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Natural and Anthropogenic Transformations of A Baltic Raised Bog (Bagno Kusowo, North West Poland) in the Light of Dendrochronological Analysis of *Pinus sylvestris* L.

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Abstract: This study was conducted in a drained, exploited, and afforested Baltic bog Bagno Kusowo, located in North West Poland. The study aimed (i) to assess if human activity has a stronger impact on tree-ring width of *Pinus sylvestris* than climatic conditions in this transformed Baltic bog; (ii) to investigate how much the human modification of the ecosystem has influenced tree growth; (iii) to use this knowledge to reconstruct changes in the ecosystem further back in time, in the study area and its immediate neighbourhood. Wood samples for dendrochronological analyses were collected from 45 trees. Next, using classic dating methods and standard procedures (cross-dating methods, COFECHA program), chronologies were constructed (raw tree-ring width and residual chronologies: de-trended, autocorrelation removed, ARSTAN program). They formed a basis for further analyses: signature years, correlation and response function, as well as percentage growth change. The results of dendroclimatological analyses show weak increment–climate relationships and the analysis of weather conditions in the identified signature years did not detect any unambiguous relations with tree-ring width. However, results of the analyses indicate that the dominant factors affecting tree growth dynamics in the bog are changes in the hydrological system. Moreover, our results show many phases of human impact on environmental changes. Dendrochronological methods, combined with an analysis of old maps and other historical records, allowed us to reconstruct transformations of the ecosystem with a high resolution.

Keywords: tree-ring width; weather conditions; environmental stress; dendroecology; human impact; raised bog; *Pinus sylvestris*

1. Introduction

Baltic raised bogs, sometimes referred to as dome bogs because of the shape of peat deposits, are associated with temperate climate, cold and moist, with high precipitation. They are found primarily in the coastal parts of Central Europe and Baltic states. In Poland, bogs of this type reach the southern limit of their continuous distribution range and are located mainly along the Baltic coast, most frequently in Pomerania [1]. Baltic bogs are formed as a result of peat accumulation in lakes, paludification of mineral substrate in a drainage divide or paludification of river valleys. As a rule they cover large areas, in Poland usually 100–200 ha, up to 10,000 ha in colder areas with high precipitation [2]. These ecosystems are extremely important for floristic and phytocoenotic diversity of a given region, as they are refuges for many valuable and rare plant species and communities. In the Polish part of Pomerania (North West Poland), which lies at the border between the Atlantic and continental climate, species from both boreal or western Europe are found and some of them reach the limits of their distribution ranges (e.g., [3–7]).

Peatland ecosystems are seriously threatened on a global scale. Many peatland ecosystems have been subject to various forms of human impact over many centuries. In Denmark, Switzerland, large parts of Austria, Germany, and United Kingdom, nearly all mires are damaged to a large extent [8]. In Finland, about 70% have been disturbed by human activity [9], whereas in Poland about 80% have been [10]. In Poland, Baltic bogs started to arouse greater interest (in economic terms) in the late 18th century. Then, many of them were drained, to facilitate peat extraction on a larger scale or afforestation. This phenomenon was intensified in the 19th century, and most strongly in the 20th century. In many cases, the habitats were completely degraded as a result of extraction of all peat deposits, fires or agrotechnical procedures preparing them for agricultural use. In nearly all the Baltic bogs in Poland, as a result of human pressure, the local site conditions changed, which affected also the vegetation. The plant cover of these bogs was transformed to a lesser or greater degree (e.g., [11–15]). Bagno Kusowo is one of the best preserved habitats of this type in Poland, despite peat extraction in the past.

Studies of the history of European peatlands has mainly relied so far on stratigraphic and palaeobotanical methods, with little dendrochronological-based research (e.g., [16–23]). These methods make it possible to track major events that took place in the last several thousand years, but because of the lack of continuous records and the low resolution and accuracy of collected data, they are not sufficient to detect changes in site conditions within the last 200 years. In contrast, dendrochronological research, on the basis of tree-ring width, provides valuable information on changes in site conditions, human impact, and climatic changes in the given area.

This study was conducted in the well-preserved bog, Bagno Kusowo, where—as a result of drainage, peat extraction and afforestation—site conditions changed remarkably over time. This area is of high conservation value, as it is a refuge for many rare and endangered species typical of bogs. Moreover, in the peat extraction sites, more or less advanced regeneration processes take place. To restore suitable environmental conditions, enabling the regeneration of bog vegetation, it seemed necessary to reconstruct the history of this bog in the last 150–200 years. Unfortunately, the available data on this subject are very poor, so we decided to use dendrochronological methods to provide more complete information and thus allow us to uncover the history of this area. The study aimed (i) to assess if human activity has a stronger impact on tree-ring width of *Pinus sylvestris* than climatic conditions in this transformed Baltic bog; (ii) to investigate how much the human modification of the ecosystem has influenced tree growth; (iii) to use this knowledge to reconstruct changes in the ecosystem further back in time, in the study area and its immediate neighbourhood.

