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Land Use and Land Cover Pattern as a Measure of Tourism Impact on a Lakeshore Zone

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Abstract: Lakes provide different ecosystem services, including those related to tourism and recreation. Sustainable development principles should be respected in lake tourism planning. The aim of this study was to assess the impact of tourism on the lakeshore zone in a typical post-glacial Lakeland in Northern Poland (Central Europe). An explanatory analysis of the distribution of individual spatial factor values was performed using the SHapley Additive exPlanations algorithm (SHAP). In a first step, the aim was to select a Machine Learning model for modelling based on Shapley values. The greater or lesser influence of a given factor on the tourism function was measured for individual lakes. The final results of ensemble modelling and SHAP were obtained by averaging the results of five random repetitions of the execution of these models. The impact of tourism on the lakeshore zone can be much more accurately determined using an indirect method, by analysing the tourism and recreational infrastructure constantly present there. The values of the indices proposed in the study provide indirect information on the number of tourists using the tourist and recreational facilities and are a measure of the impact of tourism on the lakeshore zone. The developed methodology can be applied to the majority of post-glacial lakes in Europe and other regions of the world in order to monitor the threats resulting from shore zone exploitation. Such studies can be an appropriate tool for management and planning by the relevant authorities.

Keywords: leisure infrastructure; human pressure on lakes; sustainable tourism development; machine learning modelling

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1. Introduction

Tourism is one of the largest industries in the world and despite occasional shocks, it has been growing steadily over time, which is proof of the strength and resilience of the sector [1,2]. In modern tourism, trends related to the return to nature are observed. They result from the fact that people live in highly urbanized and polluted environments [3–6]. Unfortunately, tourism also contributes to environmental pollution and global climate change [7–12]. Gössling [13] recognized five key aspects of changes in the natural environment caused by tourism: changes in land use and land cover, excessive energy consumption, reduction of biodiversity and introduction of invasive species, spread of diseases, and changes in the perception and understanding of the environment. Water bodies, including lakes, are one of the most valuable resources for the tourism industry [14]. Lakes provide ecosystem services connected to all four groups classified by the Common International Classification of Ecosystem Services (CICES) [15], including cultural services related to tourism and recreation. Cultural ecosystem services (CES) are the intangible benefits that people derive from nature. They include recreation, aesthetic pleasure, physical and mental health benefits, and spiritual experiences. Unlike other ecosystem services, such as carbon sequestration or water or air purification, which require advanced technology to record, CES are directly experienced and intuitively understood by people who interact with nature. Unfortunately, lake ecosystems and the surrounding ecotone zones are among the most sensitive and vulnerable [16–18].

In the last half of the 20th century and the first years of the 21st century, especially in highly developed countries, there was a significant increase in the popularity of water-based tourism and recreation [19–21]. Uncontrolled development of tourism has a negative impact on coastal ecosystems. The inflow of pollutants from land to coastal waters disturbs their ecological balance through eutrophication. Construction in coastal regions leads to erosion of shores and instability of beaches and has a destructive effect on fauna and flora, especially on endemic species [8,22,23]. Lakes and ponds are important freshwater habitats, determining the attractiveness to tourists of many regions of the world. In Hungary, for example, tourists have spent more than 20% of their guest nights at the country's four lakeside destinations [24]. Recreation and tourism are also the major components of the economy of the Finnish Lakeland [25]. However, tourist activities have a negative impact on the lakes' waters and their shore zones [16,21,25,26]. Coordination of Information on the Environment (CORINE) land cover may be more useful for characterizing littoral nutrient enrichment than lake water chemistry analysis [27]. Land use and land cover at the lakeshore zone also has had a greater influence on phytoplankton morpho-functional groups than the physical and chemical characteristics of the lake water [28]. The services provided to tourists in tourist reception areas pose a huge threat to shoreline ecosystems. Excessive exploitation leads to a loss of the attractiveness of the area [14]. The dangers result mainly from air pollution, water eutrophication, land use and land cover changes (LUCC), shoreline transformations, and hydrological changes. These threats are typical for many lakes, especially those located in densely populated areas of Europe [29]. Intensive tourism activities and the diversity of lake-based recreation (e.g., swimming, boating, and fishing) increase pressure on lake ecosystems [16,20,30,31]. However, the impact of tourism on lake ecosystems is difficult to monitor because of the lack of micro-data and empirical studies as well as limited methodological framework [8,14,32].

The consumption patterns of tourists at a destination may cause changes in the environment, especially regarding the LUCC. In Portugal, the increasing popularity of tourist trips since the 1960s has resulted in an overdevelopment of tourist and recreational infrastructure and the expansion of second homes in coastal areas. Tourist resorts have mainly been built in the coastal area, so land use and cover changes are particularly relevant to these areas. Between 1990 and 2000, the share of developed areas increased by 20–35%, mainly due to residential sprawl [8,33]. All stakeholders involved in the development of tourism should be responsible for reducing its negative effects. Activities carried out in accordance with the concept of sustainable tourism will contribute to improving the quality of the natural and cultural environment, which may enhance the image of tourist destinations and benefit local communities [34–36]. According to Butler's classic definition, sustainable tourism is "the tourism which is in a form which can maintain its viability in an area for an indefinite period of time" [37]. The integration of sustainability into tourism creates new challenges for spatial planning in the lakeshore zone.

