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*Original Research*

# Vegetation Richness and Nutrient Loads in 16 Lakes of Drawieński National Park (Northern Poland)

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**Abstract**

The paper provides morphometric, physicochemical and vegetation structure of the 16 lakes in Drawieński National Park (DNP). These lakes showed considerable differentiation according to their morphometrical and physico-chemical variables. There are distinguished 4 groups of lakes: (1) throughflow lakes; (2) small, eutrophic non-throughflow lakes; (3) dystrophic lakes with humic water bodies; and (4) mesotrophic lakes. A dependence of the structure of the predominant vegetation types on morphometrical and physico-chemical variables was tested. Results of study of vegetation structure proves the initial classification of the lakes into several groups on the basis of environmental variables. The most important type of vegetation of throughflow lakes are helophytes and nymphaeids. The phytolitoral of eutrophic non-throughflow lakes is scanty. The vegetation of dystrophic lakes is dominated by species with floating leaves and mosses. The common vegetation of mesotrophic lakes is dominated by *Chara* species and elodeids.

**Keywords:** aquatic macrophytes, loads of nutrients, lake functioning, lake classification

## Introduction

Water bodies are regarded in modern limnology as integral elements of larger landscape units. Relations between water bodies and other elements of landscape are a subject of research in the field of landscape ecology, which takes into account factors of a wider regional importance (e.g. climate, precipitation, landscape characteristics at the regional level) and of local importance (e.g. morphometry and hydrology of the water body, land use in the catchment area) [1, 2]. According to these assumptions, the basic mechanism that regulates the functioning of water ecosystems is run-off and supply of matter from the catchment – including nutrients responsible for the trophic level [3]. With the use of mathematical modelling, attempts are made to assess the intensity and character of interactions between the water body and its surroundings [4]. Nevertheless, there are still many examples of lakes with similar morphometric and catchment parameters and similar nutrient loadings, which are completely different in respect of the character and intensity of trophic relations. The major factors affecting environmental conditions within a lake include aquatic vegetation, i.e. hydromacrophytes, which colonize the littoral zone and edges of the water body [5]. These plants take part in matter circulation within the lake ecosystem through uptake of nutrients from water and substrate, and later through deposition of large amounts of organic matter in lake sediments, thus modifying the chemical composition of the substrate [6]. They also provide microhabitats for epiphytic organisms and food for herbivores. Plants indirectly affect the occurrence of other organisms by changing light conditions and water chemistry, creating refuges, etc. In some water bodies – depending on the proportion of the bottom covered by vegetation and on its taxonomic composition – vegetation may play a very important role [7].

DNP is one of 23 Polish National Parks and lies in northern Poland on the southern slope of the Pomeranian

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Lakeland, the young glacial outwash plain covered with the extensive Drawa Forest (Puszcza Drawska). The Park's landscape was formed by the ice sheet during the Weichselian glaciation. The outwash plain is crossed by valleys of the rivers Drawa and Płociczna, with a complicated system of flood plains and hills composed of sands and boulder clay, and post-glacial channels often filled with lakes or peat deposits (Fig. 1). About 83% of the area is covered with forest, mainly pine plantation forest, although most of the sites are more suitable for beech forest [8]. The main characteristics of the landscape are the rivers Drawa and Płociczna, with deeply cut, meandering curves and steep river banks. The Drawa flows through the western arm of the Park, while the eastern arm of the Park is delineated by the Płociczna. They are similar to mountain rivers in many respects. These aquatic ecosystems are one of the most valuable features of the Park, and they contributed significantly to the establishment of the DNP.

There are about a dozen lakes and several smaller water bodies in the area of the Park. Most of them are situated in the eastern part of the Park. They form two distinct lines. The first line consists of throughflow lakes in the valley of the River Plociczna and the second, parallel line, is a cascade of non-throughflow lakes (Fig. 1). They vary greatly in respect of morphometric and catchment parameters (Table 1). Anthropogenic perturbations in lake ecosystems are small there, e.g. waters had a relatively low content of elements, which can be interpreted as the natural level [9]. Subsequently, these lakes were considered good objects for research on mechanisms controlling the functioning of aquatic ecosystems and for assessment of the influence of external factors of trophic state and both direction and rate of plant succession in aquatic ecosystems. Different adaptations of macrophytes to the varied living conditions are reflected in the system of eco-physiological life forms of aquatic plants developed by den Hartog and van der Velde [10].