2. Study Area

The Baltic bog Bagno Kusowo (53°48.704′ N, 16°35.033′ E) covers 393 ha and is located in Pomerania (North West Poland), within a Natura 2000 site: Special Area of Conservation "Jeziora Szczecineckie" (Figure 1). Since 2005, most of the area (326.56 ha) is protected as a nature reserve. The bog developed on a moraine with kames, in an extensive depression, and its south-eastern part adjoins Lake Wielatowo. It was formerly a lake; a layer of gyttja is covered by a thin layer of fen peat, overlain by a thick (up to 12 m) layer of bog peat. The bog is clearly divided into two parts—northern and southern—separated by three mineral mounds. The northern part is better preserved, with a gently sloping "living" dome, about 3–4 m high, with some peat ponds [2]. The dome is mostly composed of *Sphagnum* hummocks and hollows of the plant association *Sphagnetum magellanici*. In places with a high water content, e.g., near peat ponds, we found patches of the *Rhynchosporetum albae*, *Eriophoro angustifolii-Sphagnetum recurvi*, and *Caricetum limosae*, which forms small patches here. Nearly half of the northern part of the study area consists of wooded habitats, primarily pine and birch bog forests

(*Vaccinio uliginosi-Pinetum* and *Vaccinio uliginosi-Betuletum pubescentis*). In the southern part, there are many remnants of peat extraction sites, where peat is intensively regenerated now. The peat extraction sites are overgrown mostly by *Sphagnum* mats typical of raised bogs, classified as the *Sphagnetum magellanici* and the *Eriophorum vaginatum–Sphagnum fallax* community, as well as patches of *Eriophoro angustifolii-Sphagnetum recurvi*. The elevated ridges between the former peat extraction sites are covered by pine and birch bog forests.

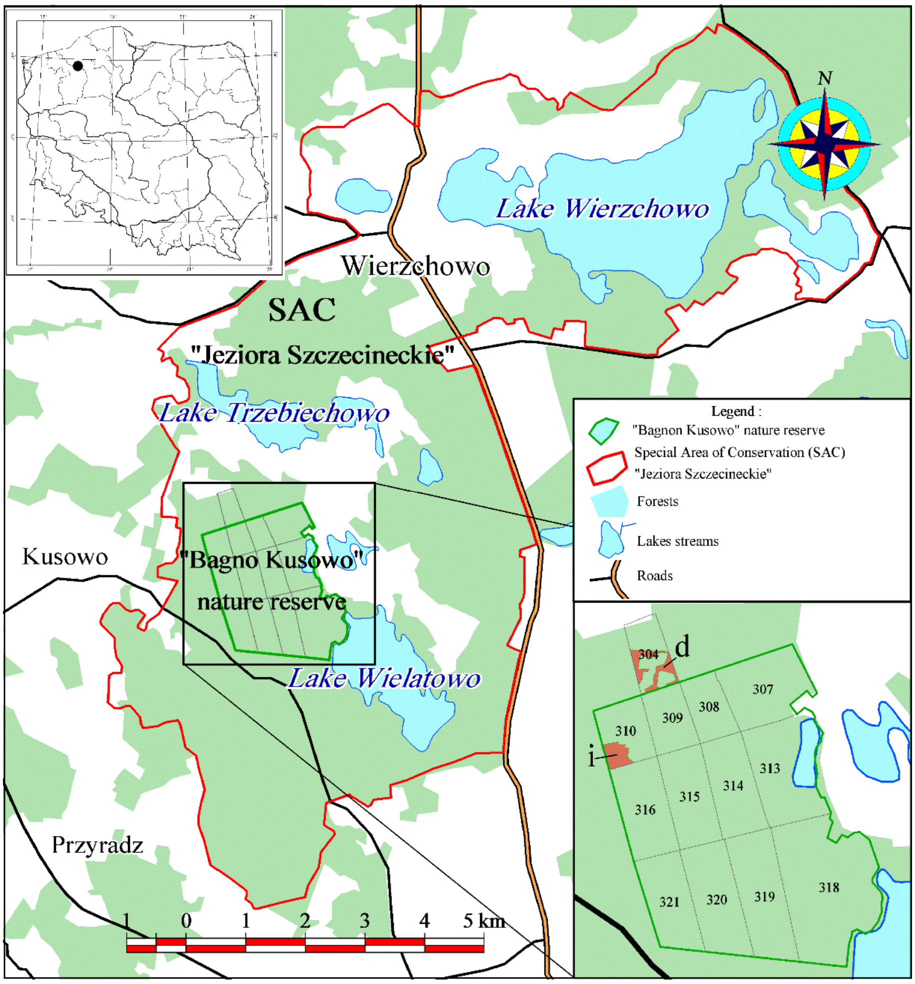

Figure 1. Location of research plots (forest sections 304d and 310i) in nature reserve "Bagno Kusowo" and Special Area of Conservation (SAC) "Jeziora Szczecineckie".

