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Role of Lake Morphometric and Environmental Drivers of Ice Cover Formation and Occurrence on Temperate Lakes: A Case Study from the Eastern Baltic Lakeland, Poland

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Abstract: The presence of ice cover on temperate lakes is a crucial factor in determining the functioning of these ecosystems. The isolation of water from atmospheric influences significantly alters physical, chemical, and biological processes, and the intensity of this impact depends on the duration of the ice cover. This study analyzed the basic parameters of ice cover on several dozen lakes in Northeastern Poland. The aim of this study is to investigate the influence of morphometric parameters, alongside environmental factors, on the variation of ice cover characteristics in lakes located within the Eastern Baltic Lakeland. Characterization of ice conditions in the analyzed lakes was based on basic statistics such as minimum and maximum values, mean, standard deviation, coefficients of variation, skewness, and kurtosis. Given that the dataset contains variables describing ice phenomena in the studied lakes and data describing location, morphometric parameters, and land cover directly adjacent to the lake (treated as independent variables), a method of Spearman's rank correlations and constrained ordination method were decided upon. Despite the relatively small study area, significant variability was observed, with average differences as follows: 26 days for the onset of ice cover, 17 days for the end date, 15 cm for ice thickness, and a 30-day difference in the average duration of ice cover. Key factors included parameters such as lake volume, average depth, and land use (urbanized and agricultural areas). Understanding parameters such as the onset and end of ice cover is essential for lake ecosystems, both from an ecological and economic perspective. This knowledge is crucial for interpreting the behavior of living organisms, water quality, and economic considerations.

Keywords: ice cover; morphometry; environmental; inland water; land use

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1. Introduction

The seasonal occurrence of ice phenomena in temperate latitudes is crucial for the functioning of various components of the hydrosphere. Ice cover acts as an effective insulator for energy exchange between the atmosphere and water, leading to changes during winter compared to the ice-free period, including differences in light penetration, heat transfer [1], and water mixing [2]. This, in turn, affects living organisms [3–5]. A new research trend in winter limnology highlights the diverse and dynamic processes occurring under the ice, which influence lake ecosystems throughout the year [6,7]. Chemical and biotic changes in winter are time-dependent and vary between the early and late phases of the season [8]. Moreover, it is important to consider the significant impact of ice cover on human activities conducted in and around lakes [9,10] or shore erosion [11,12].

Despite understanding the general patterns of ice phenomena in inland waters across different latitudes, the dynamics on a more localized scale are much more varied. This variation applies both to individual lakes [13] and to specific spatial regions such as geographic areas [14]. While ice cover can be linked to air temperature, morphological and meteorological differences lead to significant fluctuations [15]. Yao et al. [16] observed that changes in ice phenology were related to air temperature variations on a continental scale, but a comprehensive assessment requires a thorough examination of local events. Understanding the processes at individual lakes is crucial for effective management of these ecosystems. Each lake, depending on its environmental context, may respond differently to the same stimuli, resulting in variations in characteristics such as the onset and duration of ice cover, even among neighboring catchments [14].

The presence of ice cover is particularly important in regions where lakes are the dominant natural feature. In Poland, the Eastern Baltic Lakeland (located in the northeastern part of the country) is a prime example, where lakes play a crucial role in hydrological [17], biological [18], and economic processes, significantly influencing the region's economic development. Tourism and recreation are especially vital in this regard, with a well-developed infrastructure of hotels and resorts. According to Zielińska-Szczepkowska and Zabielska [19], the lakes are the most attractive features of this region for tourists. During winter, when ice cover is present, activities such as ice sailing, snowkiting [20], and ice fishing [21] extend the tourist season, making the area a year-round destination.

The study of ice phenomena in Poland has a long history, with well-documented changes in lake ice cover in the context of climate warming [22–25] and the influence of large-scale atmospheric circulation [26–29]. Research has also focused on local factors affecting ice cover [30–35]. Against this background, the study presented in the article expands the current state of knowledge by incorporating new, previously unexamined elements that may influence ice cover dynamics. These variables relate to both the characteristics of the lakes themselves and their surroundings, which further refines the understanding of changes occurring in the ice cover. This broader approach allows for an enhanced understanding of the ice regime of lakes in Central Europe.

The aim of this study is to investigate the influence of morphometric parameters, alongside environmental factors, on the variation of ice cover characteristics in lakes located within the Eastern Baltic Lakeland. This research seeks to identify how these physical and environmental variables interact to affect the formation, thickness, and duration of ice cover, providing insights into the region's hydrological and climatic processes.

2. Materials and Methods

2.1. Materials

The article presents the results of studies on the occurrence and thickness of ice cover in lakes located in the Eastern Baltic Lakeland (Figure 1), covering an area of 17,500 km^2. According to the regional division of Poland [36], this region is characterized by a large number of lakes. As previously indicated, the long-term trends of change for Poland are well-known. Based on this assumption, the study analyzed 38 lakes over a 16-year period (1977–1992). It is important to note that the observational network of the Institute of Meteorology and Water Management—National Research Institute, which provided information on the characteristics of the ice cover, has undergone multiple reorganizations. This often resulted in the closure of existing observation posts on lakes.

