

РОЗДІЛ III
Географія туризму та рекреації

UDC 556.5+556.18

DOI <https://doi.org/10.32782/geochasvnu.2024.3.09>

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EFFECT OF TOURIST TRAFFIC ON THE ECOSYSTEM OF LAKE MORSKIE OKO

Abstract. The Tatra National Park is the most frequently visited national park in Poland. Its most popular tourist trail is the route to Lake Morskie Oko, the second largest lake in the Tatra Mountains, and the best known mountain lake in Poland. The paper is based on results of field observations, and the analysis of literature and statistical data. The ecosystem of Morskie Oko in this paper is defined as the area of the lake's catchment.

The unique character of Morskie Oko is reflected by its recognition by "The Wall Street Journal" as one of five most beautiful lakes in the world. This results in exceptionally high interest of tourists in the lake despite the difficulties reaching the place. It takes walking a nine-kilometre route with a height difference of 420 m.

Study results show the annual attendance of the place by more than a million people, whereas the number of tourists per day can exceed 10,000. The tourist traffic evidently intensifies between June and September. It results in high human pressure on the lake's waters and surroundings, leading to the degradation of most components of the natural environment. Such high traffic intensity is frequently a nuisance for tourists using the trails themselves.

Moreover, high tourist traffic contributes to the intensification of slope processes, resulting in mass movements in the form of debris and snow avalanches, potentially changing the course of the trails.

Key words: Lake Morskie Oko, Tatra National Park (TNP), tourism, anthropopressure.

Хоїнські Адам, Ільїн Леонід, Маціас Анджей, Зелінські Артур. ВПЛИВ ТУРИСТИЧНОГО ПОТОКУ НА ЕКОСИСТЕМУ ОЗЕРА МОРСЬКЕ ОКО

Анотація. Татранський національний парк є найбільш відвідуваним національним парком у Польщі. Його найпопулярнішим туристичним маршрутом є маршрут до озера Морське Око – другого за величиною озера в Татрах і найвідомішого гірського озера в Польщі. Стаття базується на результатах польових спостережень, аналізі літературних і статистичних даних. Екосистема Морського Ока розглядається як територія водозбірного басейну озера.

Унікальний характер Морського Ока відображено в тому, що видання «The Wall Street Journal» визнало його одним із п'яти найкрасивіших озер світу. Це призводить до надзвичайно високого інтересу туристів до озера, незважаючи на труднощі з доступом до місця. Необхідно пройти дев'ятикілометровий маршрут із перепадом висот 420 м.

Результати досліджень свідчать про відвідування озера понад мільйоном осіб на рік, а кількість туристів на день може перевищувати 10 тисяч. Туристичний потік помітно посилюється з червня до вересня. Це призводить до високого антропогенного впливу на воду озера та його водозбір, що спричинює деградацію більшості компонентів природного середовища. Така висока інтенсивність руху іноді є незручною для туристів. Окрім того, високий туристичний потік сприяє інтенсифікації схилових процесів, що призводить до масових переміщень сміття та снігових лавин, що потенційно може змінити маршрут стежок.

Ключові слова: озеро Морське Око, Татранський національний парк (ТНП), туризм, антропопресія.

Introduction. In the system of protected areas in Poland, national parks are the highest form of nature protection. A total of 23 national parks currently function in Poland. They together occupy only approximately 1% of the area of the entire country. In 2021, Polish national parks were visited by 16.1 million people, whereas the number of visitors shows an increasing trend (Fig. 1). The most popular of the parks is the Tatra National Park, established in 1947. In 2021, it was visited by 4.8 million people (Fig. 2). In 2020, it generated 25.7% of tourist traffic, and in 2021 as much as 29.8%, considering attendance to all national parks in Poland. The Tatra National Park (TNP) is exceptional, because it is the only high mountain area in Poland with Alpine character. It features landscapes not encountered in any other place in the country, as well as high geo- and biodiversity (see: Szafer, 1962; Mirek, 1996; Przemiany środowiska..., 2002; Kele & Lucansky, 2003; Paryska-Radwańska & Paryski, 2004; Siarzewski, 2005; Januszewski et al., 2005; Choiński & Pociask-Karteczka, 2014; Atlas Tatr..., 2015). It is also a subject of interest of researchers from many scientific disciplines, including those focusing on tourist traffic and its effect on the natural environment (e.g. Czochański, 2000; Gorczyca & Krzemień, 2002; Wala, 2006; Choiński et al., 2007; Baścik et al., 2007; Skawiński, 2010; Hibner, 2012; Ziółkowska-Weiss, 2012; Pociask-Karteczka, 2014; Miazek, 2017; Ćwiek & Pater, 2020; Fesyuk et al., 2020; Senetra et al., 2020).

