Hare-Tail Cotton-Grass *Eriophorum vaginatum* L., develops on hummock above stagnant water. Plant communities characteristic for transitional mires, mainly poor fens, with sedges typical for transitional mires, e.g., the silvery sedge *Carex canescens* L. and the common haircap *Polytrichum commune* Hedw., develop around local depressions filled with water (Figure 3).

Figure 3. A – Sampling in the "Pod Małym Śnieżnikiem" peat bog; B – one of the authors under the TM15 spruce, C – group of trees in which the TM15 spruce grows (in the centre of the photo); D – Camagrostio villosae-Piceetum sphagnetosum bog subcommunity (in the foreground) within the Camagrostio villosae-Piceetum typicum complex, a typical community (in the background).

2.4. Methods

Fieldwork was performed in two campaigns in 2023: in early June and late July. During the first campaign, 50 measuring radii were collected from 25 trees. During the second campaign, fieldwork aimed to find and sample the oldest trees. Samples were collected from 21 trees, yielding 34 measuring radii. In total, samples were collected from 46 trees (yielding 84 measuring radii), and widths of 12 609 tree rings were measured. Due to the ongoing cambial activity season, the last year included in the measurements was the year 2022. Samples were collected using a 40 cm long Pressler borer, from 130 cm above the mire surface (at breast height) (Figure 3A). Trunk diameter at breast height (DBH) and tree height (using a Suunto altimeter) were also measured, and photographic documentation was performed. In the laboratory, samples were glued onto specially prepared wooden boards. Once dry, the samples were sliced using a preparation knife, and the sample surface was smeared with chalk in order to enhance tree ring boundaries. Tree ring widths were measured

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under a binocular microscope on a mobile stage connected to a counter, down to 0.01 mm accuracy, using LDB_Measure (ver. 1.0) software [28].

3. Results

Tree ring width measurements from sample TM15 yielded 370 tree rings in the radius r1 and 370 tree rings in the radius r2 (counting from the same tree ring adjacent to the pith, to the bark). Thus, the sequence can be dated to the period 1653–2022 (Figure 3B, C). The spruce from which the sample originated is growing at an altitude of 1251 m above sea level in the central part of the mire "Pod Małym Śnieżnikiem" (50.1960601N, 16.8212750E). It is 14.5 m high, and its DBH equals 31 cm. The roots of the tree are entirely concealed in a layer of peat. The trunk is singular, straight, and displays no damage, necrosis, or cavities. The tree has one top, in the lower part there is subordinate deadwood (originating from the natural process by which higher branches and crowns of neighbouring trees cast shadow on the lower branches). The static of the tree is good, the spruce is sheltered from the wind by other trees, and its health is assessed as good. The structure, general appearance and size of the tree do not differ from the other spruce trees growing in its immediate surroundings.

The average tree ring width of the TM15 spruce equaled 0.34 mm/year for the radius r1, and 0.31 mm/year for the radius r2 (on average 0.33 mm/year for TM15). Numerous tree rings are very narrow, i.e., 0.06 mm (3–4 rows of cells), and the widest tree rings reach 1.38 mm/year for r1 and 0.93 mm/year for r2. The period 1653-1771 displays rather variable tree ring widths. On several occasions tree ring widths exceed 0.8 mm/year (on average 0.44 mm/year) (Figure 4). From 1742 to 1943, the studied tree TM15 has very narrow tree rings – on average 0.19 mm/year and there is little variability in tree ring width (below 0.5 mm) (Figures 4 and 5). In the period 1944–2023, the tree ring width increases again to an average of 0.54 mm/year, and displays strong variability. An increasing trend in tree ring width is observed in the period 1944–1975, and a decreasing trend in tree ring width is observed in the period 1976–2023. The variability in cumulative tree ring width can also be subdivided into three periods: the first measured 80 years of the tree life – a significant increase in cumulative growth; the period from the mid-18th century to the mid-20th century – a small inclination of the cumulative growth curve, i.e., small growth of trunk diameter and narrow tree ring widths; from the mid-20th century to the present – an increase in cumulative growth (Figure 4).

