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# RELATIONS BETWEEN MORPHOMETRIC AND TROPHIC PARAMETERS OF SHALLOW LAKES OF THE POLISH LOWLAND

**Summary.** Majority of Polish lakes are shallow lakes, which constitutes about 60% of the total number and gather significant volume of water. Shallow lakes situated in lowlands are often susceptible to eutrophication and degradation due to influence of different factors, e.g. soil type, high density of human population and several types of human activities. Also other factors, such as lake morphometry, altitude and watershed area also influence lake ecosystem. Lakes selected to examination were characterised by altitude up to 200 m a.s.l., maximum depth up to 10 m, mean depth up to 5 m and accessible information about concentration of trophic parameters. Data used in analyses such as Secchi depth, concentration of total phosphorus, dry mass of seston and chlorophyll *a*, lake and watershed area, lake morphometry were collected mostly from public statistics edited by National Inspectorate for Environment Protection (PIOŚ) for years 1982-1993 and from own surveys for years 1997-2000. Statistical comparisons were made for seven morphometric and four trophic parameters. Significant linear correlations between chlorophyll *a*, dry mass of seston and Secchi depth and morphometric parameters were found. In case of the studied shallow lakes both the depth of water and lake water area play an important role in establishing the level of water trophy, whilst influence of Schindler coefficient is negligible. A complex impact of morphometric parameters was assessed using CCA method. Results showed, that the most diverse trophic parameter was Secchi depth, which depended on average depth, maximum depth of lake water and altitude.

**Key words:** shallow lakes, lake morphometry, trophic parameters, the Polish Lowland

## Introduction

In the total number of 7081 lakes (with area over 1 ha) in Poland the shallow lakes are majority (about 60%), thus despite relatively small water volume their contribution in total amount of water reserves is important (CHOIŃSKI 1995). Lakes situated in lowlands are generally susceptible to eutrophication due to soil conditions (erosion, availability of nutrients and others) and higher density of human population and human activities (industry, transport, waste waters, agriculture) than in mountain areas. Other factors, such as lake morphometry, altitude and watershed area influenced on lakes too and for many of them these factors are significant (WETZEL and LIKENS 1991, HEATHWAITE 1995, SAPEK 1998, NÕGES et AL. 2003). Shallow lakes and ponds are crucial in maintenance of water in rural areas of central and northern Poland where mean annual precipitation for years 1971-2000 was 507 mm (OCHRONA... 2005). These water bodies in comparison to deep lakes are strongly affected by water level fluctuations, which can significantly change water quality and food web structure (COOPS et AL. 2003, STANISZEWSKI and SZOSZKIEWICZ 2006).

Better understanding of factors influencing lake susceptibility to degradation is necessary due to inconvenient water balance and water demands in agriculture. Knowledge of interrelations between lake morphometry and water quality parameters can be also helpful in reaching a good ecological status of lake waters and in attempts to restore the degraded lakes.

## Materials and methods

Lakes selected to examination were characterised by altitude up to 200 m a.s.l. (the Polish Lowland), maximum depth up to 10 m, mean depth up to 5 m and accesible information about concentration of trophic parameters. These criteria were met by 69 lakes (Fig. 1, Annex 1).


Fig. 1. Distribution of shallow lakes used in studies in Poland
Rys. 1. Rozmieszczenie w Polsce płytkich jezior wykorzystanych do analiz

Data used in analyses such as Secchi depth (SD), concentration of total phosphorus (TP), dry mass of seston (DMS) and chlorophyll *a* (Chl *a*), lake and watershed area, lake morphometry were collected from public statistics edited by the National Inspectorate for Environment Protection for years 1982-1993 (152 records from 67 lakes) and from own surveys for years 1997-2000 (14 records from three lakes, one lake was common for both sources of data) (CYDZIK and SOSZKA 1988, CYDZIK et AL. 1992, 1995, STANISZEWSKI 2001).