Study area. According to the latest physico-geographic regionalisation of Poland, Lake Morskie Oko (Photo 1) is located in the High Tatra Mountains (514.53) mesoregion belonging to the Tatra Range (514.5) macroregion (Solon et al., 2018; Richling et al., 2021). The water surface is at a height of 1395.4 m a.s.l. The morphometric properties of the lake are as follows: surface area – 32.93 ha, water volume – 9904.3 km³, length 830 m, maximum width – 500 m, mean width – 402 m, elongation index – 1.66, length of shoreline – 2484 m, shoreline development – 1.16, maximum depth – 51.8 m, mean depth – 29.7 m, bottom slope – 13°13', bottom surface area – 34.3 ha (Choiński & Ptak, 2014; Choiński & Zieliński, 2023). It is the second largest lake in the Tatra Mountains in terms of surface area. The only larger one is Lake Wielki Staw in the Pięciu Stawów Polskich Valley. At the scale of the country in terms of surface area among more than 7000 Polish lakes (with a surface area of more than 1 ha), it occupies approximately 1650th position. In terms of maximum depth, Morskie Oko is 23rd, and in terms of mean depth – 4th.

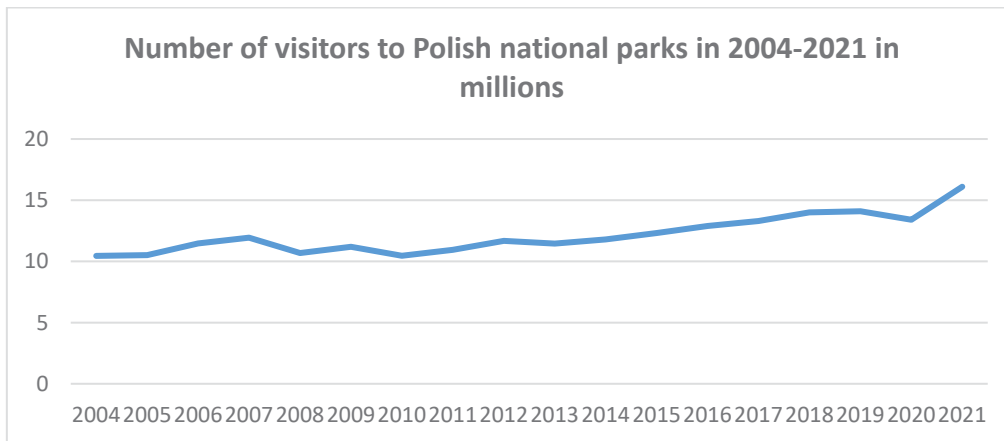


Fig. 1. Number of visitors to national parks in the period 2004–2021

Source: prepared on the basis of <https://stat.gov.pl>

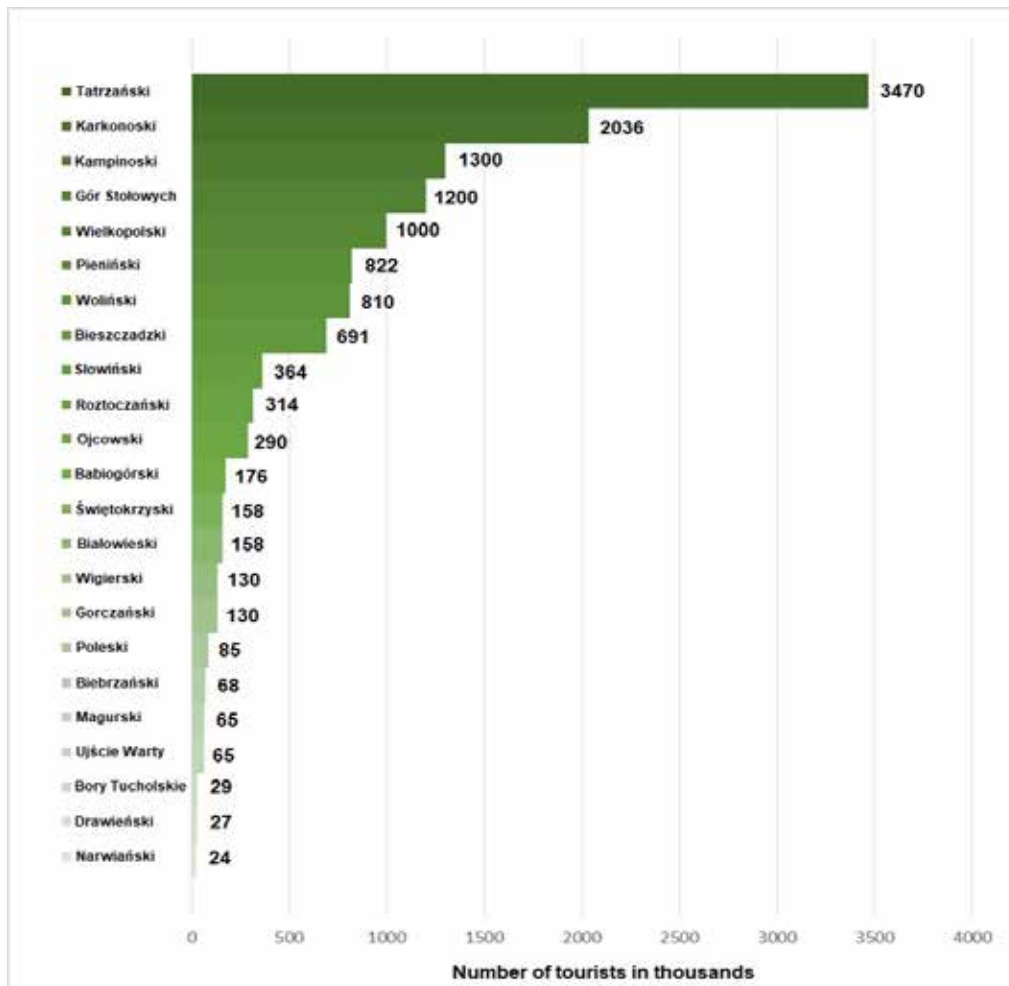


Fig. 2. Number of visitors (in thousands) to national parks in 2020