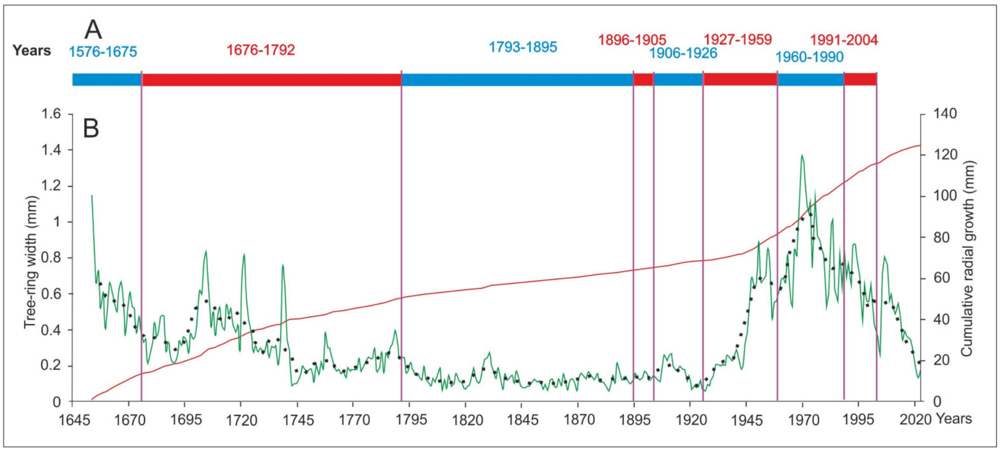

Figure 4. A – warm (red) and cold (blue) periods in the Tatra Mountains (according to Niedźwiedź [29]); B – dendrochronological sequence (green line) of the spruce TM15, 11-year moving average (black dots), cumulative radial growth (red line).

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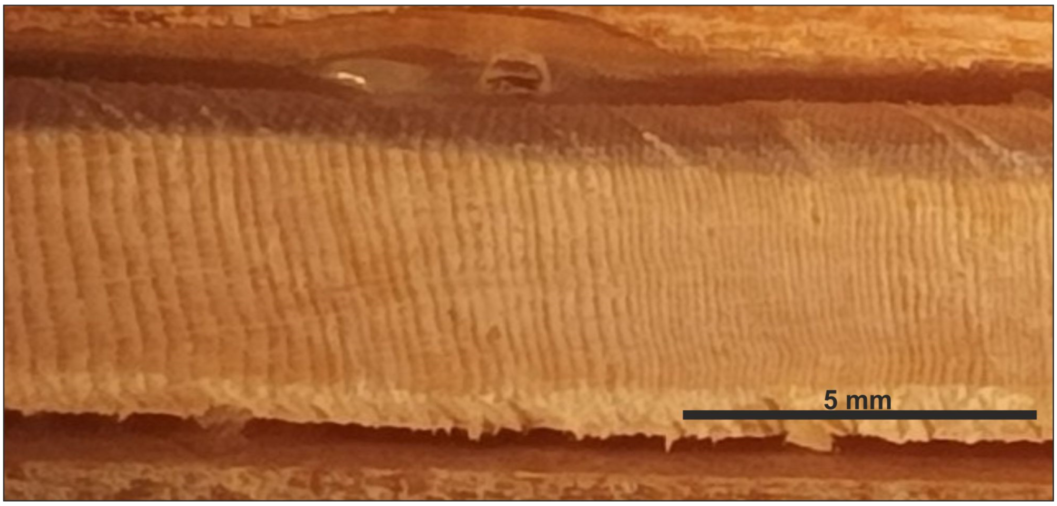

Figure 5. Tree rings from the period of the strongest reductions in the 19th century.

The spruce code-named TM15 differs from the other trees occurring at the "Pod Małym Śnieżnikiem" mire with respect to age (Figure 6). In the first sampling campaign (June 2023), the next longest obtained sequence comes from the tree code-named TM9 and spans "only" 182 years. The next longest sequences span 181 and 170 years. Most of the sequences obtained during the first field campaign have less than 125 tree rings. In August 2023, the research team was looking for the oldest trees on the mire. Specimens with high DBH and distinctive structure were targeted. Nine of the obtained sequences were longer than 182 years (209, 211, 226, 254, 247, 248, 254, 273 and 279 years). None of the studied trees, however, were as old as TM15. The age structure of the spruce stand indicates natural processes of inhabiting the mire by trees, and the lack of planned exploitation in this area over the span of the last four centuries.