The peatland was most probably exploited only in the southern part, as evidenced by remnants of the workings and topographic maps dating from 1934 and 1939 (Figure 2), where peat extraction sites are marked [24,25]. Near the southwestern margins of the nature reserve, there are traces of foundations of a building (known as "peat works"). It already existed in the late 19th century, when peat was extracted from a small nearby area, located south-west of the peatland, which can be read from historical maps [26,27], but the maps do not show any signs of peat extraction in our study area. It cannot be excluded, however, that peat extraction from Bagno Kusowo could have taken place much earlier, as suggested by the 1780 map [28] where the southern part is named Bagger Mösse (in German, *Bagger* means "excavator", while Mösse means "bog"), in contrast to the northern part, known as Grosse Mösse (i.e., "big bog"). Peat extraction was preceded by drainage of the deposits, by means of a system of ditches directing water away from the bog. We do not know, however, when the first drainage ditches were dug out. The 1934 topographic map [24] shows the whole drainage system, located both in the northern and in the southern part of the peatland, and many extraction sites in the southern part. In the course of the progressing drainage of the substrate, the edges were gradually afforested with *Pinus sylvestris*.

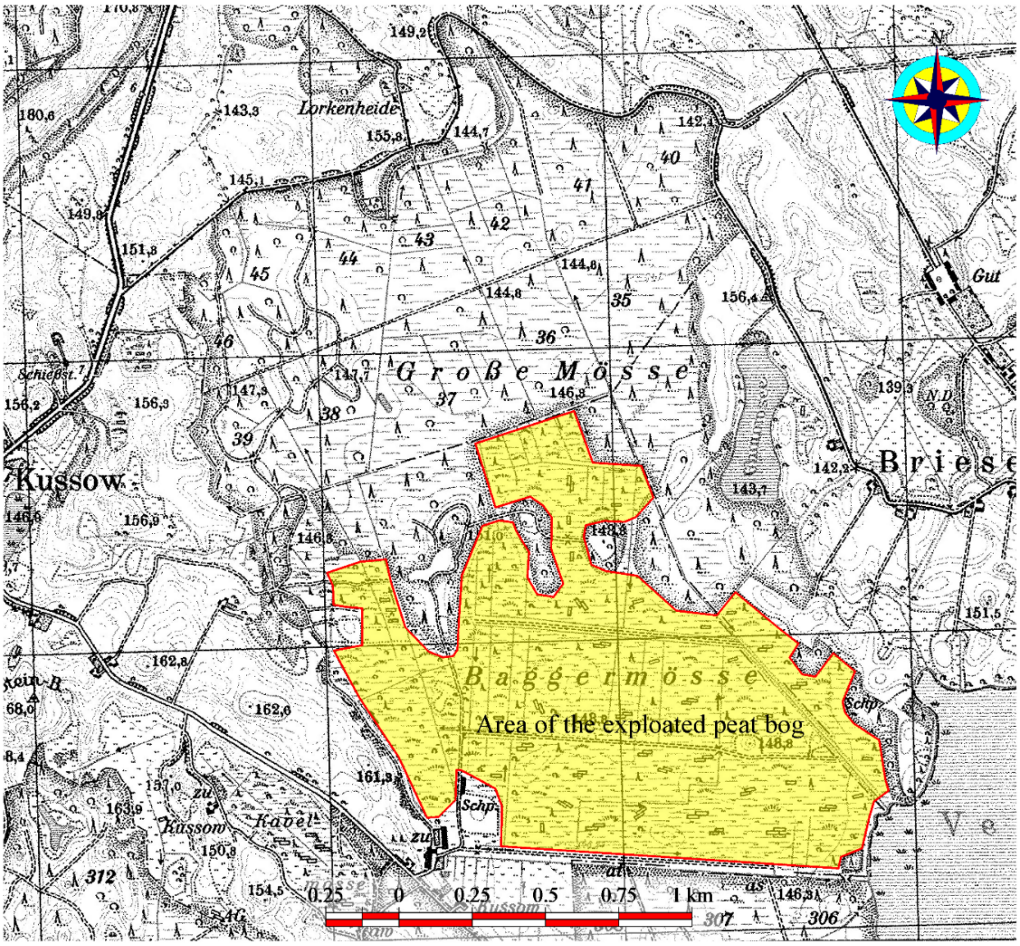

Figure 2. Topographic map of the bog Bagno Kusowo and its vicinity in 1939, with marked areas of peat extraction (according to [25]).