Source: <https://stat.gov.pl/portal-edukacyjny/polskie-parki-narodowe-wystawa/>

The analysed lake is located within the catchment of the Rybi Potok River with a total surface area of 11.3 km². The surface area of the upper part of the catchment until the hydrometric profile on the outflow from Morskie Oko, also covering the catchment of Czarny Staw at Rysy, is

5.9 km² (Wit-Jóźwik, 1974). It is so-called projected area of the catchment of Morskie Oko. Its actual surface area is 7.9 km². Other morphometric parameters of the catchment include: length of catchment – 2250 m, average width of catchment – 2620 m, terrain height difference – 1105.2 m, length of the watershed – 10.35 km, average absolute height – 1890 m a.s.l., catchment slope – 454.7‰, lake density index – 9.1%. The watershed of the catchment of Morskie Oko evidently runs along ridges with culminations, including among others: to the east – Rysy (2499 m a.s.l.), Niżnie Rysy (2430 m a.s.l.); to the south and south-west – Mięguszowiecki Szczyt (2438 m a.s.l.), Hińczowa Turnia (2377 m a.s.l.); to the west – Miedziane (2233 m a.s.l.) and Opalony Wierch (2115 m a.s.l.); to the north the catchment is confined to the watershed running down from Opalony Wierch and Żabia Czuba to the outflow of Rybi Potok from Morskie Oko. It should be emphasised that the European watershed separating the basins of the Baltic Sea and the Black Sea runs from Szpliglasowy Wierch to Cubryna.