The trophic parameters used for statistical analyses were average values from two measurements undertaken in surface layer of lake water (spring and summer period) according to the standard methodology of lake's studies (KUDELSKA et AL. 1994). Lakes morphometry and trophic level of lakes selected for further studies are shown in Tables 1 and 2.

Table 1. Morphometric characteristics of studied lakes
Tabela 1. Charakterystyka morfometryczna analizowanych jezior

| Statistics | Altitude (m a.s.l.) | Lake water area (ha) | Lake water volume (1000 $m^3$) | Maximum depth (m) | Average depth (m) | Watershed area ($km^2$) | Schindler coefficient (ha/$m^3$) |
|---|---|---|---|---|---|---|---|
| Average | 101.2 | 270.9 | 5 789.6 | 6.1 | 2.7 | 116.3 | 41.0 |
| Median | 103.2 | 85.3 | 2 151.8 | 6.2 | 2.9 | 26.4 | 10.6 |
| Maximum | 176.7 | 7 140.0 | 117 521.0 | 9.7 | 5.0 | 1 607.7 | 765.4 |
| Minimum | 0.1 | 8.8 | 149.6 | 1.9 | 0.6 | 1.0 | 0.7 |
| Standard deviation | 41.8 | 1 149.0 | 19 396.8 | 2.1 | 1.0 | 287.7 | 98.0 |

Table 2. Trophic conditions of studied lakes
Tabela 2. Warunki troficzne analizowanych jezior

| Statistics | Chlorophyll *a* (mg/$m^3$) | Dry mass of seston (mg/$dm^3$) | Secchi depth (m) | Total phosphorus (mg/$dm^3$) |
|---|---|---|---|---|
| Average | 39.23 | 12.50 | 1.23 | 0.240 |
| Median | 22.20 | 10.70 | 1.00 | 0.170 |
| Maximum | 597.20 | 65.00 | 3.70 | 0.838 |
| Minimum | 1.90 | 0.80 | 0.20 | 0.026 |
| Standard deviation | 66.31 | 12.38 | 0.69 | 0.169 |

Normal distribution of dataset was evaluated using *W* Shapiro-Wilk test. The interpretation based on this test have significant statistical power in comparison to other tests (SHAPIRO et AL. 1968). In case of most parameters the distribution of data was asymetrical and to obtain normal or close to normal distribution the transformation of data was necesarry. The optimal transformation was log ($x$ + 1), that *W* statistics was the highest. In some cases (water depth, total phosphorus, Secchi depth) other transformations such as $\sqrt{x}$ and $\sqrt[3]{x}$ were used. Only in case of altitude data distribution was close to normal and were not transformed (Table 3).

Table 3. Type of transformations used to obtain data distribution close to normal, values of *W* statistics (Shapiro-Wilk test)
Tabela 3. Rodzaje transformacji użytych celem uzyskania rozkładu zbliżonego do normalnego, wartości statystyki *W* (test Shapiro-Wilka)

| Morphometric/trophic parameter | Transformation | *W* statistics |
|---|---|---|
| Altitude | Not transformed | 0.889 |
| Lake water area | log ($x$ + 1) | 0.934 |
| Lake water volume | log ($x$ + 1) | 0.968 |
| Maximum depth | $\sqrt{x}$ | 0.939 |
| Average depth | $\sqrt{x}$ | 0.942 |
| Watershed area | log ($x$ + 1) | 0.977 |
| Schindler coefficient | log ($x$ + 1) | 0.949 |
| Chlorophyll *a* | log ($x$ + 1) | 0.985 |
| Dry mass of seston | log ($x$ + 1) | 0.993 |
| Secchi depth | $\sqrt[3]{x}$ | 0.952 |
| Total phosphorus | $\sqrt[3]{x}$ | 0.975 |

To specify the relationships between lake morphometry and trophic parameters of water the Pearson's linear correlation was used. Hydrographic features used for comparisons were lake water area and volume, maximum and average depth, watershed area and Schindler coefficient (watershed with lake area/lake water volume). Influence of lake morphometry, altitude and watershed area on trophic parameters was evaluated using one-way ANOVA method (STATISTICA... 2003). The complex influence of selected morphometric parameters on chlorophyll *a*, dry mass of seston, Secchi depth and total phosphorus was tested using canonical correspond analysis (CCA) (TER BRAAK and SMILAUER 1998).