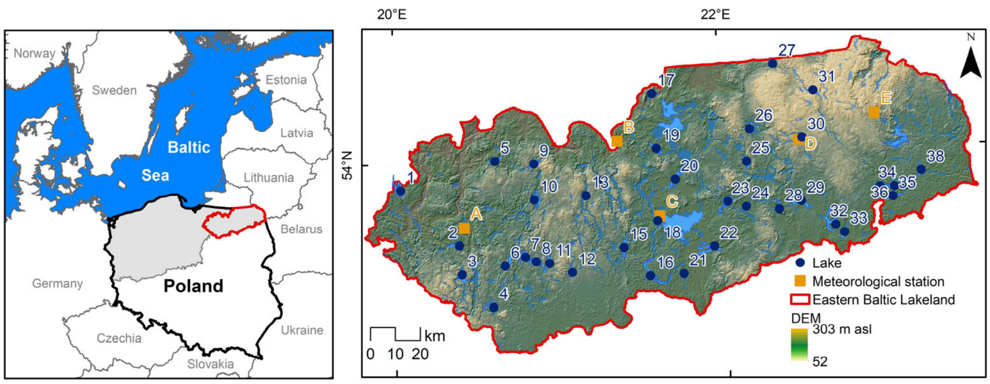


Figure 1. Location of the analyzed lakes.

The origin of the lakes in the Eastern Baltic Lakeland is linked to the last Scandinavian ice sheet, which contributes to their significant morphometric diversity. The surface area of the analyzed lakes (Area) ranges from 1.33 km^2 (Ełckie Lake) to 18.88 km^2 (Roś Lake), with an average depth (Mean_D) between 1.0 m (Pogubie Wielkie Lake) and 16.7 m (Olecko Wielkie Lake), and a maximum depth (Max_D) from 2.6 m (Pogubie Wielkie Lake) to 54.6 m (Wulpińskie Lake). The volume of these lakes (Vol) varies from 3.1×10^6 m^3 (Ełckie Lake) to 152.9×10^6 m^3 (Roś Lake), and the shoreline length ranges from 7.6 km (Gołdap Lake) to 72.9 km (Nidzkie Lake). The westernmost lake is Narie, while Serwy is the easternmost. The southernmost lake is Omulew, and the northernmost is Gołdap. The elevation of the lakes (Alt) ranges from 83.2 m (Rydzówka Lake) to 173.2 m above sea level (Rospuda Filipowska). The shoreline development index varies between 1.51 (Pogubie Wielkie Lake) and 4.97 (Orzysz Lake), while the exposure index ranges from 13.6 to 670.8 ha·m^{-1}, with Olecko Wielkie and Pogubie Wielkie lakes representing the extremes. Detailed geographical and morphometric data of the studied lakes are presented in Table S1. Geographical and morphometric parameters of the studied lakes were obtained from [37]. Additionally, land cover within a 200 m buffer around the lakes was analyzed, including the percentage of artificial (Arti), agricultural (Agri), and forested areas (For). This analysis utilized the Corine Land Cover database from 1990, provided by the Chief Inspectorate of Environmental Protection (https://land.copernicus.eu/pan-european/corine-land-cover/view, accessed on 11 July 2024). The artificial land cover around the lakes ranged from 0% to 42.5%, agricultural land from 0% to 100%, and forested areas from 0% to 99.9%. Ice cover characteristics included the date of ice cover start (IC_S), the date of ice cover end (IC_E), the duration of ice cover (IC_D), the thickness of the ice cover (IC_T), and the duration of ice cover breaks (IC_B). The data were obtained from observations conducted between 1977 and 1992 by the Institute of Meteorology and Water Management—National Research Institute. The definitions of the parameters describing ice cover presence and thickness follow Choiński et al. [14], where IC_S is the first day when 100% of the lake area within a visible measurement sector is covered with ice (calculated from November 1st, marking the beginning of the hydrological year), IC_E is the last day of the season when the main area of water is ice-free, IC_D is the number of days between the first appearance and final disappearance of ice cover (excluding periods of ice break-up), IC_B is the number of days with ice break-up, and IC_T is the maximum thickness of ice cover in a season. The data is considered in the hydrological year, where 1 November means the 1st day of the hydrological year, and 31 October of the following year is the last day of the hydrological year (365). In this study, average ice cover characteristics were correlated with their geographic location, morphometric features of the lakes, and the land cover in their immediate surroundings (Table S1).

Additionally, information on air temperature and wind speed from five meteorological stations (Olsztyn—A, Kętrzyn—B, Mikołajki—C, Olecko—D, Suwałki—E, Figure 1) was utilized. Data for these stations were also collected by the Institute of Meteorology and Water Management as part of its standard monitoring program.