Photo 1. *General view to Morskie Oko and its vicinity.
It is one of the most recognisable natural landscapes in Poland*

The catchment is dominated by rock outcrops and debris. It is primarily built of weakly sealed rocks (as much as 63.9%), mainly granitoids. Relatively considerable areas are covered by highly permeable rocks, i.e. rubbles, gravels, and sands surrounding Morskie Oko and Czarny Staw at Rysy. Plant formations primarily include dwarf pine and grassy vegetation. Forest assemblages are of island character, and grow in the immediate vicinity of Morskie Oko.

The first marked trails in the area of Morskie Oko were established in the second half of the 19th century. The catchment of the analysed lake currently covers 5 trails:

- Morskie Oko Shelter – Rysy with a length of 3840 m (including 400 m of difficult trail);
- Czarny Staw – Pod Chłopkiem Pass with a length of 1480 m (including 840 m of difficult trail);
- Morskie Oko Shelter to the intersection with the trail to Czarny Staw – 1280 m;
- Morskie Oko Shelter – Wrota Chałubińskiego from the fork in the trail to the Szpliglasowa Pass – 1040 m;
- Morskie Oko Shelter – Szpiglasowa Pass – 3840 m.

The above lengths of trails were calculated based on the “Polish Tatra Mountains” (1984) topographic map at a scale of 1:10.000. The density of tourist trails in the catchment of Morskie Oko is 1776 m/km².

The difference in height between Mięguszwiecki Szczyt, the highest peak in the direct vicinity of the lake, and the lake surface reaches as much as 1043 m. The lake and the surrounding peaks make for one of the most recognisable landscapes in Poland.

The objective of the paper is the assessment of the effect of tourist traffic on the ecosystem of Lake Morskie Oko and its functioning.

Materials and study methods. This article is based on multiannual observations and field research, both in the lake itself and in its catchment. Their results were supplemented with related literature data, analysis of master theses and literature on the subject, and selected statistical data from the Local Data Bank of the Central Statistical Office. Photographic documentation prepared during field research as well as aerial and satellite images were also used. Cartographic studies in the form of topographic maps at different scales, atlases, and thematic maps were extremely helpful.

The basic study methods included: analysis of source and statistical materials, comparative analysis, field observations and measurements, cartometric methods, surveys on trails regarding the intensity of tourist traffic, field interviews e.g. with employees of the Tatra National Park, “Morskie Oko” shelter, station of the Institute of Meteorology and Water Management (IMGW), or the Mountain Voluntary Rescue Service (GOPR).

Photographs included in this paper with unspecified source come from the collection of the authors.

Results and discussion. The Tatra National Park has been enjoying high and constantly increasing interest among tourists for many years. Already in the period 1993–2012, Pociask-Karteczka (2014) observed that the annual number of tourists can considerably exceed 2 million people. The author estimated the average number of tourists from the study period for 2,067 million. In 2021, TNP was visited by a record number of people reaching 4,600,025. High frequency was also recorded in 2022, equalling 4,580,015 people. Considering the additional estimation by TNP, the analysed park can be considered to have been visited by 4,789 thousand people in 2021, and 4,786 thousand people in 2022 (Table 1). The additional estimation considers among others visits outside of the periods of functioning of points of sale of tickets (1.5% of all sold tickets), visits of local residents and other people exempt from fees (based on monitoring conducted by dealers), visits with no tickets 3% (e.g. visits to TNP where no points of sale of tickets function and purposeful evasion), visits of residents of mountain shelters, and visits of holders of the European Large Family Card (<https://tpn.pl/zwiedzaj/turystyka/statystyka>).

Fig. 3 presents the number of visitors to TNP in 2021 by ticket offices in different places of entry. It shows the dominance of the ticket office in Łysa Polana, i.e. the trail to Morskie Oko beginning in Białczańska Palenica. Fig. 4 shows the number of tickets sold at that point in the period 2014–2022. It shows an evident decrease in the number of sold tickets in 2020 due to the COVID-19 pandemic. In 2021, the peak of tourist traffic occurred in July, and not traditionally in August. Considering daily frequency, according to Choiński et al. (2007) the maximum daily tourist traffic occurs between 10.00 am and 1.00 pm, when approximately 70% of tourists enter TNP. The intensity of tourist traffic at that time is approximate to 20 persons/min (Choiński et al., 2007).