## Results

According to Pearson correlation the Secchi depth and dry mass of seston were often related to morphometry (Table 4). In lakes with greater water area, lake water volume and watershed area the average values of Secchi depth were low but were increasing with the increase of water depth. Dry mass of seston and chlorophyll *a* concentrations showed correlation with most of studied morphometric parameters, while for the total phosphorus such a strong relationships were not observed.

Table 4. Pearson coefficients *r* of linear correlation for studied trophic parameters (after transformation of data)
Tabela 4. Współczynniki korelacji liniowej *r* Pearsona dla analizowanych wskaźników trofii (po transformacji danych)

| Morphometric parameter | Chlorophyll *a* | Dry mass of seston | Secchi depth | Total phosphorus |
|---|---|---|---|---|
| Altitude | –0.36* | –0.41* | 0.29* | –0.10 |
| Lake water area | 0.33* | 0.42* | –0.49* | 0.06 |
| Lake water volume | 0.30* | 0.42* | –0.42* | 0.10 |
| Maximum depth | –0.24 | –0.32* | 0.27* | –0.15 |
| Average depth | –0.30* | –0.31* | 0.35* | –0.12 |
| Watershed area | 0.24 | 0.26* | –0.32* | 0.01 |
| Schindler coefficient | 0.01 | –0.07 | –0.01 | –0.08 |

*Statistically significant coefficients ($p < 0.001$).

According to one-way ANOVA in case of lowland lakes the significant influence of altitude was found for DMS and Secchi depth (Table 5). Lakes situated in elevations below 100 m a.s.l. showed higher concentrations of trophic parameters. These values were strongly related to lake water area. In smaller lakes (below 100 ha) water trophy was lower and it was significant relation for most of trophic parameters except TP, which was on similar level in small and in big lakes (Fig. 2 a). According to lake water volume the significant impact was found for DMS and SD. In case of water depth the deeper lakes had lower concentrations of biogens (Figs. 2 b, 2 c). Lake watershed area had significant impact on SD, which was low when area was high. The Schindler coefficient had no significant impact on any of studied parameters but generally higher SC values were related with decrease of Chl *a* and DMS concentrations.

Table 5. Summary of results of one-way analysis of variance; *F* statistics (4, 166)
Tabela 5. Podsumowanie wyników jednokierunkowej analizy wariancji, statystyka *F* (4, 166)

| Morphometric parameter | Chlorophyll *a* | Dry mass of seston | Secchi depth | Total phosphorus |
|---|---|---|---|---|
| Altitude | | *** | ** | |
| Lake water area | ** | **** | **** | |
| Lake water volume | | * | ** | |
| Maximum depth | ** | *** | ** | |
| Average depth | **** | **** | **** | |
| Watershed area | | | *** | |
| Schindler coefficient | | | | |

*Statistically significant difference with: *$p < 0.1$, **$p < 0.01$, ***$p < 0.001$, ****$p < 0.0001$.

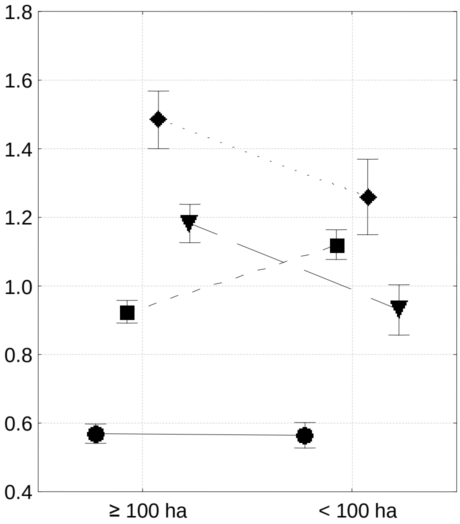


Fig. 2 a. Variety of trophic parameters according to area of lake (< 100 ha and ≥ 100 ha)
Rys. 2 a. Zróżnicowanie wskaźników troficznych na tle powierzchni jeziora (< 100 ha oraz ≥ 100 ha)