3. Methods

Field research was conducted in the probably unexploited, northern part of the bog. Material for dendrochronological analyses was collected in two forest sections: 304d and 310i (Figure 1), in patches of pine bog forest (*Vaccinio uliginosi-Pinetum*). Samples for the dendrochronological analysis (1–2 cores per tree) were taken from 45 pine trees (*Pinus sylvestris*): 45 cores of 24 trees in section 310i and 35 cores of 21 trees in section 304d, with an increment borer at breast height (1.3 m above ground) in September 2014. In the laboratory, the cores were glued into wooden mounts. After drying, their surfaces were cut with a preparation knife in order to get legible images of the annual growth rings. Measurements of the annual growth widths were made with an accuracy of 0.01 mm, using a stereo microscope, a movable measurement table connected with a counter, and Dendrometer software [29], starting from the internal parts (close to the pith) towards the bark. Altogether, 8106 annual growth rings were measured. Then, using classic methods of dendrochronological dating (cross-dating) [30–32], chronologies were constructed, and their quality was tested with the COFECHA program, from the Dendrochronology Program Library (DPL) package [33,34].

The constructed residual chronologies, RES (de-trended, autocorrelation removed), were subjected to indexation (using a negative exponential curve and autoregressive modelling), in order to eliminate the age trend and to emphasize the annual variability of the tree-ring width, in the ARSTAN program [35]. The expressed population signal (EPS) analysis was used to assess the degree to which chronologies of each plot portrayed the perfect hypothetical chronology [36].

Mutual similarity values between the chronologies were expressed with the coefficients *t* and *GLK* (*Gleichläufigkeitswert*), calculated with the TCS program [37]. The performed dendroclimatological analyses encompassed an analysis of the signature years, correlation, and response function. The signature years are those in which almost all of the examined trees demonstrated the same incremental trends: an increase in ring width with respect to previous years (+, positive signature year) or a decrease in increment width (−, negative year) [38]. The signature years were identified on the basis of data from at least 10 trees, assuming the minimum threshold of unanimity of the incremental reactions at 90%.

In analyses of correlation (CC) and response function (RF), the annual ring widths were compared with meteorological data from a weather station situated 12.5 km SE of the investigated forest sections. The values of the monthly average air temperatures (T) and total monthly precipitation (P) were analysed for a period of 66 years (1948–2013). For insolation (IN), we analysed data for a period of 34 years (1966–1999). For every year in which an annual growth ring was formed, CC and RF were computed for a 16-month period: from preceding June (pJUN) to September of the year of growth (SEP). In every case, the multiple regression coefficient of determination (R^2) was calculated, determining the strength of the relationship between the features analysed (RESPO program from the DPL package, [34].

Growth changes (releases) in plot chronologies were detected using Nowacki and Abrams' [39] method. Running comparisons of sequential 10-year ring-width means were used to detect sustained growth increases indicative of water level disturbance, while discounting short and long-term climatic change and tree aging trend. Percentage growth change (%GC) was calculated in yearly increments across individual tree-ring chronologies by using the formula:

$$\%\mathrm{GC} = [(\mathrm{M}_2 - \mathrm{M}_1)/\mathrm{M}_1] \times 100 \quad (1)$$

where M_1 = preceding 10-year mean, and M_2 = subsequent 10-year mean [23,39,40].

To interpret the results, we used all the available sources of information concerning the study area, including historical map sheets: Bublitz (now Bobolice) [41], Neustettin (now Szczecinek) [42], Polzin (now Połczyn Zdrój) [28], and Wurchow (now Wierzchowo) [24–27,42,43]. The maps were created before the 2nd World War and they document e.g., human activity in Bagno Kusowo (e.g., drainage ditches, sites of peat extraction, afforestation). Some of them are available from the Internet, while others were found in the National Archives in Szczecin. We also made use of additional pieces of evidence found in a monograph on the history of the Szczecinek region [44], concerning forest management in this area before the war. From the Szczecinek Forest District, we obtained information on extreme events and forest management practices in the last two decades, which could affect the condition of trees in the study area.

4. Results and Discussion

For trees growing in forest section 304d, on the basis of ring-width curves of 19 trees, chronology BK1 was constructed, spanning 105 years (1910–2014). Mean tree-ring width was 0.83 mm (Table 1), and the mean values for individual trees varied from 0.54 mm to 1.53 mm. The oldest dated tree-ring in this plot dates back from 1891 (tree BK14). For forest section 310i, the constructed chronology BK2 was based on cores from 21 trees and spanned 144 years (1871–2014). Mean ring width for individual trees ranged from 0.39 mm to 0.87 mm, on average 0.59 mm (Table 1). The oldest dated tree-ring in this plot dates back from 1848 (tree BK32). The chronologies were very similar, which is reflected in graphic conformity of both chronologies (Figure 3) and statistical parameters: *t* = 10.2 and *GLK* = 85%. The constructed chronologies can be regarded as representative, as the values of expressed population signal (EPS) were high: 0.89 and 0.91 (Table 1).