2.2. Methods

Characterization of ice conditions in the analyzed lakes was based on basic statistics such as minimum and maximum values, mean, standard deviation, coefficients of variation, skewness, and kurtosis. Additionally, the percentile values of 5%, 10%, 25%, 50% (median), 75%, 90%, and 95% were calculated. The interquartile range (IQR) was computed based on the 25% (Q1) and 75% (Q3) percentiles, along with the ratio of the IQR to the median (IQR/Me). Dependent and independent datasets were examined for outliers using the Grubbs-Beck (G-B) test. The conformity of the data distribution to a normal distribution was tested using the Shapiro–Wilk (S-W) test. To present the spatial variability of the start and end of ice cover, duration, and thickness of ice cover, spline interpolation methods with barriers were used in ArcMap 10.3 software. Hierarchical cluster analysis was utilized to group lakes showing similarity in the occurrence of ice phenomena. The cluster analysis was performed using Ward's method, with the Euclidean distance squared as the measure of distance. Finally, to present the differences between the distinguished groups concerning the analyzed variables, the Mann–Whitney U test was applied. Given that the dataset contains variables describing ice phenomena in the studied lakes (IC_S, IC_E, IC_D, IC_T, which will be treated as dependent variables in the analysis) and data describing location (Lon, Lat, Alt), morphometric parameters (lake area—Area, lake volume—Vol, mean lake depth—Mean_D, maximum lake depth—Max_D, shoreline development index—SDI, and exposure index—EI) and land cover directly adjacent to the lake (treated as independent variables), a simple method of Spearman's rank correlations and constrained ordination method were decided upon (multivariate direct gradient analysis). Generally, the ordination methods are designed to represent complex, multi-dimensional relationships between dependent and independent variables as accurately as possible in a low-dimensional space [13]. The idea of constrained ordination is to identify a few weighted sums of independent variables that best fit the dependent variables, i.e., give the maximum total sum of squares of the regression [38]. Detrended correspondence analysis (DCA) was used to select the appropriate method for data analysis. If the length of the first ordination axis (expressed in standard deviation units—SD) from DCA is less than 2, redundancy analysis (RDA) can summarize the relationships between variables; otherwise, canonical correspondence analysis (CCA) is more appropriate [38]. To select useful environmental variables for the analysis explaining the occurrence and thickness of ice cover on lakes, the variance inflation factor (VIF) was applied. If the VIF values for the analyzed parameter are above 10, it indicates that it is redundant in the model. The ANOVA permutation test was used to assess the significance of the axes and environmental parameters in the ordination method. During the analysis, the vegan [39] package in the R environment [40] was used. Environmental variables that had a distribution different from normal were log(x) transformed. All variables, before the analysis using multivariate statistical methods, were scaled to range from 0 to 1. Scaling was completed using minimum and maximum values. The main reason for scaling is the different ranges of values of environmental variables, which can affect the results of the analysis.

3. Results

As indicated in the introduction, a key parameter for ice phenomena is air temperature, which was relatively uniform, with a difference of 1.3 °C between the five stations for the cold half-year (November–April). The warmest station was the westernmost one (Olsztyn), with an average temperature of 0.7 °C for this period, while the coldest was the easternmost station (Suwałki), with an average temperature of −0.6 °C. At the same time, the analyses conducted indicate that the occurrence of ice cover on lakes within the study area was highly varied. The ice cover formed the earliest on 10 December on Lake Litygajno and the latest on 5 January on Lake Juno. On average, in the analyzed area, the ice cover on lakes formed on 25 December. The time of ice cover disappearance from the lakes exhibited lower variability. The ice cover disappeared the earliest on 10 March on Lake Kośno and the latest on 27 March on Lake Rospuda Filipowska, with an average disappearance date of

17 March. The duration of ice cover on the analyzed lakes varied by up to 30 days. The ice cover lasted the longest on Lake Studzieniczne (99 days) and the shortest on Lake Ełckie (66 days). The average duration of ice cover was 82 days. The longest break in ice cover occurrence was on Lake Litygajno (122 days), while on Lake Rospuda Filipowska, no breaks were observed from the formation of the ice cover until its disappearance. Considering the maximum ice cover thickness, it ranged from 21 cm on Lake Wałpusz to 36 cm on Lakes Blanki, Szóstak, and Studzieniczne, with an average of 30 cm for all lakes. The values of the remaining statistics describing the variability in the occurrence and thickness of the ice cover are presented in Table 1.

Table 1. Summary of ice cover characteristics in analyzed lakes.