The main purpose of this study was to create a comprehensive method for assessing the impact of tourism on a lakeshore zone using machine learning modelling based on game theory and a set of indices. The secondary aim of the study was to use this method in a case study of a typical post-glacial Lakeland in Northern Poland (Central Europe).

2. Materials and Methods

2.1. Study Area

The Masurian Lakeland macroregion is one of the main tourist regions in Poland and at the same time the most popular tourist lake district in the country. The Masurian Lakeland is attractive due to the large number of lakes, the rich landscape, and the many other tourist assets, both natural and cultural. The attractiveness of the region was confirmed by the fact that the Masurian Lakeland was a finalist in the world plebiscite for the New7Wonders of Nature [38].

The research was carried out in the Olsztyn Lakeland, which is the westernmost mesoregion of the Masurian Lakeland macroregion [39] (Figure 1). The Olsztyn Lakeland shares features with other lakes of the Central and Eastern European Lowlands [40]. The results are representative of this part of Europe and of post-glacial lakeside areas in other regions of the world. The geographical coordinates of the Olsztyn Lakeland are 53°26′ and 54°11′ north latitude and 19°55′ and 21°00′ east longitude. The Olsztyn Lakeland has the largest number of lakes among all the Masurian Lakeland mesoregions [41,42]. There are about 300 lakes with an area of over 1 ha in the Olsztyn Lakeland [41]. The lakes cover more than 5% of the region's area, and the forests cover almost 40%. The Olsztyn Lakeland is an area of 3820 km^2 located in 65 communes of the Warmian-Masurian Voivodeship (Figure 1). Olsztyn is both the largest city in the region (about 174 thousand inhabitants) and its capital [43]. The considerable diversity of the landscape of the Olsztyn Lakeland was created during different phases of glacial retreat. The elevation above the sea level varies between 100–200 m. In some areas, the differences in height can reach up to several dozen metres [42]. Most of the large lakes in this Lakeland are located south of Olsztyn (Figure 1).

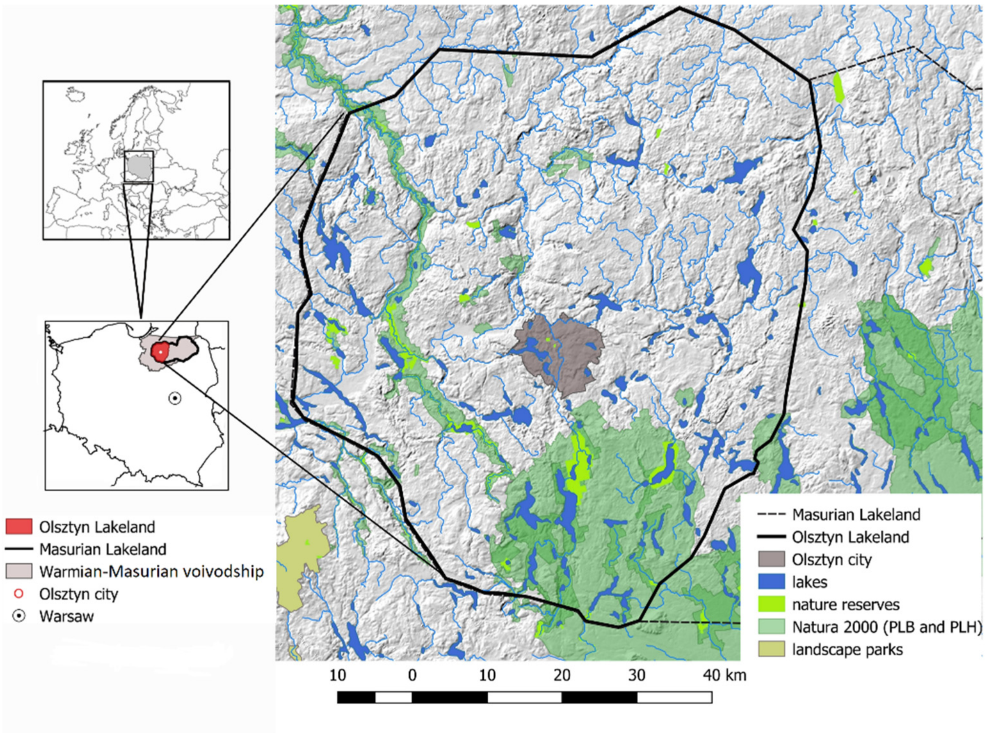


Figure 1. Distribution of lakes within Olsztyn Lakeland. The map is based on the General Geographic Database, the Database of Topographic Objects, and the Digital Elevation Model published by the National Geodetic and Cartographic Resource.