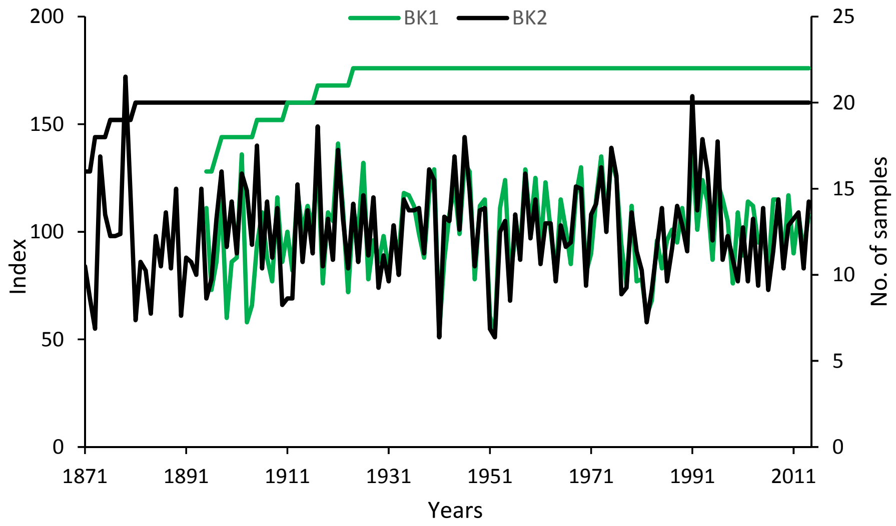

Figure 3. Comparison of *Pinus sylvestris* residual chronologies from Bagno Kusowo.

Table 1. Selected statistics of measured and indexed *Pinus sylvestris* chronologies. STD = standard deviation; MS = mean sensitivity; A1 = 1st-order autocorrelation; RBar = average correlation between trees for the common overlap period among series; EPS = expressed population signal.

Lab. Code	No. of Trees	No. of Samples	No. of Tree-Rings	No. of Years	Time Span	Mean Width Tree-Ring (mm)	Rbar	EPS	Un-Indexed Raw Tree-Ring Width			Residual Chronology		
									STD	MS	A1	STD	MS	A1
BK1	21	35	2911	105	1910–2014	0.83	0.46	0.89	0.338	0.276	0.658	0.303	0.232	−0.006
BK2	24	45	5195	144	1871–2014	0.59	0.48	0.91	0.317	0.294	0.697	0.239	0.294	−0.077
∑	45	80	8106											

Results of the conducted dendroclimatological analyses show that tree-ring width was only slightly affected by annual variation in weather conditions (Figure 4). For temperature, the analysis of correlation (TCC) for both the analysed plots did not show any statistically significant values, and for the response function (TRF) for chronology BK1, a positive value was calculated for July of the year preceding growth, whereas for BK2, for the current year: a positive value for January, and negative values for February, June, and August. Statistical significance of these values was low, with no replications between the plots, and the R^2 coefficient for temperature was very low (8% for BK1 and 13% for BK2). For precipitation, significant relationships for both plots were noted for September of the year preceding growth: positive values of correlation (PCC) and response function (PRF). In other months, no replication of results was observed, and the recorded statistically significant values were low. The R^2 coefficient was higher than for temperature, as it amounted to 21% for BK1 and 22% for BK2. For both chronologies, the strongest increment–climate relationships were recorded for insolation (IN): its R^2 reached 30% for BK1 and 22% for BK2. Significant correlations were found on both plots for August of the year preceding growth.