Statistics		IC_S (Day)	IC_E (Day)	IC_T (cm)	IC_D (days)	IC_B (Days)
Minimum		40	130	21	69	0
Mean		55	137	30	82	60
Maximum		66	147	36	99	122
Standard deviation		6.8	3.5	4.0	7.8	28.4
Coefficient of variation		12.4	2.5	13.4	9.4	47.4
Skewness		−0.30	0.49	−0.42	0.28	0.23
Kurtosis		−0.88	0.99	−0.45	−0.43	−0.45
Percentile	5%	43	131	22	69	19
	10%	45	133	24	71	26
	25%	49	135	28	77	38
	50% (Median)	56	137	30	82	57
	75%	61	139	33	87	81
	90%	63	141	35	95	107
	95%	65	144	36	97	112
IQR		12	4	5	10	43
IQR/Median		0.22	0.03	0.16	0.12	0.75

The analyzed variables exhibited low skewness values ranging from −0.42 to 0.49, suggesting that their distributions are close to normal. This is confirmed by the results of the Shapiro–Wilk test, which indicates that the analyzed variables follow a normal distribution at a significance level of 0.05. The kurtosis values for IC_S, IC_D, IC_B, and IC_T ranged from −0.88 to −0.43, indicating a somewhat flattened peak in the distribution. Such distributions are referred to as mesokurtic. However, the distribution for IC_E is more peaked around the mean, which is described as leptokurtic. The coefficients of variation range from 2.5% for IC_E to as high as 47.4% for IC_B. For IC_T, the coefficient of variation is 13.4%. Considering the values of IQR and the IQR/median ratio, the smallest variability was observed for IC_E, while the highest was for IC_B.

The spatial variability of ice phenomena and ice cover thickness in lakes within the Eastern Baltic Lakeland is presented in Figure 2. The results indicate that IC_S shows strong spatial variability (Figure 2a). In contrast, for IC_E, spatial variation is observed with values increasing from west to east (Figure 2b). Similarly, IC_D, like IC_S, is highly variable, with the highest values occurring in the southeastern part of the analyzed area (Figure 2c). In lakes located in the northeastern part of the Eastern Baltic Lakeland, no breaks in ice cover were observed, while in the southern and northwestern parts, breaks in ice cover lasted for about 100 days (Figure 2d). Regarding IC_T, the highest values were recorded in the central part of the analyzed area and at the northwestern and southeastern edges. The lowest IC_T values were noted in the southwestern part (Figure 2e).

The correlation analysis revealed that IC_S was positively correlated with the mean and maximum depths of the lakes. In contrast, IC_E was correlated with longitude (Lon) and mean depth. The duration of ice cover was correlated with the elevation of the lake, with higher-elevation lakes generally having longer-lasting ice cover. Breaks in the ice cover were negatively correlated with the depths of the lakes. However, the thickness of the ice cover was related to four parameters. It was positively correlated with both longitude and latitude and the proportion of agricultural land in the directly adjacent area, while it was negatively correlated with the presence of forests (Table 2) in the directly adjacent area. Although the results of the correlation coefficients highlighted in red are statistically significant, their interpretation requires special caution. The indicated parameters describing lake location, lake depths, or land cover alone explain only part of the variation in individual ice phenology parameters.