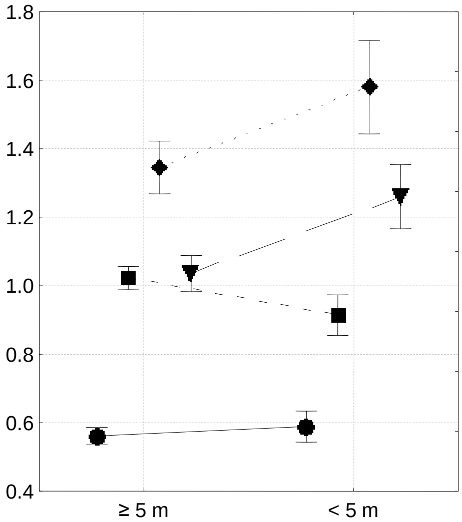


Fig. 2 b. Variety of trophic parameters according to maximum depth (< 5 m and ≥ 5 m)
Rys. 2 b. Zróżnicowanie wskaźników troficznych na tle głębokości maksymalnych (< 5 m oraz ≥ 5 m)

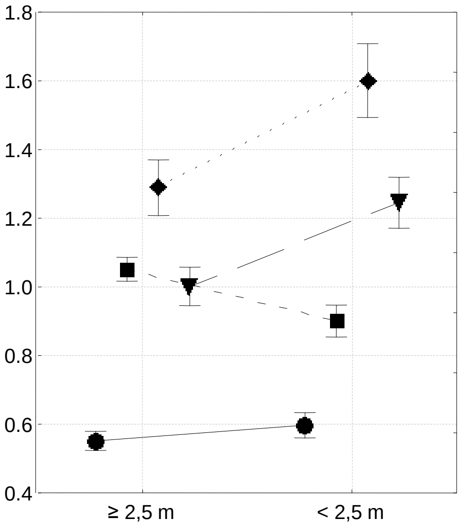


Fig. 2 c. Variety of trophic parameters according to average depth (< 2.5 m and ≥ 2.5 m)
Rys. 2 c. Zróżnicowanie wskaźników troficznych na tle głębokości średnich (< 2.5 m oraz ≥ 2.5 m)

Explanations:
total phosphorus, Secchi depth, chlorophyll *a*, dry mass of seston; whiskers showed 0.95 confidence intervals
Objaśnienia:
fosfor ogólny, widzialność krążka Secchiego, chlorofil *a*, sucha masa sestonu; wąsy przy symbolach obrazują przedziały ufności na poziomie 0,95

The relationships between trophic and morphometric parameters were shown on CCA ordination plot (Fig. 3, Table 6). The results of Monte Carlo permutation test indicate, that observed dependences between trophic and morphometric parameters are not accidental ($F$ = 5.33, $p$ = 0.002, number of permutation: 499). An impact of lake morphometry was observed with reference to two directions of changeability. First axis explained 89.8% of total variance of trophic-morphometric parameters relation and included majority of parameters (lake water volume, lake area, watershed area, average depth, maximum depth and elevation in meters above sea level). The second axis explained only 6.5% of total variance of trophic-morphometric parameters relation and was related with Schindler coefficient.