All of the lakes with an area of more than 10 ha (n = 143) were selected for the study. The total area of the lakes was about 181 km^2 (Table 1). This study focused on the 100-m strips of land around the lake shorelines, which in Poland, is considered a buffer zone. In the last three decades, legal regulations prohibiting the location of constructed objects in this zone have been abolished and restored several times. The total area of the land that was examined was 190.6 km^2. The presence of elements of tourist infrastructure (docks) in the water part of the shore zone of these lakes was also considered.

Table 1. Basic characteristics of the studied lakes in the Olsztyn Lakeland [41,44,45].

Lake Size Class	Lake Area (km^2)	Number of Lakes	Area Range (km^2)	Maximum Depth Range (m)	Average Depth Range (m)	Shoreline Development Index
small	0.1–0.4	66	0.10–0.39	1.1–30.2	0.6–11.9	1.04–2.56
medium	0.4–2.0	54	0.41–1.98	2.0–68.0	1.1–23.3	1.19–2.83
large	>2.0	23	2.02–12.40	2.0–54.6	0.7–16.1	1.58–4.40
	total	143	0.10–12.40	1.1–68.0	0.6–23.3	1.04–4.40

2.2. Methods

The study was conducted using topographic and orthophotograph maps scaled 1:10,000. All raster maps were obtained from the Provincial Centre for Geodetic and Cartographic Documentation in Olsztyn (license number IG-WODGiK.7522.65.2017_28_N, IG-WODGiK.7522.9.2018_2018_28_N, IG-WODGiK.7522.X. 2018_28_N). A 100-m-wide strip of land around the shoreline of the lakes was studied using QGIS software and direct observations in the summer seasons of 2018–2019 in order to compare the land use and land cover (LU/LC) status. The area of land occupied by different forms of LU/LC was calculated using the QGIS software.

2.2.1. Machine Learning Modelling

The group of data concerning 143 lakes of the Olsztyn Lakeland was modelled. This group consisted of the seven variables related to land use and land cover in a 100 m wide strip around the shoreline of the lakes: accommodation facility area, recreation and gastronomy area, transportation land, settlement area (developed areas), forests, semi-natural land, and agricultural land (undeveloped areas). These variables were expressed as a percentage of area within this strip.

The basic assumption for modelling the above-mentioned groups of variables, indicating (or not) the tourist function of the lakes, was to base this analysis on the interactivity of the examined factors. The value of a given spatial factor affected the tourism function of a lake. In a first step, the aim was to select a Machine Learning model for modelling based on Shapley values; i.e., SHapley Additive exPlanations algorithm (SHAP) [46]. Based on accuracy score comparisons, the model sequence Decision Tree–Random Forest–Extreme Gradient Boosting (XGB) was selected from existing available ensemble modelling schemes (Ensemble) [47]. The XGB Classifier model (from the Python language Scikit-Learn library) was trained on a random sample of 70% of the entire dataset and tested on a sample of 30% of this dataset.

An explanatory analysis in the SHAP algorithm of the distribution of individual spatial factor values was then performed. The greater or lesser influence of a given factor value on the tourism function was measured for individual lakes. The results of ensemble modelling and SHAP were obtained by averaging the results of five random repetitions of the execution of these models. In order to obtain a distribution of Shapley values for all cases (lakes), the entire dataset was trained in the SHAP algorithm. High positive Shapley values indicate an enhancement of the lakes' tourism function relative to its absence. Negative Shapley values, on the other hand, indicate a tendency for the lake not to be used for tourism purposes. The SHAP algorithm used also makes it possible to rank cases (lakes) according to the similarity of features (spatial factors) that strengthen or weaken the tourism function.

The computation of XGB Classifier model accuracies and Shapley values in the SHAP algorithm was performed in the Python 3.7 programming language.

2.2.2. Tourism Impact Indices

The following four indices were selected to determine the impact of tourism on the lakeshore zone. The use of such a set of indices allows for obtaining unambiguous and repeatable results, which is a great advantage in this type of research. The impact of tourism on the natural environment is usually associated directly with the number of tourists visiting a given place. However, the actual number of people relaxing in the lakeshore area is very difficult to determine. According to the authors, the impact of tourism on the lakeshore zone can be much more accurately determined using an indirect method, by analysing the tourism and recreational infrastructure constantly present there. The values of the indices proposed in the study provide indirect information on the number of tourists using the tourist and recreational facilities and are a measure of the impact of tourism on the lakeshore zone. The tourism impact index (T) on the environment of the lakeshore zone was calculated according to the formula:

$$T = \sum (P_i * B_i)/P_t \quad (1)$$

where P_i are particular types of developed area [m^2], B_i are mean absolute Shapley values (determining the importance of the impact of different types of land use on the lakeshore zone), and P_t is the total area of a delimitated strip [m^2].