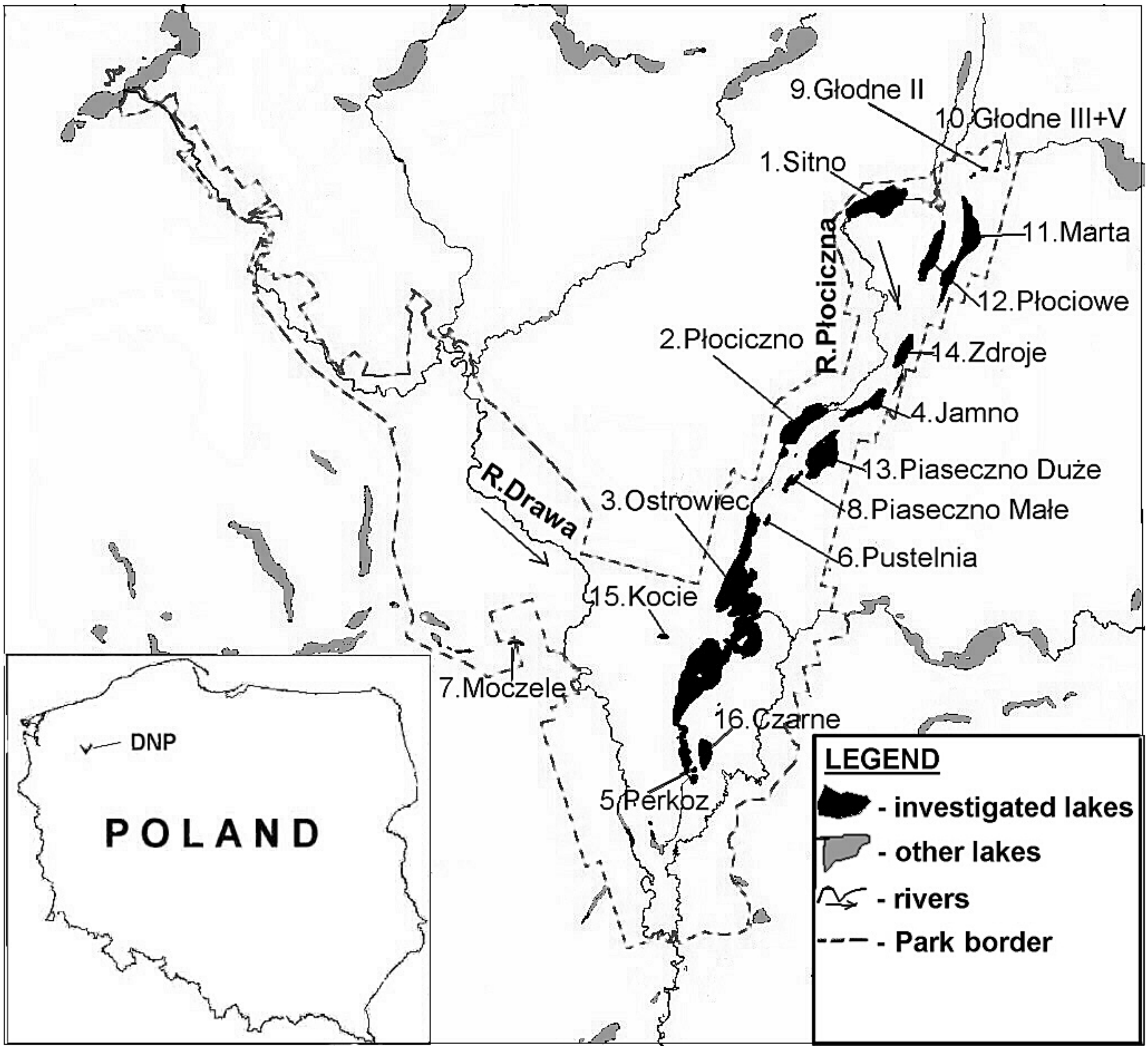


Fig. 1. Location of investigated lakes in Drawieński National Park.

Results of research conducted there in the past show that water bodies located in the young glacial landscape of the Pomeranian Lakeland (including the area of the DNP) may be subject either to accelerated eutrophication or dystrophication. Even small changes in the catchment area may affect the rate and direction of lake evolution. One of the first symptoms of these changes is restructuring of vegetation [11, 12]. The objective of this study was to describe the main mechanisms responsible for occurrence and distribution of the main communities and ecological groups of macrophytes, distinguished on the basis of growth forms in the varied lake ecosystems of the DNP. Several hypotheses have been tested:

1. Arrangement of the flora is to be different depending on morphometrical and physico-chemical variables and trophic state of lakes.
2. Throughflow lakes and lakes in the final phase of overgrowing are characterized by a simplified structure of the flora [10, 13].
3. In shallow lakes the reach of stepping out and diversifying the flora could be the result of alternative equilibria states of lake ecosystems [14].

## Materials and Methods

This paper presents data from 16 lakes located in the area of the DNP (NW Poland). The analysis of physico-chemical parameters was conducted in 1997-98, during summer stagnation. Water pH, concentration of soluble oxygen, saturation of water with oxygen, water temperature and conductivity were measured in the field with the use of the multiparameter sonde 600R and logger made by YSI Inc. Physico-chemical parameters were measured in each thermal zone. Water samples were collected every 1 metre, and then pooled for each zone or – in the case of polymictic lakes – for the whole vertical profile. The composite sample for the given zone was then poured into three 1-litre glass bottles. The first subsample was preserved with $CHCl_3$, the second with concentrated $H_2SO_4$, and the last one was not preserved but kept in darkness at 3-5°C. Concentrations of total nitrogen and phosphorus were measured according to Standard Methods for Water Examination [15]. Water colour, concentration of chlorophyll

Table 1. Basic morphometric data on lakes of the Drawieński National Park and their catchments.

| Name of lake | Area (ha) | Volume (thousands of $m^3$) | Max. depth (m) | Shoreline length (m) | Ohle's Index (Catchment area/Lake area) | Flushing rate (1 year $^{-1}$) |
|---|---|---|---|---|---|---|
| Group 1 – eutrophic, throughflow lakes | | | | | | |
| 1. Sitno | 67.2 | 2666.7 | 7.0 | 3800 | 253.2 | 18.1 |
| 2. Płociczno | 56.1 | 1530.9 | 5.2 | 5000 | 356.4 | 46.0 |
| 3. Ostrowiec | 387.5 | 36433.1 | 28.5 | 22000 | 80.8 | 1.5 |
| 4. Jamno | 27.6 | 967.9 | 9.2 | 3150 | 48.2 | 14.0 |
| Group 2 – small eutrophic lakes | | | | | | |
| 5. Perkoz | 1.3 | 27.7 | 4.6 | 408 | 2.1 | 0.2 |
| 6. Pustelnia | 2.7 | 65.8 | 5.1 | 740 | 24.7 | 1.7 |
| 7. Moczele | 2.5 | 17.5 | 1.5 | 900 | 14.3 | 3.3 |
| Group 3 – dystrophic lakes | | | | | | |
| 8. Piaseczno Male | 8.0 | 258.4 | 6.8 | 1825 | 2.7 | 0.1 |
| 9. Głodne II | 0.6 | 19.6 | 6.8 | 450 | 8.9 | 0.5 |
| 10. Głodne III+V* | 0.75 | 23.3 | 7.8 | 490/2400** | 15.8 | 0.2 |
| Group 4 – mesotrophic lakes | | | | | | |
| 11.Marta | 66.1 | 5111.4 | 25.0 | 6150 | 13.6 | 2.8 |
| 12.Płociowe | 35.3 | 3620.0 | 25.0 | 3450 | 4.7 | 0.1 |
| 13.Piaseczno Duże | 58.7 | 4519.2 | 25.9 | 3755 | 2.6 | 0.1 |
| 14.Zdroje | 21.3 | 612.1 | 4.8 | 2150 | 21.0 | 1.2 |
| 15.Kocie | 2.4 | 30.2 | 2.8 | 680 | 11.8 | 1.5 |
| 16.Czarne | 19.6 | 2137.7 | 26.5 | 1935 | 1.7 | 0.05 |

* – 2 small water bodies surrounded by peatbog

** – Length of the shorelines of water bodies/Length of the shoreline of peatbog *a* and seston were analyzed according to the Polish Standards.