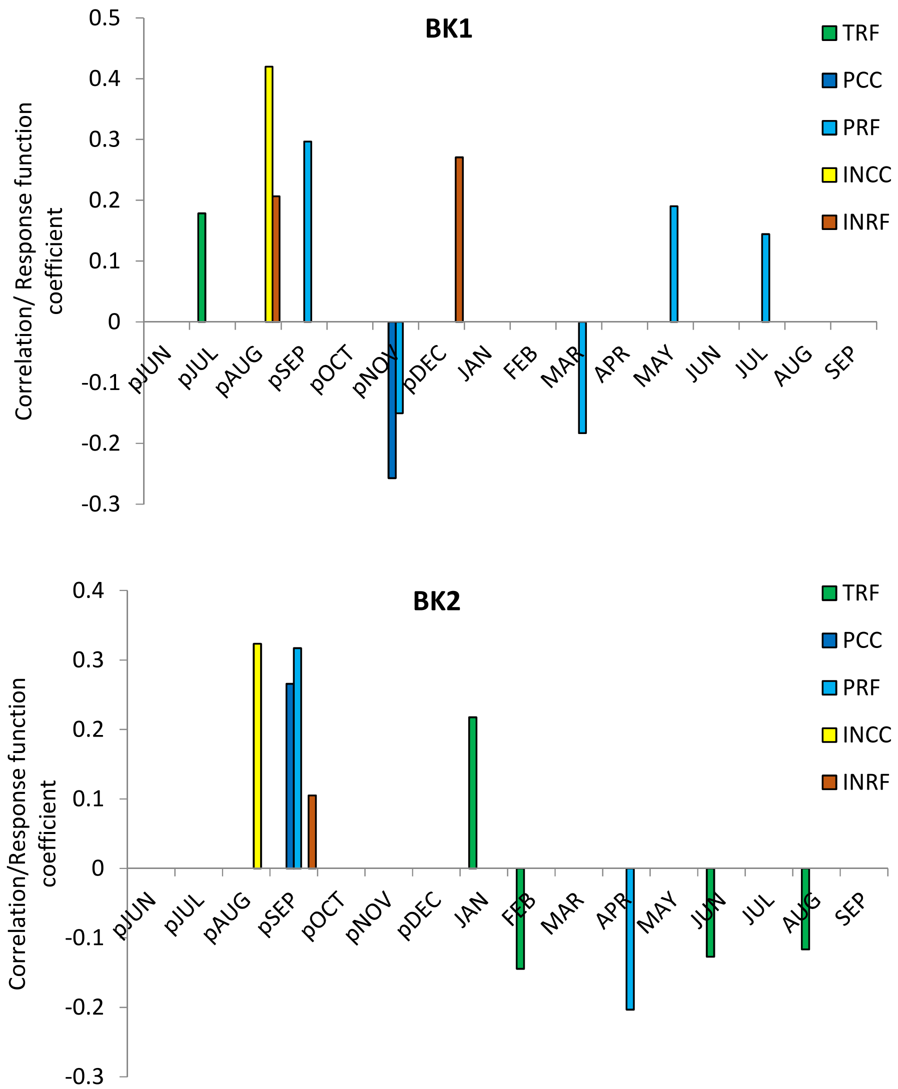

Figure 4. Significant results ($p \leq 0.05$) of correlation (CC) and response function (RF) for *Pinus sylvestris* chronologies from Bagno Kusowo and temperature (T), precipitation (P) and insolation (IN); p, previous year.

Results of the analyses indicate that the end of the preceding growing season was the period when weather conditions significantly affected tree condition and growth dynamics in the following year. Sunny August and moist September of the preceding year resulted in formation of broad tree-rings in the investigated trees. In Scotland, results of dendrochronological studies revealed that radial growth of pine trees on peat in Monadh Mor was correlated with temperature and precipitation in summer and autumn, and that the correlations were similar to those observed in pine trees growing on mineral soils [45]. Linderholm [46] reported that low temperatures, and the resultant lower evaporation as well as high precipitation, seem to limit pine growth on undisturbed parts of peatland. In contrast, in the drained parts, tree-ring width dynamics increased. Drainage of the bog altered the growth response of pine to climate, to resemble that observed on mineral soil. Moreover, he found that the variance in annual tree-ring growth, explained by temperature or precipitation or both, was low in all chronologies, but high in some of the analysed subperiods. In the disturbed bog ecosystem of Bagno Kusowo, the low values of coefficients (CC, FR, and R^2) and the lack of replications indicate that weather conditions were not the major factors that affected tree growth dynamics.

The analysis of signature years shows that in 71 years the investigated forest stands were characterized by a high similarity (over 90%) of growth trends of individual trees within plots. In both the analysed populations, the similarity was observed in 29 signature years, including 16 negative (−) years (1916, 1918, 1923, 1925, 1938, 1941, 1948, 1951, 1952, 1961, 1964, 1978, 1982, 1992, 2006, and 2013), 11 positive (+) years (1917, 1921, 1926, 1946, 1953, 1956, 1958, 1960, 1975, 1991, and 2014), and 2 years when the dominant trends differed between the plots (1986 and 2001). The analysis of weather conditions in those years did not reveal any unambiguous relationships between the weather pattern and tree-ring growth trends.

In northern Poland, among *Pinus sylvestris* trees growing on mineral soil, the most important factors in the process of tree-ring formation were temperatures in winter months and early spring preceding growth as well as precipitation in summer [47–52].

In contrast, the weak increment–climate relationships in *Pinus sylvestris* trees growing on peat soil in Bagno Kusowo justify further search for a major cause of changes in tree-ring width. Research conducted by other authors, including dendrochronological studies, indicate that human impact, involving primarily peat extraction and drainage of peatlands (with a system of ditches), was the major factor causing environmental changes in peatlands in the last 200–300 years e.g., [5–7,53–58]. Similar observations on the significance of human impact in relation to colonization of peatlands by bog pine (*Pinus uncinata* var. *rotundata*) in the Jura Mountains in Switzerland were made by Freléchoux et al. [59]. Those authors reported that in this process a major role was played by local factors, such as drainage and peat cuttings, rather than by climatic factors. However, climatic factors can increase the intensity of the ongoing disturbances of bog ecosystems resulting from human impact. For example, an increase in growth-season temperature may not only directly affect tree-ring width dynamics but also, as a result of intensive evaporation, may cause a decrease in water table [60]. The decrease in groundwater level in the bog (construction of drainage ditches and directing water away from the bog), which enabled peat extraction, simultaneously enabled afforestation of the drained organic soils. A lowered water table also contributes to improved aeration of the upper layers of peat. Then, the temperature and fertility of the substrate increases as a result of greater availability of nutrients [61]. Changes in water table are strongly related to tree growth as well as peat thickness and density [62]. The drained surface of the analysed bog was usually planted with *Pinus sylvestris*, while more moist places (e.g., edges of the dome) were colonized by trees in the course of natural succession. The successive episodes of peat cutting, drainage, or breaks in peat extraction, were recorded in the living chronicle of tree-rings. However, the records reflect not only the history of human activity in the study area but also changes in weather conditions (especially extreme events), the history of insect outbreaks, fires (caused by natural and anthropogenic causes), and lowering of the peatland surface due to peat decomposition.