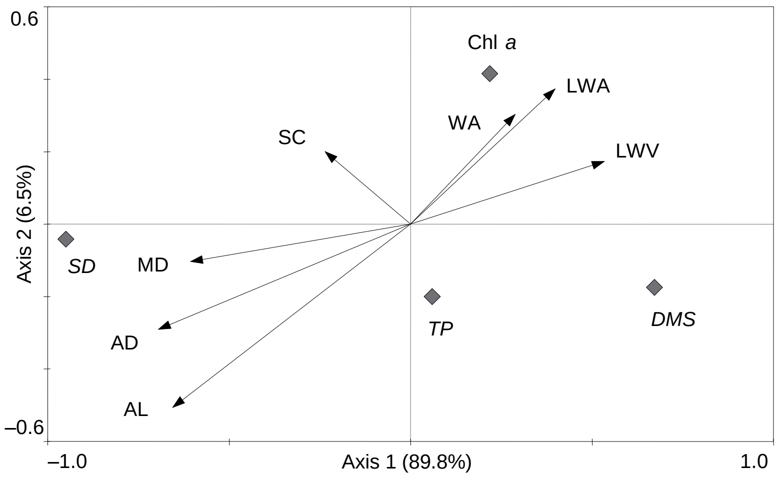


Fig. 3. Canonical correspondence analysis (CCA) ordination diagram with trophic parameters (marks) and morphometric parameters (arrows). Explanations: AD – average depth, AL – altitude, LWA – lake water area, LWV – lake water volume, MD – maximum depth, SC – Schindler coefficient, WA – watershed area, Chl *a* – chlorophyll *a*, *DMS* – dry mass of seston, *SD* – Secchi depth, *TP* – total phosphorus.

Rys. 3. Wyniki zależności pomiędzy wskaźnikami troficznymi (znaczki) a morfometrycznymi (strzałki) uzyskane za pomocą kanonicznej analizy korespondencji (CCA). Objaśnienia: AD – głębokość średnia, AL – wysokość nad poziomem morza, LWA – powierzchnia jeziora, LWV – objętość jeziora, MD – głębokość maksymalna, SC – współczynnik Schindlera, WA – powierzchnia zlewni, Chl *a* – chlorofil *a*, *DMS* – sucha masa sestonu, *SD* – widzialność krążka Secchiego, *TP* – fosfor ogólny.

The most diverse trophic parameter, from four analysed ones, was Secchi depth, which most of all depended on average depth, maximum depth and elevation and its value was the highest when values of those three parameters were also high. Other lake characteristics, as like lake water volume, lake area and watershed area also had influence on water transparency. Analysed morphometric parameters were in a small relationship with total phosphorus.

Table 6. The basic statistics describing two first axes from canonical correspondence analysis (CCA)
Tabela 6. Podstawowe statystyki opisujące dwie pierwsze osie wyodrębnione w kanonicznej analizie korespondencji (CCA)

| Statistics | Axes | |
|---|---|---|
| | 1 | 2 |
| Eigenvalues | 0.051 | 0.011 |
| Trophic-morphometric parameters correlations | 0.540 | 0.312 |
| Cumulative percentage variance | | |
| of water tropic parameters | 20.8 | 22.3 |
| of trophic-morphometric parameters relation | 89.8 | 96.3 |

Dry mass of seston and chlorophyll *a* were mostly depended on lake water volume, lake area and watershed area changes. Moreover, e.g. the low elevation of researched lakes and low average depth correlated with high content of chlorophyll *a*. Small maximum depth was related to the high content of dry mass of seston. The relationships between Schindler coefficient and Secchi depth, dry mass of seston, chlorophyll *a* were not observed.

## Discussion

The area of watershed, morphometric parameters and lake type affects strongly all processes occurring in lake ecosystems, e.g. sedimentation, internal loading and outflow, thus they have impact on water quality parameters (KUDELSKA et AL. 1994, KAJAK 1998, HÅKANSON 2005). This influence is observed also in shallow lakes.