Morphometric features of the studied catchments were assessed according to the methods suggested by Soczyńska [16], with the use of situation-altitude maps on a 1:25,000 scale, corrected during fieldwork. Nutrient concentrations and other physico-chemical parameters of Lake Ostrowiec were measured in the northern part, through which the Płociczna River flows. That part of the lake accounts for about 35% of total surface area, and has a maximum depth of 11.2 m. The central – non-throughflow – part of the lake is the deepest (up to 28.5 m).

The loading of the lakes with phosphorus and nitrogen from diffuse sources of pollution (woodland, farmland, etc.) were estimated on the basis of unit loads reported by Giercuszkiewicz-Bajtlik [17]. Data on the rate of water exchange in the lakes were extracted from earlier works [18].

Two small water bodies – Głodne III and V – form one hydrological system including the bog surrounding both water bodies, so cumulative nitrogen and phosphorus loads received by the lakes and the bog were calculated. In the calculations, results of field research [19] were taken into account, as they indicated that within the bog zone, between its outer edge and the edge of the lake, nitrogen loads were reduced by 45% and phosphorus loads were reduced by 17%. During the estimation of the rate of water exchange in II and Głodne III + V, the surface areas of the lakes and the surrounding bogs were summarized in each case, because they formed two complex hydrological systems. Consequently, the results differ from data published earlier [20].

The vegetation of the lakes was analyzed according to the Braun-Blanquet phytosociological method. Submerged plants were collected from a pontoon, using a rake. To assess the percentage cover of lake bottom for each species (both in terms of depth and distance from the lake edge) the transect method was applied. The number of transects ranged from several to several dozen, depending on the size of patches and their distribution in a given lake. The distribution of vegetation was immediately plotted on magnified bathymetric maps. On this basis, maps of vegetation in lakes were prepared and the contribution of various communities of hydromacrophytes to total phytolittoral area was estimated. Also the growth form of dominant plant species in each patch of vegetation was classified according to the system of den Hartog and Segal [7].

The statistical methods included Cluster Analysis (CA) and Factor Analysis (FA). The data were processed by STATISTICA for Windows software [21]. Morphometric-catchment features and the following physico-chemical and biological parameters were considered: Secchi depth, water colour, pH, seston, chlorophyll *a* and percentage of cover of the phytolittoral zone with various phytosociological communities of macrophytes.

## Results

### Loads of Nutrients and Trophy

#### Throughflow Lakes

These lakes are characterized by large catchment areas composed of farmland and woodland. The Płociczna River, which flows through the lakes, supplies the lakes with a large amount of nutrients (Table 2). The largest quantities of nutrients are delivered into the three lakes: Sitno, Płociczno and Ostrowiec. The Płociczno Lake, which is additionally supplied with loads of nutrients through inflow from Jamno Lake, is the most loaded lake in the DNP. This lake receives in excess of 180 g N and 17 g P per square meter of surface water area per year.

However, the water flushing rate in this lake belongs to the highest, and occurs 46 times a year. It means the lake water residence time is very short and lasts only a little longer than one week. The fast rate of water exchange is also associated with fast removal of large amounts of nutrients from the lake. The nutrients are then transported to Lake Ostrowiec. In Lake Płociczno the highest concentrations of phosphorus and nitrogen were recorded (Table 2). However, in relation to the area of the lake the amounts of both nutrients were not so striking because of their small mean depth (Table 1). The Ostrowiec Lake show the least spatial pattern of nutrient supply. That is both the biggest and one of the deepest among all lakes of the Park. Thereby the lake water flushing rate takes place relatively slowly, only 1.5 times per year.

Although the concentration of nitrogen per volume unit in Lake Ostrowiec was similar to other throughflow lakes, nitrogen loads per 1 $m^2$ of that lake were relatively high. Phosphorus loads per 1 $m^2$ in Lake Ostrowiec were similar to other throughflow lakes, although phosphorus concentration per 1 $m^3$ was very low there.

Lake Ostrowiec was markedly different form the other throughflow lakes in terms of phosphorus and chlorophyll *a* concentrations as well as Secchi depth. The differences result from:

- a several times higher actual depth and mean depth of the throughflow part of the lake, which enables the dilution of the water of the Plociczna;
- water exchange between the throughflow part and other parts of the lake, which reduces nutrient concentrations in the throughflow part;

#### Small, Non-Throughflow Shallow Lakes

This group is composed of three lakes that are quite different from each other. Lake Perkoz, although small, is relatively deep, with steep banks and beech forest. It contains amounts of phosphorus, nitrogen and chlorophyll *a* lower than other lakes of this group (Table 2). Lake Pustelnia, of a similar size as the first lake, is the most eutrophic. This is reflected in the small Secchi depth and high amounts of nutrients (both per unit volume and per unit area). The third lake, Moczele, is a very shallow polymictic water body, elongated in shape, with organogenic sediments.