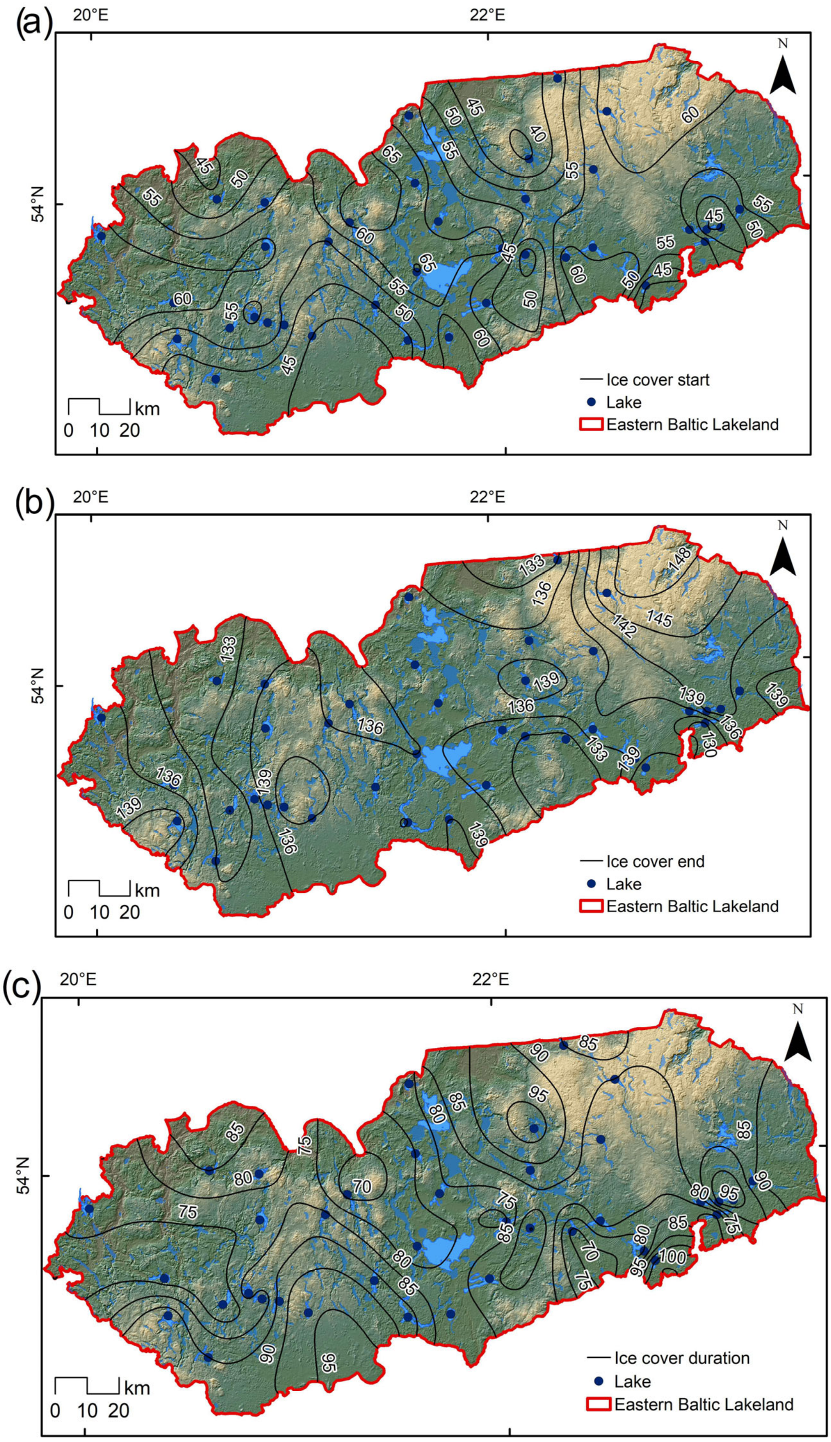
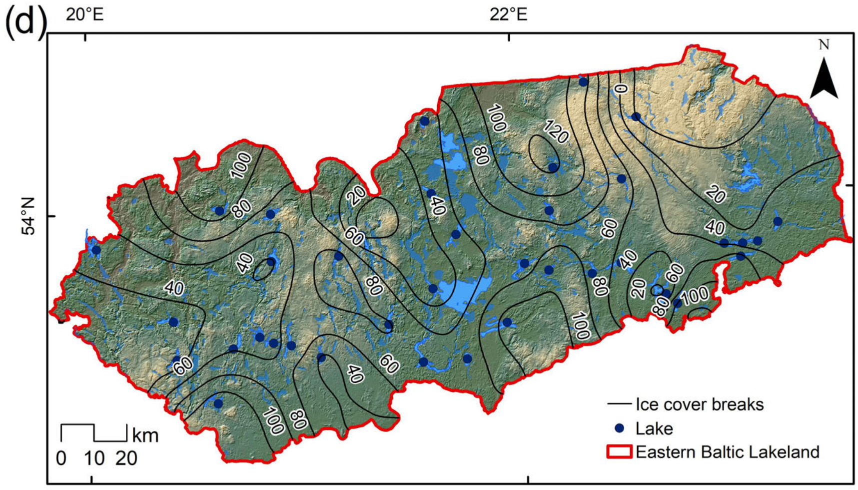


Figure 2. *Cont*.



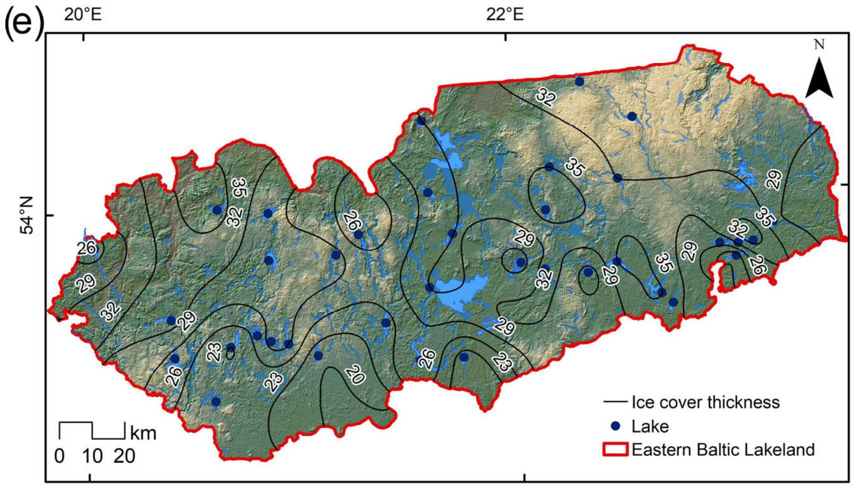


Figure 2. Spatial distributions of lake ice phenology parameters (average values for years 1972–1992): ice cover start (**a**), ice cover end (**b**), ice cover duration (**c**), ice cover breaks (**d**), and ice cover thickness (**e**).

Table 2. Spearman's rank correlation coefficients between ice phenology parameters and geographical and morphometric parameters of the studied lakes.