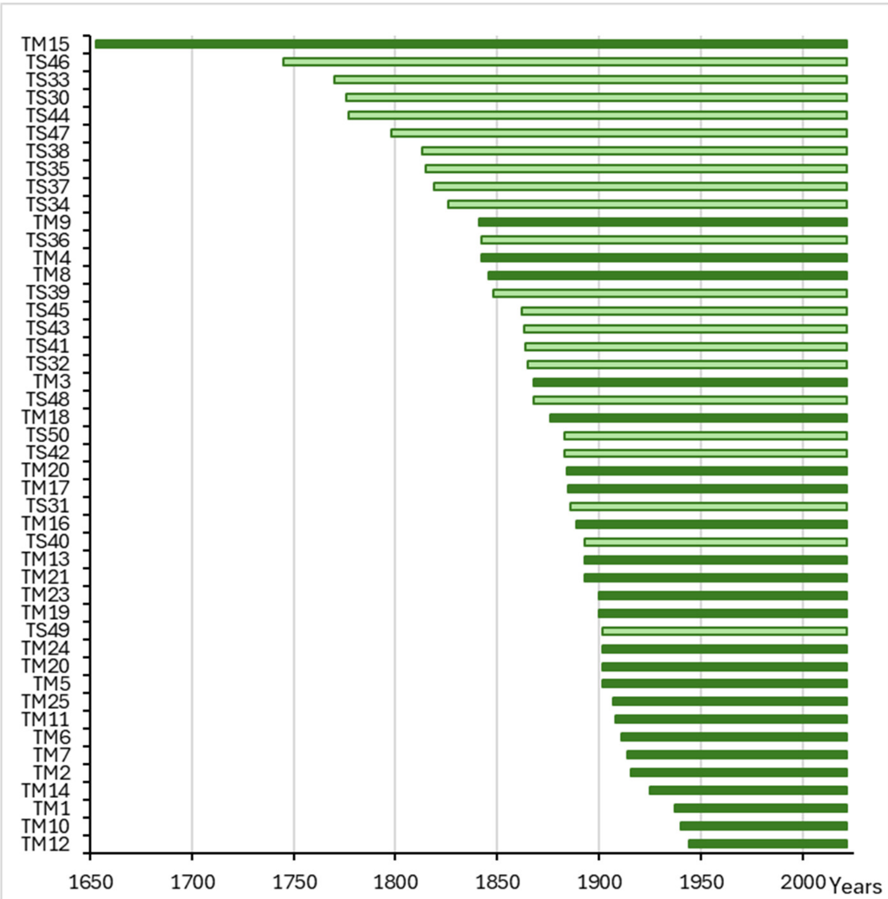

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Figure 6. Dendrochronological dating of growth sequences obtained from trees from the "Pod Małym Śnieżnikiem" mire. Dark green samples taken in June 2023, light green samples taken in July 2023.

Apart from the age, the tree TM15 does not differ from the adjacent trees and the entire spruce population on the mire neither in structure nor height nor DBH. The group of trees that include the TM15 spruce range in height from 14 to 16 m (TM15 is 14.5 m tall). The DBH values in this group equal 31, 31, 31 (TM15), 32 and 29 cm, and the obtained sequences' lengths are 130, 98, 370 (TM15), 134 and 142 years. DBH for the studied population equals on average 32.5 cm (minimum 18 cm, maximum 52 cm), and for TM15 – 31 cm. The population displays a relationship between DBH and tree age (the older the tree the higher the DBH), with TM15 being the only outlier (Figure 7).

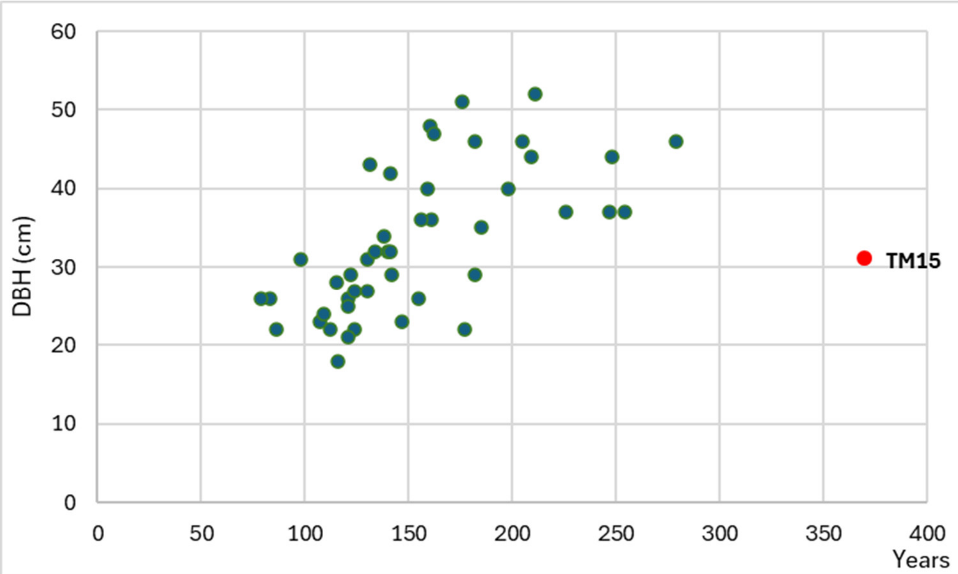

Figure 7. Diameter at breast height (DBH, in cm) versus the number of measured tree-rings.