The smallest euthrophicated lakes of DNP are supplied by N and P from surface water runoff. The catchment areas which are entirely forested vary in size, which is confirmed by Ohle's Index, which is relatively high (14.3 and 24.7) for two out of three lakes. Calculated loads of N and P flowing to the lakes from the drainage basin (4.7- 8.9 g N $m^{-2}$ $year^{-1}$ and 0.13 – 0.27 g P $m^{-2}$ $year^{-1}$) can be considered low, although the concentration of P and seston belongs to the highest from all the lakes of the Park. Large quantities of the suspended solids cause the visibility of SD to be comparable to the lowest of the throughflow lakes of the Park. The comparable concentrations of nitrogen and phosphorus in lakes Perkoz and Moczele can be explained by the limiting role of their catchments. However, the limiting mechanisms are different in each of the lakes. The catchment of Perkoz Lake, which is located at the bottom of a deep land basin, is dominated by a broad-leaved forest. During the growing season the forest stand shades the surface of the lake and thus limits growth of phytoplankton and hydromacrophytes. In autumn, leaf litter is one of the major sources of allochthonous matter received by the lake, and contributes to its eutrophication. By contrast, in Lake Moczele the influence of the catchment is limited by patches of bog and fen vegetation. This barrier greatly reduces the effects of the surface flow of nutrients to the lake. Nevertheless, since the lake is polymictic, nutrients circulate continuously between the sediments and open water.

Dystrophic Lakes

The group of three dystrophic lakes represents a much higher number of lakes of this type found in the area of the DNP. We analyzed one larger lake, Piaseczno Male, and 3 small lakes of about 0.5 ha each. They are typical dystrophic water bodies, with low pH and brown water colour caused by humic substances. According to the criteria suggested by Eloranta [22], most of them are polyhumic lakes. Very low values of electrolytic conductivity, despite the high concentrations of nitrogen and phosphorus, indicate a deficit of soluble forms of these nutrients. The lakes differed mainly in chlorophyll *a* concentration, which in this group was the highest in Piaseczno Male, although in comparison with other groups of lakes it was still relatively low. Chlorophyll *a* concentration was not correlated with seston concentration, which was the highest in Głodne III+V, the water body having the darkest water colour due to very high concentrations of humic substances.

The nutrient loading they receive is almost the same as the eu- and mesotrophic lakes of DNP. It could be much more, as Ohle's Index (from 2.7 to 15.8) indicates. However, bog moss are restricted factor here. The bog moss circle surrounds the lakes, which is why it plays the role of a barrier that is capable of reducing quantities of the nutrients flowing into the lakes. The N and P reduction were estimated as follows: 47% for N and 37% for P. In addition, some quantities of $H_2S$ changes oxygen conditions of the lake water environment. As a consequence, low concentrations of chlorophyll *a* and higher levels of the dissolved reactive phosphorus and nitrate were noted.

Mesotrophic Lakes

Six mesotrophic lakes are considered to be the most interesting group of natural reservoirs of water. They belong to the middle size of water surface, but not bigger than 70 ha, with the exception of one – 2.4 ha, the smallest. Catchment lakes in this group, although varying in size, are almost entirely covered with forest (96.5-100%). The small patches of open habitats are mainly fens or intermediate mires. Thanks to such a structure of the catchments, the mesotrophic lakes receive relatively low nutrient loads. On the basis of published reports [18] it can be estimated that the annual area's loading of those lakes ranges from 0.12 to 0.50 g P $m^{-2}$ $year^{-1}$ and from 4.4 to 15.4 g N $m^{-2}$ $year^{-1}$. Physico-chemical parameters and nutrient concentrations in all lakes of this group are very similar. However, if the values are expressed per unit area, some differences can be observed, attesting to differences in the size of resources of those elements between the lakes.

From among mesotrophic lakes the more interesting one there is Czarne Lake, which is a meromictic lake due to its small surface area, large depth, and hilly catchment covered by pine-oak forest. The lake receives the smallest loads of nitrogen and phosphorus among all the studied lakes. This results from the relatively small size of the catchment area, reflected in the low value of Ohle's Index (Table 1). All these factors contribute to the low trophic state, as the mixolimnion is classified as β-mesotrophic. The large Secchi depth recorded there is typical of oligotrophic lakes according to the criteria of OECD [23]. During summer stagnation, the zone of water mixing (mixolimnion) was 5 m deep. The chemocline ranged from 5 m to 14 m according to temperature measurements, but the chemocline was 2 m deeper according to oxygen measurements. Thus monimolimnion ranged from 14-16 m to the bottom, i.e. to the maximum depth of 29 m. Oxygen measurements in spring indicated that mixolimnion reached down to a depth of 13 m, the chemocline was between 13 m and 18 m, and the completely deoxygenated monimolimnion ranged from 18 m to the very bottom. A much deeper mixolimnion was observed in the spring of 1997, due to unusually strong winds (80-100 $km \cdot h^{-1}$). In the following years the depth of mixolimnion was slightly smaller because of the lack of long-lasting ice cover in winters. The surface of the lakes was frozen for no more than 2 weeks in the last few winters. The specificity of physico-chemical parameters of mixolimnion corresponds in some respects to mesotrophic lakes, with some characteristic features of oligotrophic lakes, such as a large Secchi depth (10.8 m) and relatively low phosphorus concentration. The other thermal zones of the lake, especially monimolimnion, were also specific. Apart from the obvious differences in oxygen concentration between mixolimnion and monimolimnion, considerable differences in phosphorus concentration were recorded. In the cumulative zone, i.e. monimolimnion, phosphorus concentration was twice as high as in mixolimnion. Nitrogen concentration was similar in both zones.

### Vegetation

The vegetation of throughflow lakes, except Lake Ostrowiec, is dominated by nymphaeids – communities from the alliance *Nymphaeion* – over the other types of hydromacrophytes. Nymphaeids occupy 45-75% of the area of the phytolittoral zone. They are most abundant near the place where the river flows into the lake and near the place where it flows out, as well as in shallow inlets sheltered from wind. Elodeids – communities from the alliance *Potamion* – and helophytes *(Phragmition + Magnocaricion)* occupy the rest of the phytolittoral zone (Table 3). The variation reflects morphometric differences between the lakes. The dominance of nymphaeids in throughflow lakes in the DNP and in other lakes is stimulated by the following environmental factors:

- low water transparency, which limits growth of elodeids and eliminates their competitive pressure on nymphaeids;
- the presence of fertile organic-mineral sediments near the place where the river flows into the lake and near the place where it flows out;
- gentle slopes of the lake basin in the phytolittoral zone;
- the presence of inlets sheltered from wind.