The tourist traffic shows high frequency throughout the year. It is even substantial in winter months (Fig. 3), despite frequently very difficult conditions due to avalanches and thick snow cover on the trail. Owing to the location and exceptional popularity of Morskie Oko, tourist traffic is channelled there, resulting in considerably less traffic on other tourist trails, and consequently less human pressure. In June, July, and August, tourist traffic in the area of Morskie Oko appears to exceed the capacity of the area.

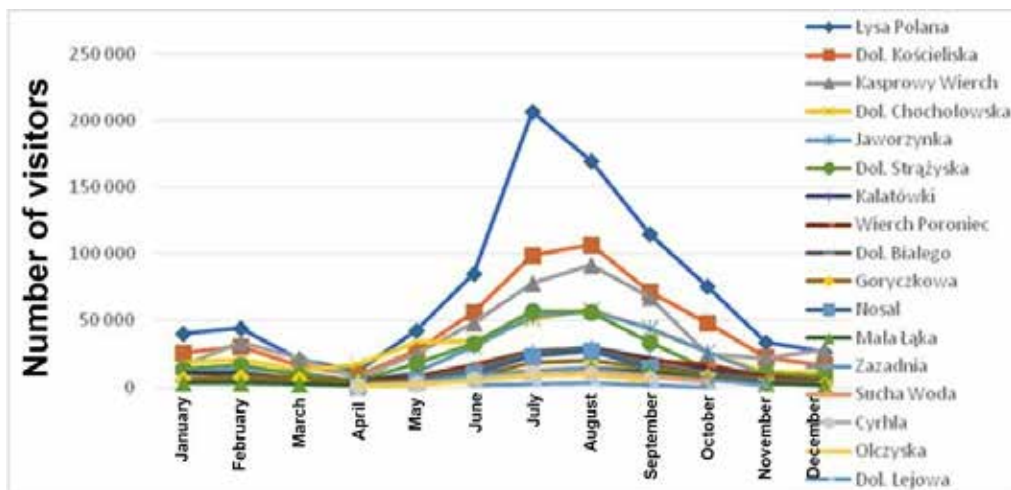


Fig. 3. Number of visitors to TNP in 2021 based on sale of tickets in particular ticket offices
 Source: <https://tpn.pl/zwiedzaj/turystyka/statystyka>

Table 1

Number of visitors to TNP in the period 2015-2022 (with additional estimation by TNP)

No.	Year	Number of tourists in millions
1.	2022	4,786
2.	2021	4,789
3.	2020	3,470
4.	2019	3,947
5.	2018	3,974
6.	2017	3,770
7.	2016	3,683
8.	2015	3,348

Source: <https://tpn.pl/zwiedzaj/turystyka/statystyka>

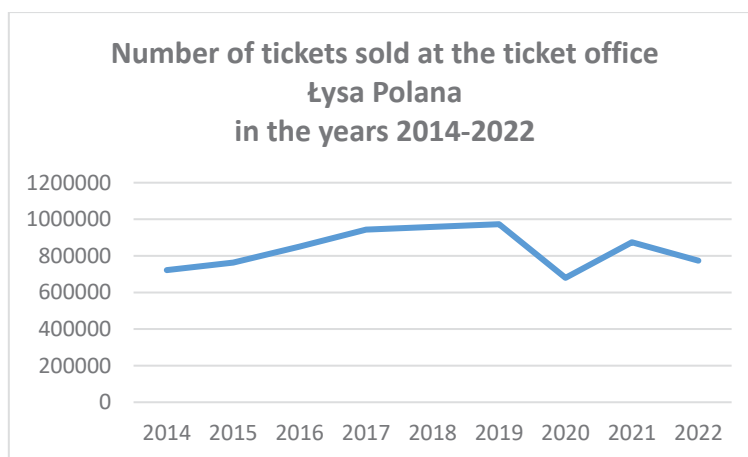


Fig. 4. Number of visitors to TNP in the vicinity of Morskie Oko in the years 2014–2022 based on sale of tickets at the ticket office Łysa Polana

Notice: the period does not consider online sale of tickets, 7-day tickets, and entry of persons exempt from the fee, as well as local residents, skiturers, and entries based on the European Large Family Card.