Parameters	IC_S	IC_E	IC_D	IC_B	IC_T
Lon	−0.12	0.36	0.25	−0.13	0.38
Lat	0.10	0.10	−0.02	−0.06	0.43
Alt	−0.23	0.20	0.33	0.03	−0.24
Area	0.16	0.00	−0.18	0.00	−0.12
Vol	0.31	0.11	−0.24	−0.30	−0.03
MeanD	0.40	0.33	−0.22	−0.56	0.00
MaxD	0.35	0.19	−0.25	−0.41	−0.09
SD	0.00	−0.21	−0.07	0.18	0.06
EI	−0.11	−0.14	0.01	0.26	−0.09
Arti	0.19	−0.15	−0.23	−0.13	0.01
Agr	0.19	0.10	−0.10	−0.10	0.41
For	−0.30	0.00	0.22	0.08	−0.41

Red color—statistically significant correlations.

Cluster analysis based on the parameters characterizing the course of freezing (IC_S, IC_E, IC_D, and IC_B) and the thickness of the ice cover (IC_T) allowed the division of lakes into two groups (Figure 3), each containing 19 lakes. In lakes belonging to group A, the beginning and end of freezing occur later than in lakes from group B. Based on the Mann–Whitney U test, it was found that these differences are significant at the 0.05 level. On average, the start of freezing in lakes from group A is five days later than in lakes from group B, and the ice disappearance in lakes from group A is, on average, three days later as well. In lakes belonging to group A, the duration of freezing is about half as long compared to lakes in group B. These differences are significant at the 0.05 level. However, considering the morphometric parameters of the lakes in both groups, it was shown that in lakes from group A, the average and maximum depths are higher by 3 and 10 m on average (differences significant at the 0.05 level), and the volumes of these lakes are higher by an average of 20 million cubic meters (differences significant at the 0.1 level). Moreover, it was shown that in the surroundings of lakes belonging to group A, the share of agricultural areas is higher, averaging about 61%, compared to an average of 43% in lakes classified in group B.

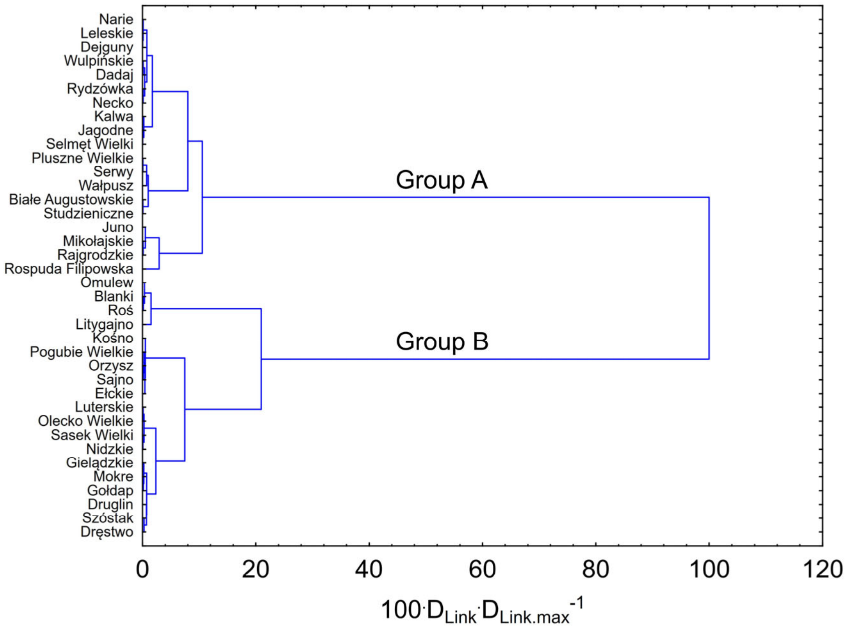


Figure 3. Results of lake clustering based on the course of freezing and ice thickness.

Finally, given that this study had access to a multivariate dataset containing both dependent variables (describing the course of freezing and ice cover thickness) and independent variables (explanatory) (geographical, morphometric, and land use parameters), an ordination method, which belongs to multivariate statistical methods, was applied. In the first stage, a DCA analysis was conducted, which showed that the length of the first ordination axis has a value lower than 2, indicating that the RDA method should be used for further data analysis. In the next step, to select the optimal set of independent variables in the RDA analysis, the step function from the vegan package was used. This resulted in identifying the following variables for inclusion in the RDA model: The selected variables were examined for multicollinearity to ultimately build a simpler model by calculating the Variance Inflation Factor (VIF). A VIF above 10 was obtained for Area (VIF = 14.3), Vol (24.5), Arti (13.7), Agri (168.5), and For (167.1). In the subsequent stage, the RDA analysis was repeated, omitting the Agri variable, which had the highest VIF. For this constructed RDA model, VIF was recalculated for the explanatory variables, with values higher than 10 obtained for Area and Vol. In the following stage, the RDA model was refined for the variables Lon, Alt, Vol, Mean_D, Arti, and For, achieving VIF values ranging from 1.1 to 2.7 for all variables. This led to the conclusion that the model based on these explanatory variables is optimal. Using the *Anova* permutation test function in the initial stage, it was demonstrated that the created RDA model is statistically significant at the 0.05 level of significance. Furthermore, the permutation test confirmed the significance of the RDA1 and

RDA2 axes, which explain 52.8% and 34.1% of the total variance, respectively. The results of the ordination using the RDA method are presented in Figure 4 and Table 3. MeanD, Vol, Arti, and For have the largest negative contributions to RDA1. In contrast, RDA2 is most strongly negatively associated with Lon.