4. Discussion

The highest native tree in Europe is the Norway spruce growing in Slovenia, which is 62.7 m high [30]. Until recently, a spruce growing in the Beskid Żywiecki range (51.8 m high) and a spruce growing in the Białowieża Forest (50.60 m high) were considered to be the two tallest spruce trees in Poland. The former was at the same time considered to be the highest native tree in Poland. In 2021, an airborne laser scanning survey showed that a 55.07 m high spruce growing in the Forest Inspectorate Bardo Śląskie (in the Sudetes) was the highest tree in Poland [31]. The spruce, which was named Antoni, grows in close proximity (about 600 m to the south) to the highest tree in Poland, a 59.40 m Douglas fir [32]. The height of the TM15 spruce examined here is only 14.5 m and thus it is not a distinguishing feature of the tree.

A spruce growing in the Białowieża National Park (NE Poland) is considered the thickest spruce in Poland. Its circumference is 4.84 m, which results in a 1.54 DBH [31]. European spruce trees with a circumference exceeding 3 m, i.e., DBH close to 1 m, grow in many sites in Poland [33,34]. The DBH of the tree TM15 equals 31 cm, which translates into a 97 cm trunk circumference. Thus, also this feature does not distinguish this tree from the thickest spruce trees in Poland.

The spruce trees are thought to live 400–500 years [35]. At present, the oldest spruce tree in the world is thought to be the Old Tjikko growing in Sweden, on Fulufjället in the province of Dalarna, which is 9550 years old. This estimate, however, is not derived from tree ring count. Instead, it was obtained by radiocarbon dating of a genetically matching plant material collected from underneath the tree (a clonal tree) [36,37]. The list of the oldest trees in the world [36] lacks spruce trees in the top 30. The oldest is the bristlecone pine (*Pinus longaeva*) from Nevada (USA), which is over 4900 years old.

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The Norway spruce trees growing in the Tatra mountains (540 and 515 years old) are considered the oldest in Poland [35,38]. These data, however, are from the 1970s and no information is available on the dating method used [39,40]. A study by Pacyniak from the 1990s estimates the ages of the oldest spruce trees at: 314 years (Łysa Polana, Tatra Mts), 337 years (Strzelce Opolskie, city park), 313 years (Zakopane-Kuźnice, Tatra Mts), 311 and 327 years (forests of the Babia Góra National Park) [41]. A study by the same author from 1998 reports five localities of old (>300 years; ages computed in 1995) spruce trees: Łysa Polana, Tatra Mts: 301 and 325 years, Zakopane-Kuźnice, Tatra Mts: 325 years, „Pod Rysianką" Reserve: 306, 341, 349, 362 and 462 years, Forest Inspectorate Szczytno: 302 years, Babia Góra National Park: 338 years (1995) [35]. The latter study also does not reveal how the tree ages were computed. Some authors have questioned the tree ages reported by Pacyniak [35,41], for instance: the spruce from the Masuria is dated at 302 years old by Pacyniak [35], while Koprowski [42] determined its age at 175 years, using dendrochronology. Zielonka [43] discussed the oldest spruce trees in the Tatra Mts and determined the age of the oldest tree as 400 years, based on tree ring counts at breast height. That particular tree was growing at an elevation of 1350 m a.s.l. on Czuba Roztocka (northern exposure), and was surrounded by a group of spruce trees whose breast-height ages varied from 210 to 365 years. Also Kaczka [44] reported old spruce trees in the Tatra Mts: "The longest time series was obtained from a living tree growing at Dubrawiska since the 16th century". The life span of the oldest spruce trees in the Tatra Mts is determined more precisely at 425 years in Kaczka [45]. In a doctoral dissertation on upper mountain spruce forests of the Tatra Mts, Zwijacz-Kozica [46] determines the age of the oldest spruce tree at 390 years (data from 1999). The longest chronology from NE Poland (Białowieża National Park) was obtained in a study by Koprowski and Zielski [47], which focused on the spruce trees from the whole of Poland. The chronology spans 215 years and covers the years 1785-1999. A still longer chronology was obtained by Bednarz [48], who created a chronology for the Babia Góra mountain dating back to 1650.