The method of Nowacki and Abrams [39], using growth changes (releases), enabled us to distinguish several phases of increased or decreased tree-ring width (Figure 5). The phases are synchronous on both plots and last several or about a dozen years each. Peaks of each phase are marked with arrows (e.g., phase III lasts from 1916 to 1922). On the basis of collected data, we succeeded to associate some phases (of mostly increased tree-ring width) with various events in the history of the forest stand in the studied peatland. An exception is phase VI, describing the period of strongly reduced growth rate, which could be linked with a specific destructive agent. The other periods of growth reduction (e.g., around the year 1896) were not marked as phases because of (i) an insufficiently small number of trees used to construct the chronology at that time and a lack of replication in both chronologies; or (ii) a lack of data on the forest stand in the given period.

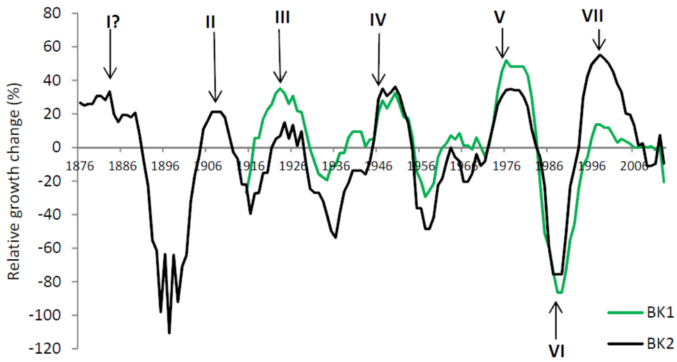

Figure 5. Running relative growth changes (releases) of *Pinus sylvestris* from Bagno Kusowo (BK1 and BK2). The relative growth change was calculated as the % difference between the mean ring-width in 10 preceding years and the mean in 10 subsequent years. I, II, III, and IV = phases of bog drainage; V, VI, and VII = phases associated with other factors (forest management practices, outbreak, fires).