As most of the above factors are lacking in Lake Ostrowiec, its vegetation is dominated by elodeids, which cover about 63% of the phytolittoral area. Helophytes rank second, as they occupy nearly ¼ of the phytolittoral area, while stoneworts (*Characeae*) rank third, accounting for 9% of phytolittoral area. Nymphaeids are very rare there, covering only 4% of phytolittoral area. The different pattern of vegetation in Lake Ostrowiec is due to the distinct morphometric features of the lake basin. Only the northern part of the lake, where the river flows in and out, has some features typical of the other throughflow lakes. The dominant type of vegetation in throughflow lakes – nymphaeids – are represented by *Nuphar lutea, Nymphaea alba* and (to a lesser extent) *Potamogeton natans*. The most frequent among elodeids are: *Myriophyllum spicatum* and *Ceratophyllum demersum*. Helophytes are dominated by *Phragmites communis* and *Typha angustifolia.* Other species are rare and do not play any significant role, but attest to the diversity of lake biocoenoses. In all studied throughflow lake vegetation reaches down to the depth of about 2.5-3.0 m.

The group of eutrophic non-throughflow lakes (Perkoz, Pustelnia and Moczele), are characterized by a considerable variation in phytolittoral size, which is in accordance with hypothesis nr 2. In lake Perkoz the phytolittoral zone consists of a very narrow belt of helophytes (Table 3). Nymphaeids and elodeids are limited to several small patches. The other two lakes are similar to each other, as they are dominated by nymphaeids. The most frequent species were *Nuphar lutea*, *Nymphaea alba Stratiotes aloides.* The codominant type of vegetation – helophytes – occur in two distinct plant formations: in Lake Moczele helophytes form a floating mat –association *Thelypteridi-Phragmitetum* – extending from lake verges, while in Lake Pustelnia they form a typical belt of vegetation.

The interdependence between trophic state, water transparency and occurrence of different types of vegetation is confirmed by the group of mesotrophic lakes. The limit of vegetation in the four deepest lakes is at a depth of 10 m. In the remaining two lakes vegetation covers the whole bottom. Mesotrophic lakes are dominated by characeans (Table 3). Proportions of other types of vegetation vary considerably between the lakes. In some lakes of this group helophytes are more important, while in others elodeids are more frequent. In the deepest four lakes *Chara* and *Nitella* spp. account for 82-88% of the phytolittoral zone. The remaining part of this zone is occupied by elodeids or helophytes. Nymphaeids do not find suitable sites there. In the smallest and shallowest lakes of this group, the importance of characeans is reduced by elodeids and helophytes. Characeans cover 39-67% of the phytolittoral zone, although in lake Kocie they are present even in the deepest parts of the lake. Along the margins submerged vegetation is replaced by helophytes. In lake Zdroje, characeans and elodeids cover similar proportions of the phytolittoral zone. The dominance of characeans is based on the following species: *Chara tomentosa, Ch. fragilis, Ch. rudis, Ch. vulgaris* and *Nitella flexilis, N. opaca* or *Nitellopsis obtusa.*

Nymphaeids constitute the basic vegetation of dystrophic lakes. They are dominated by *Nuphar lutea*. Because of the brown colour of water, caused by a high concentration of humic substances, no submerged vascular vegetation occurs there. Only lake margins are completely or nearly completely occupied by moss communities from classes *Scheuchcerio-Caricetea fuscae* and *Oxycocco-Sphagnetea.* They form mats overgrowing lake margins.

## Discussion

The above survey shows that the variation in morphometric parameters of lakes and their catchment areas is reflected in physico-chemical parameters of water and – as a result – in vegetation structures. Lakes differ within these divided groups too, e.g. Lake Piaseczno Małe is larger than other dystrophic water bodies, but their water is characterized by relatively low pH, conductivity, concentration of calcium (15.7 g $L^{-1}$) and of other dissolved ions. Despite the seemingly unfavourable conditions, a relatively high concentration of chlorophyll *a* was recorded there [19].

Table 2. Loads of nitrogen and phosphorus received by the studied lakes and mean physico-chemical parameters of water.