Taking into account data from 69 lakes the significant linear correlations between Chl *a*, DMS, SD and several morphometric parameters were found. Positive correlations were found between Chl *a* and DMS and lake water area and volume and negative correlations were observed in case of water depth and altitude. In general, lakes with greater area have greater adjacent watershed area and longer shore line than small lakes (with exception of lakes with very irregular shore line) that watershed is influence on water quality could be stronger (KUDELSKA et AL. 1994). Such lakes, especially shallow ones are more susceptible for degradation and thus e.g. water transparency can be low. Secchi depth values depends strongly on lake morphometry and other factors, such as autochthonous production, allochthonous materials and resuspension (HÅKANSON 2005).

Total phosphorus in studied shallow lakes (average from spring and summer measurements) did not show any significant relationships with lake morphometry or watershed area. It is probably due to diversity of sources of TP in lake waters. Sources of phosphorus in lake waters are sewage input, internal load, agricultural activities, industry and other sources of phosphorus and also nitrogen (RYSZKOWSKI and BARTOSZEWICZ 1989, WETZEL and LIKENS 1991, HEATHWAITE 1995, SAPEK 1998, SØNDERGAARD et AL. 1999, 2001). Phosphorus input is additionally regulated by climate, vegetation, soil conditions, landscape structure, altitude and latitude (RYSZKOWSKI and BARTOSZEWICZ 1989, KUDELSKA et AL. 1994, KAJAK 1998, SAPEK 1998, NÕGES et AL. 2003, HÅKANSON 2005).

In recent studies (HÅKANSON 2005) it was found, that TP (mean annual values) can depend on lake morphometry but both deep and shallow lakes were taken into account. Southward increase of TP was found by NÕGES et AL. (2003).

Results obtained using one-way ANOVA due to limited number of lakes in dataset gave general view on the problem.

In ANOVA method the influence of altitude was found for DMS and SD and lakes situated in area elevated below 100 m a.s.l. had higher water trophy than others. Trophic level was correlated with lake water area. In small lakes (below 100 ha) water trophy was lower and it was significant difference for most of trophic parameters except for TP, which was on similar level in both groups. Higher concentrations of trophic parameters in surface layer of shallow lakes were observed in lakes with greater water volume. According to ANOVA the average water depth below 2.5 m accelerate eutrophication in comparison to deeper lakes (with average depth between 2.5 and 5 m) and it was taken into account in earlier studies, e.g. in KUDELSKA et AL. (1994) elaboration on estimation of lake susceptibility for degradation. In case of watershed it was observed that only lake water transparency responds strongly to increase of catchment area. Increase of this area caused significant decrease of SD and minor changes of other parameters. Total phosphorus concentration was not depending on changes of watershed area. The Schindler coefficient had no significant impact on any of the studied parameters.

A complex impact of morphometric parameters on trophic level was analysed using CCA method (Fig. 2). The most diversed trophic parameter was water transparency, which depends on average depth, maximum depth and altitude. The highest values of Secchi depth were related to higher depth of lake. Low lake water volume, lake area, watershed area were also related to higher values of SD. As in earlier analyses (Pearson, ANOVA) morphometric parameters had little impact on concentration of total phosphorus in lake waters. Dry mass of seston and chlorophyll *a* depended on greater lake water volume, lake area and watershed area. Low altitude and average depth of studied lakes showed relation with high level of Chl *a* and low maximum depth was related to high concentration of dry mass of seston. Other relationships, such as between Schindler coefficient and values of Secchi depth, dry mass of seston and chlorophyll *a* were not visible.

## Conclusions

The statistical analyses made on the example of 69 shallow lakes do not allow to formulate very strong conclusions about the role of lake morphometry and watershed area on concentration of certain trophic parameter but gave solid characteristics of these relationships.

Analyses of gathered data showed, that in shallow lakes situated in the Polish Lowland concentration of total phosphorus does not strongly depend on lake morphometry.

Other trophic parameters showed significant relations to lake water area, lake water volume, water depth and altitude. Secchi depth was a parameter with the strongest dependence on lake morphometry and watershed area. There was no significant correspondence between Schindler coefficient and TP, Chl *a*, SD and DMS for studied lakes.