The analysis of the density of accommodation facilities and other tourist and recreational facilities located in a 100-m strip around the lakes was carried out. The accommodation density index (P_A) was calculated according to the following formula:

$$P_A = N/S \quad (2)$$

where N is the number of beds and S is the area of the delimited strip [km^2] [48,49].

This index was used to assess the tourism function of a settlement [50]. In a 100-m strip around lakes, accommodation facilities are often located outside the administrative area of any settlement. Therefore, it was reasonable to use this index to calculate the tourism function of a 100-m strip of land around the lake's shoreline. The value of the index above 50 means that tourism function is the primary or one of the main functions of the studied area (Table 2).

Table 2. The accommodation density index (based on Mika, 2004 [51], modified).

Role of Tourist Function in the Functional Structure	Number of Accommodation Beds per 1 km^2 (P_A)
Primary or one of the main functions	>50
Equivalent to other functions or additional	25–50
Additional	6.25–25
In the initial stage of development	0.75–6.25
No development of tourist function	<0.78

The density index of other tourism and recreation items (P_O) was calculated according to the following formula:

$$P_O = N_O/S \quad (3)$$

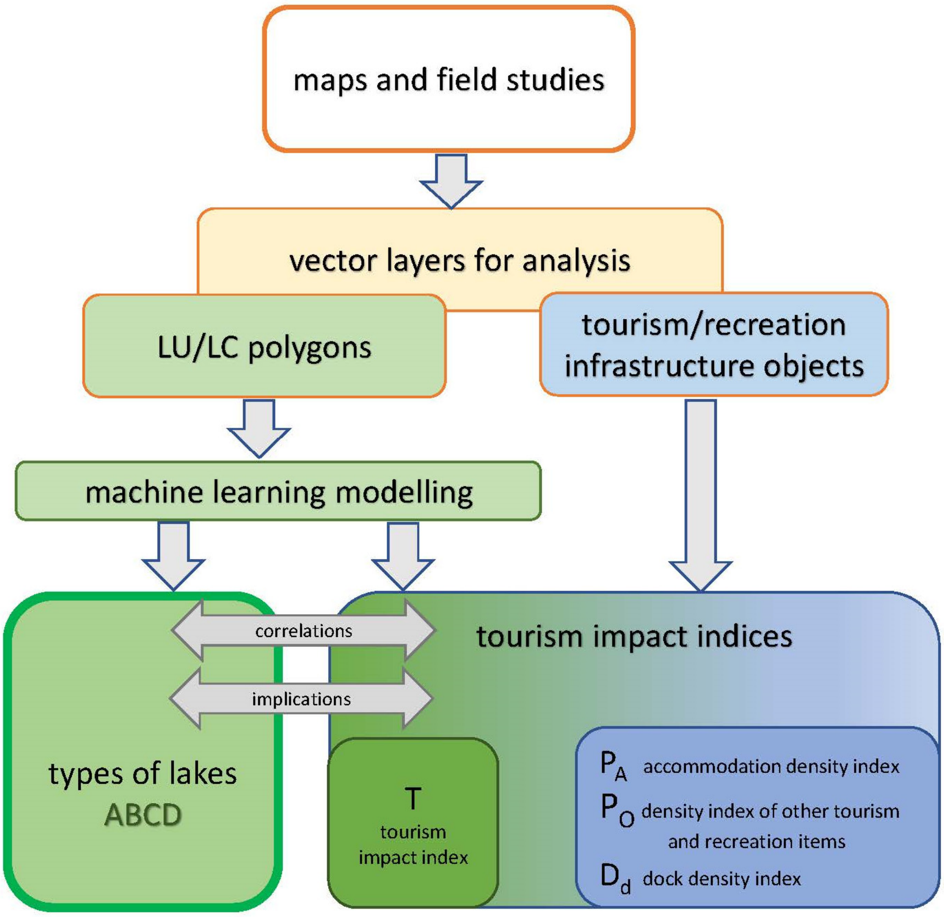
where S is the area of the delimited strip [km^2] and N_O is the number of the other tourism and recreation items [49].

Information on the number of accommodation facilities and the number of beds at these facilities was obtained in two steps. Preliminary data were obtained from Google Maps and a website with the function of browsing and searching for accommodation offers under the domain e-turysta.pl. Finally, this was verified by interviewing particular accommodation facility managers. The other tourism and recreation items were first classified and counted at the orthophotograph maps and next verified by field studies. The dock density index (D_d) was calculated as a measure of the impact of docks and related activities on the water shore zone of the lake [52]. The actual state of development was determined by manual identification of artificial water structures such as marinas, harbours, bathing sites with piers, large recreational platforms and small fishing piers on the orthophotograph maps. These structures are referred to in this study as "docks" [52,53]. Smaller and simple docks have been designated as single objects, while larger docks (with at least two branches) have been designated as complex objects. Each branch within a complex dock has been treated as a separate object so that the total number of docks better reflects the actual impact of the individual dock on the development status of the water shore zone of the lake. Lakes with a D_d index over 5 have been defined as highly developed [52]. Dock density index (D_d) was calculated according to the following formula:

$$D_d = D/M \quad (4)$$

where D means the number of docks and M is the shoreline length [km].