| Name of lake | Nutrient loads ($g\ m^{-2}\ year^{-1}$) | | Secchi disc depth | Colour | Conductivity | pH | Mean concentration of total phosphorus | | Mean concentration of total nitrogen | | Seston | Chlorophyll |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | per volume unit | per surface unit | per volume unit | per surface unit | | |
| | P | N | (m) | (mg Pt $L^{-1}$) | $\mu S\ cm^{-1}$ | – | ($g\ P\ m^{-3}$) | ($g\ P\ m^{-2}$) | ($g\ N\ m^{-3}$) | ($g\ N\ m^{-2}$) | ($g\ m^{-3}$) | ($mg\ m^{-3}$) |
| Group 1 – *eutrophic, throughflow lakes* | | | | | | | | | | | | |
| 1. Sitno | 13.35 | 130.4 | 1.3 | 27.0 | 340 | 7.5 | 0.261 | 1.044 | 1.99 | 7.94 | 4.9 | 13.79 |
| 2. Płociczno | 17.01 | 184.1 | 1.4 | 23.0 | 356 | 7.8 | 0.340 | 0.917 | 2.40 | 6.47 | 5.4 | 16.28 |
| 3. Ostrowiec* | 1.72 | 28.8 | 3.2 | 20.0 | 382 | 8.0 | 0.115 | 0.678 | 1.79 | 10.53 | 4.4 | 4.22 |
| 4. Jamno | 1.20 | 38.6 | 1.8 | 15.0 | 307 | 6.6 | 0.213 | 0.747 | 1.60 | 5.56 | 4.1 | 12.58 |
| Group 2 – *small eutrophic lakes* | | | | | | | | | | | | |
| 5. Perkoz | 0.13 | 4.7 | 1.7 | 27.0 | 278 | 7.5 | 0.115 | 0.241 | 1.20 | 2.52 | 4.2 | 4.63 |
| 6. Pustelnia | 0.19 | 6.4 | 1.1 | 37.0 | 273 | 7.6 | 0.201 | 0.482 | 2.37 | 5.70 | 12.0 | 12.47 |
| 7. Moczele | 0.27 | 8.9 | 1.5 | 50.0 | 251 | 8.2 | 0.179 | 0.125 | 1.76 | 1.23 | 9.2 | 18.39 |
| Group 3 – *dystrophic lakes* | | | | | | | | | | | | |
| 8.Piaseczno Male | 0.15 | 5.2 | 2.6 | 25.0 | 73 | 6.4 | 0.153 | 0.489 | 1.97 | 6.32 | 1.6 | 4.49 |
| 9. Głodne II | 0.13 | 3.81 | 2.8 | 22.0 | 38 | 6.0 | 0.143 | 0.442 | 1.89 | 5.87 | 2.5 | 0.75 |
| 10. Głodne III+V | 0.33 | 8.7 | 1.5 | 54.0 | 43 | 5.7 | 0.145 | 0.448 | 1.59 | 4.93 | 4.6 | 1.07 |
| Group 4 – *mesotrophic lakes* | | | | | | | | | | | | |
| 11. Marta | 0.48 | 15.1 | 6.0 | 15.0 | 241 | 7.8 | 0.113 | 0.873 | 1.42 | 10.89 | 1.9 | 0.86 |
| 12. Płociowe | 0.21 | 7.0 | 4.7 | 16.0 | 227 | 7.4 | 0.144 | 1.441 | 1.63 | 16.35 | 2.3 | 0.56 |
| 13. Piaseczno Duże | 0.15 | 5.2 | 5.7 | 15.0 | 96 | 7.2 | 0.134 | 1.016 | 1.54 | 11.71 | 0.2 | 1.60 |
| 14. Zdroje | 0.50 | 15.4 | 2.6 | 15.0 | 276 | 7.3 | 0.149 | 0.432 | 1.13 | 3.28 | 3.9 | 1.71 |
| 15. Kocie | 0.42 | 13.4 | 2.7 | 21.0 | 130 | 7.8 | 0.103 | 0.134 | 1.79 | 2.33 | 1.0 | 1.28 |
| 16. Meromictic Czarne Lake | | | | | | | | | | | | |
| *mixolimnion* | 0.12 | 4.4 | 10.8 | 18.0 | 288.5 | 7.88 | 0.065 | 0.260** | 1.14 | 4.56** | 2.4 | 4.38 |
| *chemocline* | - | - | - | 19.5 | 290 | 7.74 | 0.057 | 0.399** | 1.71 | 11.97** | 2.7 | 3.71 |
| *monimolimnion* | - | - | - | 21.5 | 332.5 | 7.22 | 0.135 | 2.340** | 1.97 | 35.46** | 2.6 | 0.99 |

* – northern part – explanation in text

** – mean concentration × thickness of layer

Table 3. The range of phytolittoral (as a ratio of the phytolittoral area to the lake area between isobaths 0.0 and 2.5 m) and vegetation coverage of phytolittoral (in %) by different communities (0.1% means only sporadic occurrence).