Source: prepared on the basis of <https://tpn.pl/zwiedzaj/turystyka/statystyka>

According to Pociask-Karteczka (2014) and other sources (e.g. Stachowska, 2006), Morskie Oko is the destination of approximately 30-35% of visitors to TNP. This suggests that relatively after 2020, Morskie Oko is annually visited by more than 1 million people, averaging above 3500 people daily. According to surveys, the Morskie Oko trail had constituted the destination from 2 to 5 times for more than 50% of respondents. The share of respondents that attended the trail to Morskie Oko for the first time did not exceed 20%. Based on answers of tourists that had visited TNP several times, they consider the trail to Morskie Oko as a place that needs to be visited during every stay. People that had visited TNP many times (10 times or more) often skip the trip to Morskie Oko and instead search for places considerably less frequented by tourists. Almost half of respondents in the survey declared that the choice of the trail to Morskie Oko plays an important role in the improvement of their physical and mental condition. Slightly less respondents reported that the purpose of the trip to Morskie Oko is to admire the landscape and take photographs. According to the reports of tourists, a drawback of the trail is excessive intensity of tourist traffic. Such an opinion was expressed by as many as 1/3 of respondents. They also drew attention to people disturbing the peace and quiet, and loud participants of numerous summer camps for the youth. Another nuisance is the asphalt road, strongly damaged on certain sections, potentially causing falls and injuries. This problem was pointed out by approximately 30% of respondents. Tourists also point to the lack of trash cans along the asphalt road to Morskie Oko (!), as well as horse faeces that make its use difficult. The lack of trash cans can be easily explained with the fact that they would serve as sources of food for wild animals, and particularly bears. This in turn would pose a serious threat to tourists walking on the trail. Regarding horse faeces, the opinion of tourists is justified – it should be removed. It constitutes an additional uncontrolled source of nutrients that are supplied to the streams with precipitation waters.

It is particularly worth emphasising that a high number of respondents are completely ignorant to the negative effect of tourist traffic on the abiotic and biotic elements of the natural environment. The problem of damage to vegetation due to excessive tourist traffic is particularly evident along the trail running around Lake Morskie Oko. In our opinion it results from the fact that it is several times larger than the trail running to the lake on the asphalt road.

High intensity of tourist traffic, exceeding the natural capacity of the area, results in strong human pressure (Paulo et al., 2002). It is manifested in the degradation of particular components of the natural environment.

The direct consequence is a high number of people in the zone of the lake's shoreline, with the following negative effects:

- wading in the lake, causing supply of nutrients to the water;
- throwing unconsumed food to the water, also contributing to the eutrophication of the lake waters;
- leaving waste in the shore zone of the lake (often hiding it between boulders) which at high water levels results in its washing to the lake;
- “traditional” tossing of coins to the lake “for luck” or in the scope of the superstition that it results in returning to the same place in the future;
- defecating and urinating among boulders and dwarf pines resulting in the supply of the waste to the lake with intensive surface flows;
- trampling and damaging vegetation adjacent to the trails;
- damage to soils, particularly initial, through compression;
- incidental dragging of plant species alien to the ecosystem of Lake Morskie Oko;
- collecting specimens of plants and rocks as a “souvenir”;
- making noise and disturbing wild animals, resulting in the disturbance of the functioning of fauna;
- in winter, due to a high number of tourists stepping onto the ice cover under snow, leaving substantial amounts of waste behind, resulting in its falling to the bottom after melting of the ice cover;

- throwing (for “fun”) high amounts of rock material to the shore zone of the lake;
- despite ban on bathing, bathing (swimming) in the lake waters (Photo 2);
- washing the face and hands in the lake after using sun protection creams and oils, resulting in so-called “greasy stains” on the water surface;
- washing (with no detergents) of sweaty clothing that is later dried on nearby dwarf pines;
- rinsing by tourists of dishes after having a meal at the shore of the lake.