Scheme 1 summarises the used methodology.



Scheme 1. Methodological framework.

2.2.3. Statistics

The Spearman's rank correlation coefficient was used to check the presence of correlation between the studied parameters. The Kruskal-Wallis test was used to determine statistically significant differences in values of tourism impact indices for the different LU/LC types of the shore zone.

3. Results

3.1. LU/LC Type Importance for Tourism Function of Lakes

Using modelling based on Shapley values (SHAP algorithm), a ranking of the influence of LU/LC types on the tourism function of the lakes was obtained (Table 3). A greater or lesser tendency as well as its direction to strengthen or weaken this function was defined as a greater, lesser, positive, or negative influence of the studied parameters of the lakes' surroundings on this function.

Table 3. Overall LU/LC type importance for tourist function of lakes expressed by normalised absolute Shapley values (in %): mean +/− Standard Deviation (SD) and Extreme Gradient Boosting (XGB) accuracy. Mean was calculated for 5 SHAP model executions.

Shapley Value	LU/LC Type							XGB Model Accuracy	
	Accommodation Facility Area	Recreation and Gastronomy Area	Settlement Area	Transportation Land	Semi-Natural Land	Agricultural Land	Forests	Training Subset	Test Subset
Mean	80.6	41.2	15.4	0.8	4.4	4.0	6.4	96.0	90.9
SD	13.5	13.9	7.3	1.3	3.2	2.7	2.5	1.0	1.6

Analysis of the SHAP model showed that the prediction of the tourist function of the lakes of the Olsztyn Lakeland was most strongly related to the presence of accommodation facilities in the shore zone: 80.6% Shapley value. The second most important factor was recreational infrastructure on the shores of the lakes and gastronomy objects (41.2%), and the third was the presence of local settlements (15.4%). The importance of the tourist function of lakes of land use types in their immediate vicinity, such as forests, agricultural lands, semi-natural lands, and transport networks (except for inhabited areas) was found to be relatively small: 0.8–6.4% (Table 3). The above validity calculations confirm the high accuracies of the XGB model obtained for both train (96.0%) and test (90.9%) subsets (Table 3).

3.2. Types of Lakeshores with Tourism Functions Development

Assessing the similarity of the lakes of the Olsztyn Lakeland based on the share of different LU/LC types in their surroundings (Table 3), four lake categories were distinguished based on the analysis of the SHAP model (Figure 2).

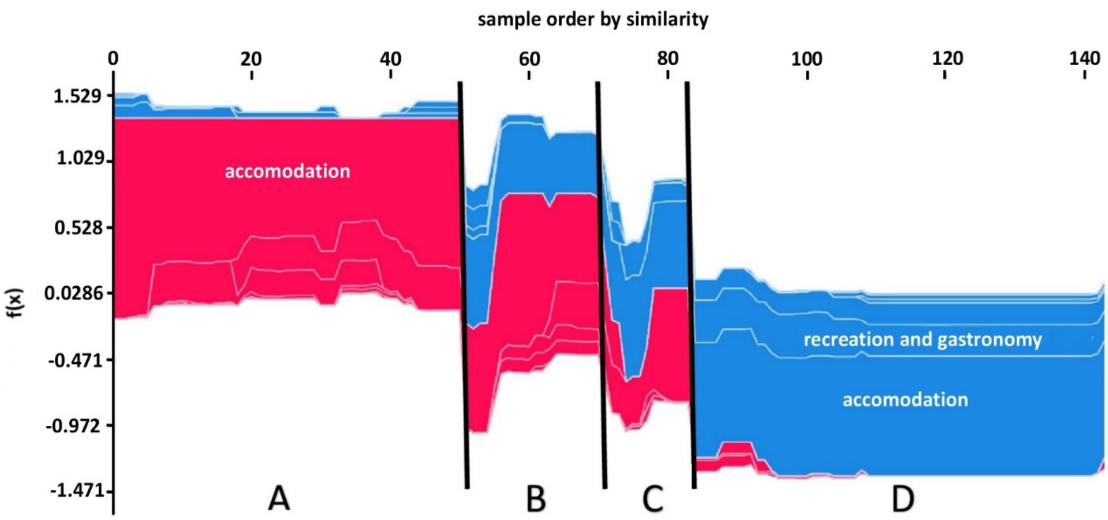


Figure 2. Assessment of the similarity of the lakes of the Olsztyn Lakeland based on the share of different LU/LC types in their surroundings on the basis of SHAP model analysis. (**A**) Shore zone with the tourism function developed; (**B**) shore zone with the recreational function developed; (**C**) shore zone with the settlement function developed; (**D**) undeveloped shore zone.