| LAKE | Group 1 eu., throughflow lakes | | | | Group 2 small eu. lakes | | | Group 4 mesotrophic lakes | | | | | | Group 3 dystrophic lakes | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.SITNO | 2.PŁOCICZNO | 3.OSTROWIEC | 4.JAMNO | 5.PERKOZ | 6.PUSTELNIA | 7.MOCZELE | 11.MARTA | 12.PŁOCIOWE | 13.PIASECZNO DUŻE | 14.ZDROJE | 15.KOCIE | 16.CZARNE | 8.PIASECZNO MAŁE | 9.GŁODNE II | 10.GŁODNE III+V |
| ***The range of phytolittoral*** | ***0.78*** | ***1.09*** | ***1.10*** | ***0.87*** | ***0.65*** | ***0.60*** | 0.72 | ***2.10*** | ***1.73*** | ***3.30*** | ***1.82*** | ***1.12*** | ***3.20*** | ***0.57*** | ***0.80*** | ***0.60*** |
| **Patches from *All. Magnocaricion*** | **3.7** | **8.7** | **0.9** | **8.8** | **27.2** | **27.5** | **46.6** | **4.4** | **0.1** | **0.1** | **0.1** | **0.1** | **0.0** | **0.8** | **0.0** | **0.0** |
| *Caricetum acutiformis* Sauer 1937 | 0.1 | 6.5 | 0.7 | 0.0 | 27.2 | 17.0 | | 0.1 | | 0.1 | | | | 0.8 | | |
| *Caricetum rostratae* Rubel 1912 | 0.9 | | 0.1 | 0.6 | | 3.5 | | | 0.1 | | | 0.1 | | | | |
| *Caricetum paniculatae* Wang 1916 ex Roch. 1951 | 2.8 | | | | | 7.0 | | | | | 0.1 | | | | | |
| *Thelypteridi-Phragmitetum* Kuiper 1957 | 0.0 | 2.2 | 0.1 | 8.0 | | 0.1 | 46.5 | | | | | | | | | |
| *Cicuto-Caricetum pseudociperi* Boer 1942 | | | | 0.1 | | | 0.1 | | | | | | | | | |
| *Cladietum marisci* (Allorge 1922) Zobr. 1935 | | | | | | | | 4.3 | | | | | | | | |
| **Patches from *All. Phragmition*** | **26.8** | **30.7** | **22.8** | **3.5** | **56.0** | **2.1** | **0.0** | **7.9** | **1.7** | **5.8** | **11.1** | **23.8** | **18.0** | **1.1** | **0.0** | **0.0** |
| *Phragmitetum* (Gams. 1927) Schmale 1939 | 20.8 | 15.3 | 17.6 | 0.1 | 56.0 | 2.1 | | 7.5 | 1.0 | 5.8 | 7.1 | 9.1 | 16.8 | | | |
| *Typhetum angustifoliae* (Allorge 1922) Soo 1927 | 0.1 | 8.5 | 0.1 | | | | | 0.4 | | | 4.0 | 10.4 | 1.3 | | | |
| *Scirpetum lacustris* (Allorge 1922) Chouard 1924 | 5.3 | 5.1 | 5.1 | 0.1 | | | | | 0.7 | | | 0.3 | | | | |
| *Sparganietum erecti* Roll. 1938 | | 1.5 | | | | | | | | | | 1.1 | | | | |
| *Glycerietum maximae* Hueck 1931 | 0.4 | 0.0 | 0.1 | 3.2 | | | | | | | | 2.9 | | | | |
| *Acoretum calami* (Schulz 1941) Kob. 1948 | 0.1 | 0.1 | | | | | | | | | | | | | | |
| *Eleocharitetum palustris* Schenn. 1919 | 0.1 | 0.1 | | 0.1 | | | | | | | | | | | | |
| *Typhetum latifoliae* Soo 1927 | | | | | | | | | | | | | | 1.1 | | |
| **Patches from *All. Nymphaeion*** | **44.7** | **58.3** | **3.9** | **85.0** | **0.1** | **70.2** | **53.4** | **0.1** | **0.8** | **0.0** | **15.0** | **6.1** | **0.0** | **34.8** | **24.4** | **9.2** |
| *Nupharo-Nymphaeetum albae* Tomasz. 1977 | 44.6 | 57.1 | 3.8 | 77.5 | 0.1 | 32.6 | 44.1 | | 0.7 | | 15.0 | 6.1 | | 27.1 | 24.4 | 9.2 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Potametum natantis* Soo 1927 | 0.1 | 1.2 | 0.1 | 7.5 | | 2.0 | | 0.1 | 0.1 | | | | | 7.7 | | |
| *Stratiotetum aloidis* Krausch 1964 | | | | | | 35.6 | 9.3 | | | | | | | | | |
| **Patches from *All. Potamnion*** | **24.8** | **2.2** | **62.7** | **2.7** | **16.8** | **0.1** | **0.0** | **0.0** | **14.9** | **4.1** | **39.8** | **0.0** | **25.4** | **0.0** | **0.0** | **0.0** |
| *Myriophylletum spicati* Soo. 1927 | 24.5 | 1.1 | 26.1 | | 16.8 | | | | 14.9 | 4.1 | 26.2 | 0.0 | 0.1 | | | |
| *Ceratophylletum demersi* Hild. 1956 | 0.1 | 1.2 | 9.4 | 2.6 | | 0.1 | | | | | 13.6 | | | | | |
| *Najadetum marinae* (Koch. 1926) Phil. 1969 | | | 8.0 | | | | | | | | | | 25.3 | | | |
| *Potametum perfoliati* Koch 1926 em. Pass. 1964 | 0.1 | | 14.5 | | | | | | | | | | | | | |
| *Potametum pectinati* Carst. 1955 | 0.1 | | 0.1 | | | | | | | | | | | | | |
| *Ranunculetum circinati* Sauer 1937 | | | 4.5 | 0.1 | | | | | | | | | | | | |
| **Patches from *Cl. Charetea*** | **0.0** | **0.0** | **9.1** | **0.0** | **0.0** | **0.0** | **0.0** | **87.7** | **82.5** | **84.2** | **34.0** | **66.6** | **56.6** | **0.0** | **0.0** | **0.0** |
| *Charetum tomentosae* (Sauer 1937) Corillion 1957 | | | 2.1 | | | | | 53.5 | 43.5 | | 16.7 | | 12.7 | | | |
| *Nitelletum flexilis* Corillion 1957 | | | | | | | | 24.3 | 11.4 | 13.0 | | | 30.5 | | | |
| *Charetum contrariae* Corillion 1957 | | | 0.1 | | | | | 0.1 | 1.5 | | | 0.1 | | | | |
| *Charetum rudis* Dąmbska 1966 | | | | | | | | 0.4 | 22.9 | | | | | | | |
| *Charetum fragilis* Fijałk. 1960 | | | | | | | | 2.2 | 0.0 | 71.2 | | 21.2 | 0.1 | | | |
| *Charetum vulgaris* Corillion 1957 | | | | | | | | 7.3 | 3.2 | | | 39.7 | | | | |
| *Charetum asperae* Corillion 1957 | | | | | | | | | 0.1 | | | | | | | |
| *Nitellopsidetum obtusae* Dąmbska 1961 | | | 6.9 | | | | | | | | 17.3 | 5.6 | | | | |
| patches with *Nitella opaca* | | | | | | | | | | | | | 13.3 | | | |
| **Patches of submersed bryophytes** | **0.1** | **0.1** | **0.6** | **0.1** | **0.0** | **0.0** | **0.0** | **0.0** | **0.0** | **5.7** | **0.0** | **0.0** | **0.0** | **0.0** | **0.0** | **0.0** |
| *Fontinaletum antipyreticae* Kaiser 1936 | 0.1 | 0.1 | 0.6 | 0.1 | | | | | | | | | | | | |
| patches with *Drepanocladus sordidus* | | | | | | | | | | 5.7 | | | | | | |
| **Bog veg. from *Cl. Scheuchcerio- Caricetea fuscae* and *Oxyccoco-Sphagnetea*** | **0.0** | **0.0** | **0.0** | **0.0** | **0.0** | **0.1** | **0.0** | **0.0** | **0.0** | **0.1** | **0.0** | **3.5** | **0.0** | **63.3** | **75.6** | **90.8** |
| *Caricetum lasiocarpae* Os.1923 em.Koch 1926 | | | | | | | | | | 0.1 | | 3.5 | | 26.0 | 8.0 | 0.1 |
| patches with *Menyanthes trifoliata* | | | | | | 0.1 | | | | | | | | 5.3 | 1.1 | 0.5 |
| Moses from *Cl. Oxyccoco-Sphagnetea* | | | | | | | | | | | | | | 32.0 | 66.5 | 90.2 |

The vegetation of Lake Ostrowiec (group nr 1) is somewhat similar to the vegetation of mesotrophic lakes because of the presence of characeans and elodeids. However, these types of vegetation cover only small proportions of the phytolittoral zone, so this lake is intermediate between throughflow and mesotrophic lakes.