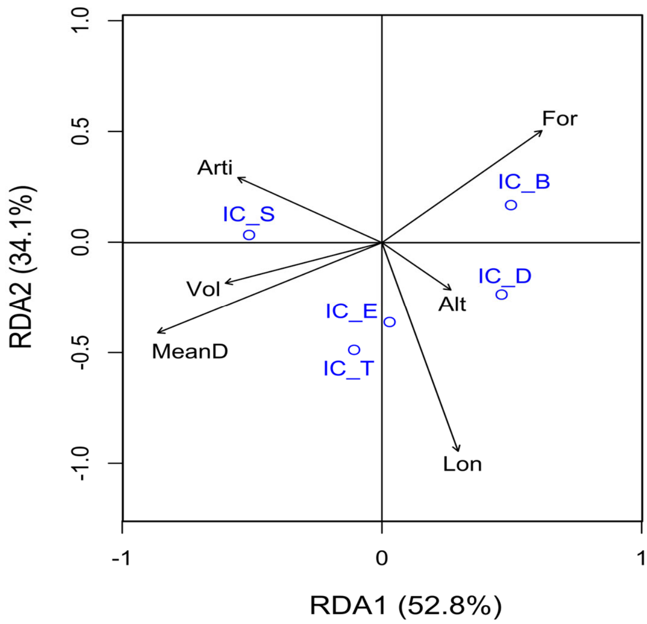


Figure 4. RDA biplots presenting relations between parameters of lake ice phenology (and environmental variables).

Table 3. RDA biplot scores for constraining variables.

Variables	RDA 1	RDA2
Lon	0.22	**−0.70**
Alt	0.20	−0.16
MeanD	**−0.64**	−0.31
For	**0.46**	0.38
Arti	**−0.41**	0.22
Vol	**−0.45**	−0.14

Bold—statistically significant values.

The results indicate that in lakes with larger volumes (Vol), greater mean depth (MeanD), and a higher proportion of artificial areas in the vicinity (Arti), the ice cover appears later (Figure 4). In contrast, the end of the ice cover and its thickness are associated with longitude and the share of agricultural areas. Generally, ice disappears later from lakes located further east, and the thickness of the ice cover on these lakes shows a similar tendency. Breaks in the presence of the ice cover are associated with the average depth. Specifically, in shallower lakes, interruptions in the ice cover are less frequent. Overall, the results of the RDA analysis are consistent with the results of the correlation analysis between ice phenology parameters and the geographical and morphometric parameters of the studied lakes.

4. Discussion

Changes in the state of water aggregation are a significant process influencing the functioning of lakes in regions where climatic conditions allow ice formation. Significant variations were observed in the characteristics of the ice cover, with the start date of the ice cover differing by 26 days on average, the end date by 17 days, the duration of the ice cover by 30 days, and the ice thickness by 15 cm. This observed situation in a relatively small research area allows us to conclude the crucial role of the individual characteristics of the lakes and their immediate surroundings. According to the RDA analysis results, ice cover formation occurred later in lakes with a greater average depth, larger water resources, and anthropogenic areas. These findings align with previous research in this field. As noted by Solarski and Rzetala [41], the rate of water freezing primarily depended on air temperature and lake capacity. A lake with a larger volume (or depth) will require more time to cool down (or warm up) than a lake of similar surface area but smaller volume (or shallow depth) [42]. Analysis of over a hundred lakes in Norway revealed that, due to their smaller volume, small lakes froze earlier [43]. A larger volume, and thus greater heat capacity, leads to a slower freezing process [44]. The significant amount of energy accumulated by lakes is a characteristic feature distinguishing this hydrospheric element from other environmental components [45]. The general arrangement is such that heat is accumulated during the summer season and then gradually released into the surroundings. Therefore, the larger the lake's capacity (the greater the amount of warmed water), the longer the potential for heat transmission to the atmosphere. It is important to also consider the second factor, namely the average depth. Shallow lakes undergo multiple mixing events, and the water, throughout its volume, quickly acquires thermal properties similar to the atmosphere. Based on research conducted on three Southern Wisconsin lakes, Vavrus et al. [46] established that lake depth is a key morphometric parameter for determining the ice formation date.

The impact of human activity on ice phenology is challenging to determine [47]. The results of the analyses conducted in this study highlight the role of urbanized areas in the later formation of ice cover, which should be associated with pollutants entering the lakes. Several reservoirs in Southern Poland exhibited similar ice regimes, except for four that were directly influenced by human activity [48]. Sojka et al. [49] noted that variations in ice cover could be influenced by pollutants affecting water mineralization, such as runoff from road salt used for de-icing streets.