The main function in the shore zone of the lakes from category A was tourism. The lakes from category B showed a high level of recreational development. The settlement function was the main one in the shore zone of lakes from category C. Category D consisted of lakes with semi-natural shore zones. The largest number of lakes (60) belonged to category D. Categories A, B, and C included 46, 25, and 12 lakes, respectively (Figure 3).

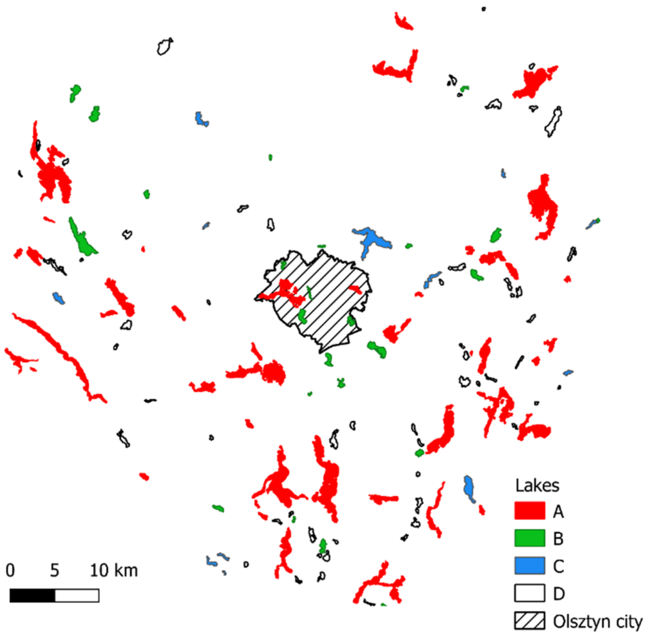


Figure 3. Distribution of lakes belonging to particular LU/LC types (categories).

3.3. Tourism Impact Indices

The study showed that 26 lakes without accommodation facilities in the shore zone ($P_A = 0$) represented the recreational function related to the settlement (T, P_O, and $D_d > 0$). An accommodation density index (P_A) above zero was recorded for 47 lakes (46 from group A and 1 from group B). For 37 lakes, the value of this index exceeded 50. All studied lakes belonging to group A and C were characterized by the presence of docks ($D_d > 0$). A highly developed water part of the shore zone ($D_d \geq 5$) was recorded for 29 lakes. An undeveloped water part of the shore zone ($D_d = 0$) was recorded for 34 lakes. The remaining lakes ($n = 80$) were characterized by a moderately developed water part of the shore zone. In the case of lakes where the T-value was zero and the P_O-value was higher than zero ($n = 34$), only access to the water surface was observed. The lowest values of all indices were recorded in group D.

The Kruskal-Wallis test showed significant ($p < 0.01$) differences between the LU/LC types (categories A, B, C, and D) as well as the size classes of studied lakes (Table 4). All four tourism impact indices were strongly, positively correlated to the developed area share at the lakeshore zone ($p < 0.01$, r = 0.59–0.95). This correlation is also maintained after excluding from the analysis the areas developed for tourism and recreation to avoid cyclical references ($p < 0.01$, r = 0.48–0.83). The values of tourism impact indices were also positively correlated ($p < 0.01$, r = 0.34–0.47) with the water surface area. Tourism impact of the water part of the lakeshore zone (measured by D_d) was positively correlated ($p < 0.01$, r = 0.50–0.68) with P_A, P_O, and T indices values (tourism impact on the land part of the lakeshore zone). The share of forests in the lakeshore zone was negatively correlated ($p < 0.01$) with values of P_O (r = −0.30), D_d (r = −0.31), and T (r = −0.39) indices. The degree of lake cover with water vegetation was negatively correlated with the share of developed area in the lakeshore zone (r = −0.37) and values of all four tourism impact indices (r = −0.27 to −0.40).

Table 4. Tourism impact indices for the LU/LC types of the lakeshore zones and the size classes of the lakes.