Photo 2. Photographs illustrating an example of breaking the ban of bathing in Morskie Oko

Such amounts of biogenic substances from different sources supplied to the lake waters very negatively affect its quality. According to Choiński et al. (2007), the lake waters represent the ultraoligotrophic type, and according to Żelazny et al. (2014), the ultrafresh type. They are characterised by a low level of mineralisation, high transparency (approximately 15 m), good oxygenation, and low temperature. The ecosystem of the analysed lake shows strong internal integration and strong dependencies between particular components. As a result, it is a highly susceptible lake, sensitive to any changes. Even small concentrations of nutrients can disturb or alter its homeostasis (dynamic balance) through an increase in the trophic status and primary production. This in turn contributes to changes at higher levels of the food web, and to the degradation of the lake’s water resources.

Theoretically, a single bathing person contributes 0.05 g of phosphorus and 1 g of total nitrogen per day (Szyper, 1983; Bajkiewicz-Grabowska, 2002). Assuming that in summer months, from June to the end of August, approximately half of visitors to Morskie Oko submerges their arms and legs in water for 0.5 h, they are estimated to contribute 34 kg of phosphorus and 680 kg of total nitrogen to the lake during that period. Moreover, with surface flow, the lake waters are supplied with biogenic compounds from faeces of tourists in the shore zone of the lake. This results in an increase in the production of biotic mass in the lake waters, bacteriological contamination of the waters, and an increase in the BZT₅ index (see Kownacki et al., 1996). According to Kajak (1979), introducing 1 kg of phosphorus to the waters allows for the production of approximately 1 tonne of fresh algal mass. Considering the volume of the lake waters, it seemingly appears a low value. It should be emphasised, however, that it is only one of the components of the total supply of nutrients to the waters. It is difficult to estimate other components such as the supply of nutrients with slope surface flow. In a longer time perspective, such supply may increase with an increase in the number of tourists.

According to Choiński et al. (2007), over the year, the peak abundance of heterotrophic bacteria is strongly correlated with the intensity of tourist traffic, and the general presumption of the cleanliness of water in the lake is no longer thoroughly confirmed today. Czapski and Mizgajska (1996) reported finding eggs of the roundworm and human whipworm in the vicinity of Morskie Oko (and not only) as a result of contamination with human faeces.

Throwing coins into the lake reduces the aesthetic value of the water due to its high transparency, and it may cause release of some metal elements or their compounds through oxidation (Choiński et al., 2007).

Wading in the shore zone of the lake, including between boulders (where sediment of fine fractions is deposited) causes water turbidity and disturbs the structure of bottom sediments. It is important to realise that walking on the ice cover of the lake can also be dangerous due to the risk of avalanches (Photo 3 and 4).



Photo 3. *Snow avalanche and the organic and mineral material brought by it visible on the surface of Morskie Oko. The avalanche damaged a large area of the ice cover of the lake with a thickness exceeding 0.5 m*

(Author: W. Denega, 2023)



Photo 4. *In the foreground, remains of snow avalanche that encroached Morskie Oko in winter visible on the lake shore*

Conclusions. The rich and diverse environmental values of the area of Morskie Oko and its favourable location near the international border crossing on Łysa Polana, as well as its high accessibility and good tourist infrastructure provide for high tourist attractiveness of the discussed area. Unfortunately, it also causes excessive and intensive tourist traffic posing a serious threat for the natural values of the area. All trends and forecasts regarding tourist traffic show intensification of the

traffic in the future. Although access to the mountain shelter cannot be restricted, measures should be undertaken aimed at reducing the pressure of tourists on the ecosystem of Lake Morskie Oko. One of them is the postulate of restricting traffic around the lake, already proposed in 2007 by Choiński et al. (2007). It particularly concerns the western shore of Morskie Oko. It also appears justified to introduce monitoring of the direct vicinity of Morskie Oko including information boards notifying visitors on the monitoring. It also appears necessary to undertake activities aimed at dispersing tourist traffic from excessively visited places within TNP.

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Стаття надійшла до редколегії
15.12.2023 р.