The disappearance of the ice cover showed smaller variations compared to the dates of its formation—17 and 27 days, respectively. This situation is mainly due to the insulation of water and the crucial role of atmospheric factors. As Vavrus et al. observed [46], the simulated date of ice cover breakup is more sensitive to changes in air temperature than the dates of ice formation. Similarly, Yang et al. [50] noted that ice cover disappearance is more dependent on climate changes, particularly air temperature. Figure 2b shows that in the northeastern part, the average ice cover disappearance time for all lakes occurs around mid-March (17 March). In this month, the average air temperature for March at the station located furthest west (Olsztyn) is 1.7 °C, while at the station furthest east (Suwałki), it slightly exceeds 0 °C at 0.2 °C. This is reflected in the contour map showing the average end date of the ice cover (Figure 2), which is assigned to the northeastern part of the analyzed area.

The results indicating a connection between ice cover thickness and the presence of agricultural areas near lakes are particularly interesting. This situation can be interpreted as a lack of orographic barriers (such as forests or buildings) for snow transport, which is carried over from open field spaces. Although there are no data on snow cover thickness on the ice (as Institute of Meteorology and Water Management—National Research Institute does not standardly monitor this), it can be assumed to be a significant factor affecting ice cover thickness. For example, based on data from Finnish lakes, increased ice thickness is likely due to a large amount of snow on the ice, leading to the formation of snow ice [51]. The relationships observed in this study encourage future, more detailed research in Poland on the relationship between snow cover and ice cover.

The research results obtained in this study, along with the referenced literature, demonstrate that processes related to the presence of ice cover on lakes are complex. Therefore, in addition to global studies on lake ice regimes, regional findings are crucial. Understanding parameters such as the start and end dates of ice cover is important for lake ecosystems, both from a natural and economic perspective. For instance, varying ice-out dates affect the local dynamics of species dependent on open water, where different settlement dates of common goldeneyes have been observed even within the same watershed [52]. As noted by Smits et al. [53], water temperature and dissolved oxygen are likely to increase in most lakes during winter, and morphological characteristics will determine the sensitivity of ice phenology and under-ice processes to climate change. Winters with shorter ice durations and more thawing periods may result in reduced NO3− loss and higher peak NO3− concentrations in shallow eutrophic lakes, which could have potential implications for nitrogen cycling [54]. Based on data from the shallow Langer See, it was found that the absence of ice cover or its reduction can shorten the settling time of particles and their integration with sediments [55]. Conversely, prolonged ice and snow cover during one winter season on Lake Mutek (located within the research area) led to mass die-offs of fish and possibly crayfish [56]. Research conducted on Lake Jasne shows that variations in ice cover impacted phytoplankton species composition and dynamics [57]. The results obtained for Lake Mikołajskie indicate a high abundance of planktonic organisms, particularly algae and rotifers, along with a very low number of crustaceans under the ice [58]. The breeding success of the Goosander in Northern Poland was higher in winters when the ice cover melted earlier [59]. For most lakes in the region discussed in the article, the waters exhibit eutrophic characteristics [60]. Enhancing knowledge about ice cover distribution and dynamics can be pivotal for assessing water quality in different seasons and undertaking potential remediation work. Regarding the analyzed area, Marks et al. [61] suggest that rural tourism enterprises, such as agro-tourism and other rural tourism facilities, should view the activation of the winter season as an opportunity to improve utilization rates and increase earnings. Therefore, providing opportunities for active recreation through winter sports (such as ice fishing, ice sailing, and skating) is crucial for enhancing attractiveness. These activities are dependent on the presence of ice cover, and knowledge in this area will help in optimally managing the tourism industry or organization of sports competitions. As shown in the study, the variability of ice cover, even over relatively small areas, is significant, necessitating an individual assessment of each lake for various forms of activity.

5. Conclusions

Lakes in temperate zones undergo annual processes associated with changes in water state, with the timing of ice cover formation and disappearance being influenced by numerous variables. Key factors include the morphometric parameters of the lakes themselves and their surroundings. The analysis conducted in the article of several dozen lakes within the Eastern Baltic Lakeland revealed significant variability in the basic parameters of ice cover. The differences observed were as follows: the average start date of ice cover varied by 26 days, the end date by 17 days, ice thickness by 15 cm, and the average duration of ice cover by 30 days. Crucial factors included lake volume, average depth, and land use type (urbanized areas and agricultural areas). The notably longer formation time of ice cover is attributed to the extended release of heat accumulated in the water to the atmosphere, which occurs over a longer period in deeper lakes. Information on the appearance and disappearance of ice cover can vary considerably, even within relatively small areas or adjacent lakes. This knowledge is essential for interpreting the behavior of living organisms, water quality, and economic aspects. Further research on lake ice phenomena should focus on measurements and the role of snow cover, a parameter not yet measured in standard hydrological observations in Poland.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/resources13100146/s1, Table S1. Ice cover characteristics and morphometric parameters of the analyzed lakes.

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