Tree age in the study area (the oldest dated tree-ring at breast height, i.e. 1.3 m from the ground, dates back from 1848) suggests that its afforestation was started in the 1840s or earlier. It cannot be excluded that its afforestation took place earlier, as we are not sure if the sample was collected from the oldest tree. The presence of forest was confirmed by the 1877 topographic map, indicating that the analysed northern part of the bog (named then Grosse Mösse) was covered by coniferous trees, while the southern part (Bagger Mösse) was mostly overgrown by mixed forests [26]. Similarly, a coniferous stand in the northern part of the bog was is marked on the 1916 topographic map of the Szczecinek County [63]. However, it should be remembered that the maps show a more generalized image, so they do not take into account any smaller treeless patches. We suppose that the peatland was not completely covered by forest at that time. The peatland was afforested gradually because of its large area and varying moisture content of the surface. BK1 plot could be afforested 40 years later, in the mid-1880s (oldest dated tree-ring from 1891). A drainage episode at that time could be evidenced by relative growth change (phase I), but considering that these were the initial years of the chronology, we could not prove any increase in ring width, like in the next phases (Figure 5). Drainage took place also at the very beginning of the 20th century (phase II) and in the early 1920s (phase III). This was indirectly confirmed by the 1934 and 1939 maps, showing a system of drainage ditches. Peat was then extracted from nearly the whole southern part of the study area (Figure 2). The large-scale cuttings could indicate an advanced, long-term process of peat mining. Thus, the drainage of the area, enabling peat extraction, probably started much earlier, which was documented by the presented dendrochronological data. The changes in hydrological conditions resulted not only from directing water away from the bog by means of drainage ditches, but also from peat extraction. The drained parts of the study area were afforested as well as naturally colonized by trees due to ecological succession. At that time, large-scale monocultures of *Pinus sylvestris* and *Picea abies* (L.) H. Karst. were introduced, which was continued after the 2nd World War. This lowered the resistance of forests to fungal diseases and insect pests [44], contributing to their rapid spread in later years. Drainage took place also in the late 1940s (phase IV) (Figure 5). It could be associated with e.g., intensive tree felling in the first years after the war, to meet the growing demand for building materials [44] and simultaneous afforestation. The decrease in groundwater level in the bog due to drainage causes changes in its physical, chemical, and biological properties, involving the process of peat decomposition, and accelerates the humification and mineralization of organic matter. This results in increased soil fertility and improvement of soil aeration and water conditions and, consequently, in increased tree-ring width. The phases of intensive peat extraction took place between wars because in wartime most of the men participated in fighting, there were not enough resources for enterprises unrelated to warfare, and people focused on survival due to the threat of death and frequent shortages of food. The drainage phases coincided with the end of the 1st and 2nd World War, when men could be employed as peat miners and the economy was restored after warfare. In the first post-war years, peat was used on a large scale as fuel, especially by the local inhabitants. Peat was then much cheaper than coal. The intervals between the phases of bog drainage were characterized by reduced tree-ring width. Probably, the low growth dynamics in those periods was due to the slow increase in water level, deteriorating soil aeration and water conditions due to overgrowing of the drainage ditches, and the resultant decrease in water flow from the bog (Figure 6). Unfortunately, in the documentation available in the Szczecinek Forest District, we found no materials on forest and water management of the study area after both wars. Post-war peat extraction was finished in 1962, which was reflected in the lack of relative growth change in the 1960s and early 1970s. In spite of the end of peat mining, tree-rings in the last four decades reflected some other episodes of rapid relative growth changes (Figure 5). The lack of appropriate documentation did not allow us to associate phase V with specific human activities, but interviews with employees of the Forest District indicate that forest management practices, including thinning, were the factors affecting tree-ring width on both plots. In contrast, the strong reduction of growth rate in the 1980s (phase VI) was most probably caused by a very strong outbreak of the nun moth (*Lymantria monacha* L.). The outbreak started in 1981 and peaked in 1982–1983 (data from the Szczecinek Forest District). The following phase (VII) was characterized by an increase in tree-ring width, in spite of the gradual rise in water level in the bog because of the lack of restoration of drainage ditches (the natural process of overgrowing of the ditches with vegetation and the resultant storage of larger amounts of water in the study area). The 1990s and the very beginning of the 21st century were a period characterized by several droughts in summer and several fires caused by human activity (data from the Szczecinek Forest District). In Bagno Kusowo, fires were recorded in 1989, 1994, and 2000, and involved both the vegetation and the drained peat deposits. The fires did not spread to the analysed forest stands but influenced the groundwater level in the study area (drop in water level), which for trees unaffected directly by fire was a positive factor and resulted in an increase in tree-ring width. Lavoie and Pellerin [64] suggest that an accumulation of several disturbances of the bog ecosystem (fire, drainage, and years drier than average) is favourable for development of pine and spruce forest stands. The early 21st century was a period of stabilization at a low level (about 0.6 mm/year) or a slight decreasing trend in tree-ring width. This was connected with a rise in water level in the study area, due to overgrowing of the drainage ditches and construction of water gates, which block water flow from the bog (Figures 4 and 5).

Many phases of bog drainage have been reported also by Läänelaid et al. [23], who studied a peatland in Estonia. At least four episodes of drainage took place there, and three of them were recorded in tree-ring width very well (1910s, 1930s, and 1960s). Different growth responses to changes in water level in a peatland (drying and rewetting of peat) in various tree species were noted by Obidziński et al. [19]. During peat extraction and the associated low water level, peatland was overgrown by coniferous trees (*Pinus rhaetica* Brügger and *Picea abies*), characterized by fast growth, and next also by *Betula pubescens* Ehrh. However, when peat was no longer extracted, peat formation was restored and tree roots were flooded, the condition and growth dynamics of conifers deteriorated (some trees died), but an increase was observed in ring width of *Betula* and its contribution to the forest stand. Similar relationships between tree-ring width and water level in a peatland or phases of drainage and regeneration have been described by Cedro and Lamentowicz [17,18].

Figure 6. A water gate and overgrown drainage ditch at the border of forest section 310i in Bagno Kusowo.

Bagno Kusowo, because of the partial afforestation of the drained parts of the bog, can be used as a model object for application of dendrochronological methods, allowing us understand better the history of the mire and the local environmental conditions in the past. This study will help us (and others) to apply dendrochronological techniques to investigate environmental history in similar systems, both in the Baltic bogs and elsewhere in the world. This is particularly important because mires are of high conservation value and play an important role in preserving the biodiversity of the given region. They are seriously endangered and declining habitats. Unfortunately, usually little is known about their history. Application of the methods used in this study will make it possible to collect necessary data, which will be used to plan proper protection measures, either initiating or facilitating the ongoing regeneration processes.

5. Conclusions

Annual growth rings of trees are very good records of environmental changes taking place in peatlands and their immediate vicinity. In peatlands, in contrast to mineral soils, weather conditions are not the major factor affecting tree-ring width. In peatlands transformed by human activity, the dominant factor is the changing groundwater level and extreme events (e.g., fires), usually also caused by human disturbance. An analysis of tree-ring width, combined with an analysis of old maps and other historical records, make it possible to reconstruct environmental changes in a study area, and may form a basis for prediction of reactions of ecosystems during on-going climatic changes.

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Abbreviations

The following abbreviations are used in this manuscript:

RES	residual chronology
STD	standard deviation
MS	mean sensitivity
A1	1st order autocorrelation
EPS	expressed population signal

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