		T Mean (±SD) Median	P_A Mean (±SD) Median	P_O Mean (±SD) Median	D_d Mean (±SD) Median
LU/LC type	A	0.30 [a] (±3.03) 6.05	190.4 [a] (±223.49) 113.14	7.18 [a] (±9.44) 4.80	6.03 [a] (±7.09) 3.99
	B	0.21 [a] (±3.26) 2.58	0.8 [b] (±3.86) 0.00	6.54 [a] (±5.29) 5.30	2.68 [b] (±3.34) 1.18
	C	0.18 [a] (±1.13) 2.04	0.0 [b] (±0.00) 0.00	1.35 [ab] (±1.55) 0.55	4.07 [ab] (±4.22) 2.81
	D	0.01 [b] (±0.29) 0.00	0.0 [b] (±0.00) 0.00	0.00 [b] (±0.00) 0.00	0.88 [c] (±1.61) 0.00
Lake size class	Small	2.12 [a] (±3.17) 0.25	27.06 [a] (±104.33) 0.0	2.78 [a] (±6.02) 0.0	2.82 [a] (±6.16) 0.87
	Medium	3.08 [a] (±3.54) 1.31	64.74 [a] (±187.44) 0.0	3.03 [a] (±4.57) 1.19	2.01 [a] (±3.18) 0.56
	Large	5.42 [b] (±3.12) 4.81	152.06 [b] (±153.76) 120.9	7.11 [b] (±10.65) 4.98	5.51 [b] (±4.40) 3.83

Data marked with the same letter did not differ in a statistically significant manner ($p < 0.001$).

4. Discussion

This study shows that uncontrolled expansion of the tourism infrastructure in the shore zone of the studied lakes has been avoided. The structure of the accommodation facilities located in the shore zone of the studied lakes was consistent with the concept of sustainable tourism. Moreover, the structure of these facilities in the Olsztyn Lakeland may be beneficial with regard to epidemic threats. Built-up areas and related infrastructure have clearly attracted tourism. Field studies showed that new facilities have been built in the region. Moreover, modernized facilities built before the political transformation continue to operate. The number of second homes at the shore zone of some lakes (category C) has increased.

There is a strong correlation between the topography and human activity in the landscape [54]. Lakes are valuable natural resources used by humans for various uses for thousands of years. Archaeological data show that the lakeshores have been settlement sites for centuries [55]. The settlement function of lakes has been significant up until the present day, but their tourist and recreational functions are becoming equally important [25,56,57]. The impact of tourism activities on coastal, marine, and lake areas has been the subject of many studies [8,18,22,58,59].

Ramazanova et al. [18] focused on the indirect effects of tourism activities on the lake, paying great attention to the accommodation sector. The consequence of the Olsztyn Lakeland lakes' tourist attractiveness was the presence of accommodation facilities in the lakeshore zone. It was noted that the accommodation facilities were always accompanied by recreational infrastructure. The presence of recreational infrastructure in the shore zone of the lakes was not always connected to the availability of accommodation facilities. The presence of residential buildings in the shore zone, even if there were no accommodation facilities, was always connected to the presence of docks and access to the water surface. This situation indicates the recreational function of the lakeshore zone as a derivative of the settlement function.

The methodology for modelling the tourism function of lakes used in this study was based on Shapley's game theory. In Shapley's view, a team of players interacts with each other and obtains a 'payoff' in terms of function [46]. The players are not identical, and different players can have different meanings. The problem to be solved is how to distribute the generated 'profit' among the players.

The above problem of "players" can be translated into a model for predicting the tourism function of lakes; i.e., an interaction model of the relationship between spatial factors in a lake's surroundings gaining "profit" in the form of enhancing the lake's tourism function. The explanatory variables are seven spatial factors, and the model acts as a predictor of the tourism function (or lack thereof). Thus, Shapley values are used here to assess the local importance of a variable [60] and its validity for the model [61].

Shapley value-based modelling is not only applied in cooperative game analyses. It is also used for classification analyses [62,63]. In this paper, modelling with the SHAP algorithm is applied for the first time to the analysis of the tourism function of lakes and to tourism research in general.

The coexistence of forests and lakes increases the attractiveness of the landscape both for tourism and settlement [26,64,65]. Moreover, the socio-economic development strategy of the Warmian-Masurian Voivodeship considers tourism to be the main sector of the economy, generating employment [66]. Similar strategies are pursued by many countries and regions of the world considered to be attractive for tourism [67,68]. A clear effect of attracting tourism by built-up areas and related infrastructure is visible. Moreover, the positive correlation of the values of the tested indices with the lake water area shows that smaller lakes, more sensitive to anthropopressure, are less charged by tourism and recreation. Uncontrolled development of residential buildings and tourist infrastructure in the shore zone disturbs the landscape and disrupts the functioning of ecosystems [16,26,69]. For example, in Turkey, small coastal towns have been over-expanded as a result of legal and institutional incentives to invest in tourism. The development of tourist infrastructure, including hotels and second homes, has resulted in aesthetic pollution and severe negative environmental impacts [22]. Most of lakes in Holarctic region are disturbed and their biodiversity is severely threatened [70]. Twenty-one dimensions of tourists' aesthetic evaluation were identified, which were structured into nine themes: Scale, Time, Condition, Sound, Balance, Diversity, Novelty, Shape, and Uniqueness [71]. In relation to the present study, it can be assumed that aesthetic pollution occurs in three areas. Litter left by tourists in the shore zone and in the water is a big problem (Condition). Noise from motor boats on lakes without a quiet zone (Sound) can also be regarded as aesthetic pollution. In many places, the architecture of tourist facilities is inconsistent or does not relate to local traditions (Balance). This applies to an even greater extent to the architecture of settlements, including second homes.