The data reviewed above indicates that the oldest spruce trees in Poland are growing in the Tatra mountains and they reach an age of about/above 400 years [43,44,46] (these trees are still growing) and in Babia Góra National Park, reaching an age of nearly 400 years [48]. These data were verified in October 2023. The trees in the Tatra Mts are still growing, despite numerous events threatening their health and life (strong winds, vermin gradations). Unfortunately, the spruce stands in the Reserve "Pod Rysianką" (Babia Góra National Park) - about 400 years old – are in a terminal phase due to strong winds and bark beetle gradations. The age reported here for the tree TM15 – 370 years – was obtained at breast height. In such difficult habitat conditions (ombrogenic peat bog, upper limit of the forest zone), it may have been growing for dozens of years before reaching a height of 1.3 m. It is not, however, the oldest spruce tree in Poland, but one of the oldest ones. It is probably the oldest specimen of this species in the Polish part of the Sudetes. The specimen is unique not because of its size (height or DBH), but because of its age.

The growth of the oldest spruce tree in the Śnieżnik Massif undoubtedly began during the Little Ice Age (LIA), which lasted in the mountains of Europe from about 1300 to 1950 AD (from a glaciological perspective), and from about 1570 to 1900 AD (from a climatic perspective) [49–51]. During this period, both the glaciers of the Alps [50,52,53] and in Scandinavia reached their largest extent [54]. For the mountains of Central Europe, and especially for the highest massifs of the Sudetes (Karkonosze, Śnieżnik Massif), detailed information on the environmental response to the climatic changes during LIA is lacking, in contrast to the Tatra Mts [55,56]. Based on the climatic reconstructions available for Europe [57], one may assume that during LIA the upper limit of the forest zone became considerably lower [58], and that snow cover, especially on the flattened, naked ridges of the highest sudetic massifs, lasted significantly longer. Present-day factors influencing the upper limit of the forest zone include: the presence of convex parts of slopes with extreme microclimatic conditions [59], and slope processes, such as debris flows or snow avalanches [60].

Considering all this, the presence of a >370-year-old spruce at an elevation of ~1250 m a.s.l. is especially intriguing. The period around 1650 AD, when its growth probably began, is also the period of the maximum range of the largest glacier of the Alps: the Grosser Aletsch Glacier [52,53]. It was also the period for which relatively low summer temperatures have been reconstructed for the Tatra

Mts [29] (Figure 4a). According to the latter author, from 1576 to 1675, there was an apparent cool phase in the Tatra Mts, recorded in the lowest growths in the spruce trees in the 17th century [44]. At the same time, considering the strong correlation between tree ring widths in the spruce trees between the Tatra Mts, Karkonosze and the Śnieżnik Massif [61], it is safe to assume that climatic conditions during LIA were similar in these two areas. Thus, the onset of growth of the oldest spruce tree in the Śnieżnik Massif during one of the coldest phases of the Little Ice Age may be surprising. However, the number of tree rings measured at 130 cm above ground certainly does not cover an unknown number of tree rings from the initial period of the tree's growth. Thus, it cannot be ruled out that the beginning of the tree's growth was associated with a warmer period preceding the cool phase of the LIA between 1576 and 1675.

Notably, up to the late 19th/early 20th century, the cool and warm periods in the Tatra Mts as reconstructed by Niedźwiedź [29] are clearly consistent with the tree ring width values from the oldest spruce tree from the Śnieżnik Massif (Figure 4a). From the beginning of the 20th century, the values are not as consistent, although Kaczka and Pawełczyk [61] argue that the chronologies from the Sudetes and from the Tatra Mts are the most convergent in this period. Such synchroneity points to a common factor's influence on tree ring production. This is most likely not, however, the summer temperature, reconstructed for this period by Niedźwiedź [29], mostly based on measurement data. Determining the growth-climate relationship for the spruce population growing at the mire "Pod Małym Śnieżnikiem" will be published elsewhere.

The study area belonged to Princess Marianne of Oranje-Nassau (1810-1883) since 1838, and her subordinates developed a network of forest roads and maintained intensive forestry. Furthermore, the immediate surroundings of the peak of Mały Śnieżnik had tourist infrastructure (an inn and a stone lookout tower, and hiking trails [62,63]. Despite all this, the mire and the tree stand suffered little human impact.

5. Conclusions

The mire "Pod Małym Śnieżnikiem" underwent natural succession processes under changing climatic conditions, as indicated by the Norway spruce stand age structure, and the presence of a >370-year-old specimen of this species. In the absence of planned forestry, the touristic character of the terrain, and an inaccessible location enabled the survival of unique habitat and old trees. Should the mire "Pod Małym Śnieżnikiem" be granted additional protection (i.e., planned expansion of the "Śnieżnik Kłodzki" Reserve), this valuable area will be protected in an unchanged form, the slow growth of the mire and the old spruce stand growing at the mire will continue and there will be a lasting record of climate change and human impact.

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