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Annex 1. List of lakes selected for analyses
Załącznik 1. Lista jezior wybranych do analiz

| | | |
|---|---|---|
| Bądze | Kunów | Skiertąg |
| Bikcze | Lubowo | Skotawsko Duże |
| Bobecińskie Małe | Lubstowskie | Skotawsko Małe |
| Brajnickie | Łąckie Wielkie | Spore |
| Brdowskie | Łebsko | Spychowskie |
| Bukowo | Łękuk | Stargardzkie Południowe |
| Chalińskie | Maśluchowskie | Stargardzkie Północne |
| Ciechomickie | Mieliwo | Stopka |
| Ciemno | Modzerowskie | Straduńskie |
| Dębno | Osetno | Stręgielek |
| Dołgie Wielkie | Ostrowieckie | Szczutowskie |
| Drzesno | Ostrowin | Szczytno Małe |
| Firlej | Ostrowite (Drwęca River watershed) | Szymon |
| Gardno | Ostrowite (Wisła River watershed) | Urszulewskie |
| Głodowskie | Pauzeńskie | Wiecanowskie |
| Górskie | Pątnowskie | Wielatowo |
| Hartowieckie | Piasutno | Wieldządz |
| Jakuba | Pozezdrze | Wielimie |
| Jeziorak Mały | Przedeckie | Wilczkowo |
| Kajkowskie | Rańskie | Wilkus |
| Karaś | Rekąty | Zdworskie |
| Klebarskie | Sarbsko | Żnińskie Małe |
| Kołowin | Sędeń | Żywki |

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# ZALEŻNOŚCI POMIĘDZY MORFOMETRIĄ PŁYTKICH JEZIOR NIŻU POLSKIEGO A WSKAŹNIKAMI TROFII WODY

**Streszczenie.** Większość polskich jezior to jeziora płytkie. Stanowią one około 60% całkowitej liczby jezior i gromadzą znaczną część objętości wód jeziornych. Płytkie jeziora zlokalizowane na nizinach są często podatne na eutrofizację i degradację, które są spowodowane różnymi czynnikami, np. warunkami glebowymi, zagęszczeniem populacji ludzkiej i wieloma rodzajami działalności człowieka. Także inne czynniki, takie jak morfometria jeziora i wielkość obszaru zlewni, wpływają na ekosystem jeziorny. Jeziora wybrane do analiz charakteryzowały się wysokością do 200 m n.p.m., maksymalną głębokością do 10 m, średnią głębokością do 5 m i dostępnością do informacji o parametrach troficznych wody. Dane użyte w analizach, takie jak widzialność krążka Secchiego, koncentracja fosforu ogólnego, chlorofil *a*, sucha masa sestonu, powierzchnia jeziora i zlewni całkowitej, morfometria zbiornika – zostały zebrane głównie z danych publikowanych przez Państwową Inspekcję Ochrony Środowiska (PIOŚ) w latach 1982-1993 oraz z własnych badań z lat 1997-2000. Analizy statystyczne zostały przeprowadzone dla siedmiu parametrów morfometrycznych i czterech troficznych. Znaczące korelacje liniowe stwierdzono pomiędzy chlorofilem *a*, suchą masą sestonu i widzialnością krążka Secchiego a parametrami morfometrycznymi. W przypadku badanych płytkich jezior zarówno głębokość wody, jak i powierzchnia jeziora odgrywały ważną rolę w kształtowaniu poziomu trofii wody, podczas gdy wpływ współczynnika Schindlera był mało istotny. Kompleksowy wpływ parametrów morfometrycznych został określony z wykorzystaniem wielowymiarowej kanonicznej analizy korespondencji (CCA). Wyniki pokazały, że najbardziej zróżnicowanym parametrem troficznym była widzialność krążka Secchiego, która zależała od średniej i maksymalnej głębokości wody w jeziorze i od wysokości nad poziomem morza.

**Słowa kluczowe:** jeziora płytkie, morfometria jezior, wskaźniki trofii, Niż Polski

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