The Warmian-Masurian Voivodeship is one of the poorest regions in Poland with the highest unemployment rate [72]. The development of tourism increasing the number of jobs is a priority for the authorities [73]. Nevertheless, so far, uncontrolled expansion of the tourism infrastructure in the shore zone of the studied lakes has been avoided. The structure of the accommodation facilities located in the shore zone of the studied lakes is consistent with the concept of sustainable tourism. Facilities with up to 50 beds constitute 70% of the number of accommodation facilities and offer about 15% of beds. The different structure of the accommodation facility complexes (resort towns) was represented in many tourist destinations (e.g., Mediterranean seaside, coasts of the Black and the Red Seas, lake Balaton shores, etc.). The benefits of the use of shared tourism resources are often seen as more significant than the potential long-term shared costs of degradation of these resources [74]. Therefore, the concept of sustainable tourism loses out on the current interests of business and local authorities [75]. Field studies have shown that new facilities have been built in the region. Moreover, modernised facilities built before the political transformation continue to operate. Between 1989 and 2018, the number of new accommodation facilities in the lakeshore area increased, but the number of lowstandard resorts decreased. The resorts were replaced by residential buildings. Moreover, some farms were transformed into agritourism farms or guesthouses [76]. Renovation of historical buildings (castles, palaces, manors, mills), which were transformed into hotels and guesthouses, was also popular [77,78]. This is also an example of sustainable tourism development. The main phenomenon related to the development of accommodation in the lakeshore zone was the improvement of the standard, not the expansion of new facilities ([76], present study). The research also shows that the structure of the accommodation facilities in the Olsztyn Lakeland may be beneficial in the context of epidemic threats such as the recent coronavirus SARS-CoV-2 pandemic. Small facilities such as tourist cottages, agritourism farms, or homestay, without the need to contact other tourists and staff, are more secure for several people from the point of view of public health. After a pandemic, the psychological effects may persist in the form of tourists cancelling their stays in large facilities with an abundant number of services, in favour of smaller facilities offering only accommodation.

A cross-functional conflict of tourism and settlement functions in the lakeshore zone in the Olsztyn Lakeland was noted by Furgała-Selezniow et al. [76]. The present study showed the impact of the settlement process on the shore zone (land and water) in the case of some lakes. All lakes with a developed tourism or settlement function (categories A and C, respectively) were characterized by the presence of docks. However, docks were common even in lakes whose shore zone lacked areas developed for tourism or recreation. The field studies showed that after the political transformation in Poland, many accommodation facilities that were state-owned during the socialist period were sold to private persons. The new owners transformed them into residential buildings. The information obtained from the members of the local community shows that this process was caused by the sprawl of the city of Olsztyn. There was also an expansion of second homes associated with the holiday migration of the high-income segment of the society from Warsaw (the capital city of Poland, see Figure 1) and its vicinity. During the COVID-19 pandemic (March & April 2020), the use of second homes by their owners increased. These facilities, due to their remoteness from large human centres, are a good shelter for people living in large cities. They can also be used as quarantine facilities. The area occupied by residential buildings in the shore zone of 143 lakes in the Olsztyn Lakeland increased by 82% during last three decades, mainly at the expense of agricultural land [76]. The main limitation of this study is that it was not possible to determine the dynamics of changes in the development of the shore zone of the lakes. In order to achieve this, similar analyses should be carried out regularly at 5- to 10-year intervals. Comparison of the present results with those obtained in the future will indicate the main trends. This will enable recommendations to be formulated for local administrations in the future.

5. Conclusions

1. Using the SHapley Additive exPlanations algorithm for land use and land cover in the lakeshore zone of the Olsztyn Lakeland, four basic lake types were distinguished.
2. The development of tourism infrastructure in the lakeside area of the Olsztyn Lakeland was carried out in accordance with the principles of sustainable development.
3. A worrisome phenomenon of the expansion of second homes in the shore zone of some lakes in the Olsztyn Lakeland has been noted.

Tourism infrastructure does not threaten lake ecosystems and their shore zone if local authorities apply the concept of sustainable development and tourism activity in the region is properly organised. Residential buildings are almost always accompanied by recreational infrastructure connected to the lake shoreline and the water surface (docks, small private beaches, access to the lake). The key to proper use of the lakeshore zone is the development of tourism based on the improvement of the existing tourism and recreation facilities. Small accommodation facilities may be beneficial for sustainable tourism development and in the context of epidemic threats, such as the recent COVID-19 pandemic. In the present paper, a basic set of indices for the impact of tourism on a lakeshore zone was developed. This methodology can be applied to most post-glacial lakes in Europe and other regions of the world in order to monitor the threats resulting from shore zone exploitation.

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