Lake Piaseczno Duże (group nr 4) has many features characteristic of oligohumic dystrophic lakes: low concentrations of calcium and seston, large Secchi depth, but a relatively large concentration of chlorophyll *a*. It is supposed that the chlorophyll is produced by the smallest fraction of algae: picoplankton. In dystrophic lakes energy flows mainly through the community of picoplankton and bacteria, through phagotrophic algae and other elements of the food chain, excluding web phytoplankton [24, 25].

A diagram dividing the lakes into several groups was obtained as a result of CA, using City distances with average linkage for 19 morphometrical, physico-chemical and biological variables (Fig. 2). At a dissimilarity level between 30 and 50% it was possible to distinguish groups of lakes – very similar to those presented in Table 1. Throughflow lakes are markedly different from the others. This is particularly noticeable for lakes Sitno and Płociczno, through which the Płociczna River flows. They are in a category by themselves. However, lake Jamno is connected with the subgroup of eutrophicated, small non-throughflow lakes. The next group is composed of clear water and deep mesotrophic lakes dominated by *Charales*. It also includes Lake Czarne, which is a meromictic lake, and small shallow lakes Kocie and Zdroje.

Interactions between lakes and their catchments are crucial. The shape of lake basins, throughflow, flushing rate, and catchment characteristics affect the present trophic state and biotic structure of lakes in the DNP. The trophic state, and the physico-chemical parameters associated with it, exert a significant impact on the occurrence of different types of hydromacrophytes [26, 27]. This is reflected in the stimulation of growth of the species that are best adapted to the specific conditions [28]. Lakes of DNP are integral components of larger land-water systems, which explains the variation in their trophic state. The shape of lake basins, water residence time, as well as the size and character of the catchment, are reflected in the trophic state and biotic structure of lakes, including types of hydromacrophytes. Heegaard et *al.* [29] analyzed the occurrence of the 32 most common species of macrophytes in 547 lakes of Northern Ireland and concluded that various environmental features are reflected in nutrient availability, which determines the ecological reaction of macrophytes and exerts a significant local influence on species composition of vegetation in lakes. Those authors show that occurrence of a given species in a lake is determined by land use in the catchment area, by agriculture in particular. Lakes can be classified on the basis of analysis of vegetation structure, especially if it is possible to use aerial photographs and satellite data [26]. Vestergaard & Sand-Jensen [27] divided a population of 82 Danish lakes into 5 groups depending on characteristic species composition. The main factor responsible for species distribution was alkalinity of lake water. Vascular plants of the *Elodea* growth type dominated in lakes with high alkalinity. Lakes with intermediate alkalinity had a varied composition of elodeids and vascular plants of the *Isoetes* growth type, while lakes with a low pH are rich in isoetids and bryophytes, but poor in elodeids. Alkalinity was an approximate descriptor of $CO_2$ concentration, which was an important source of inorganic carbon for many elodeids. Thus species distribution was dependent on their ability to utilize $CO_2$ and assimilate inorganic carbon, indicating that the above classification had an eco-physiological basis, although its significant variation suggested the influence of phenotypic plasticity and local heterogeneity of habitats. Very significant also was the trophic state – highly eutrophic lakes were colonized only by some large species of elodeids that are able to compensate for the considerable turbidity.

Recently a description of morphological features of hydromacrophytes as a reflection of the existing trophic conditions in the aquatic ecosystem has aroused increasing interest, as it can enable prediction of changes in community structure. Many authors analyse the problem of stimulating the development of species whose features enable them optimum growth under different conditions of water clarity and the problem of eliminating other species [7, 28]. Results of other research indicate that substrate plays a major role, as its properties are as important as properties of water, and in the case of communities of helophytes their role even more important [30, 31]. Other studies confirm the significance of vegetation in habitat transformation. Individual species of macrophytes substantially affect the functioning of aquatic and wetland ecosystems [32, 33]. According to the latest reports, at least some species of hydromacrophytes modify the circulation of matter in the water body, determining, for example, the availability of nutrients accumulated in bottom sediments [34]. Even last-year shoots of reed (*Phragmites*), depending on nutrient concentration in lake water and on frequency of flood-

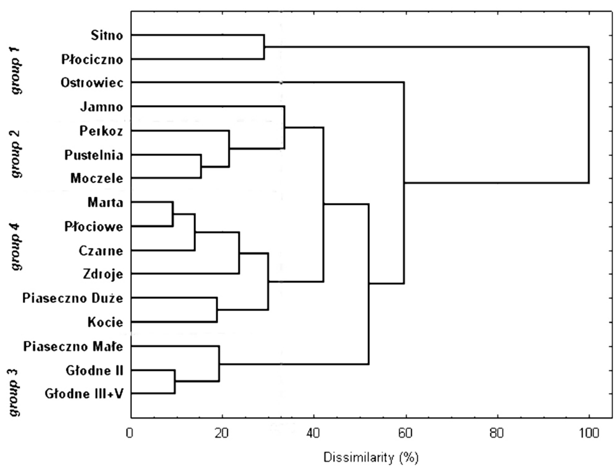


Fig. 2. Tree diagram for 19 morphometrical, physico-chemical and biological variables. Average linkage method with City distances

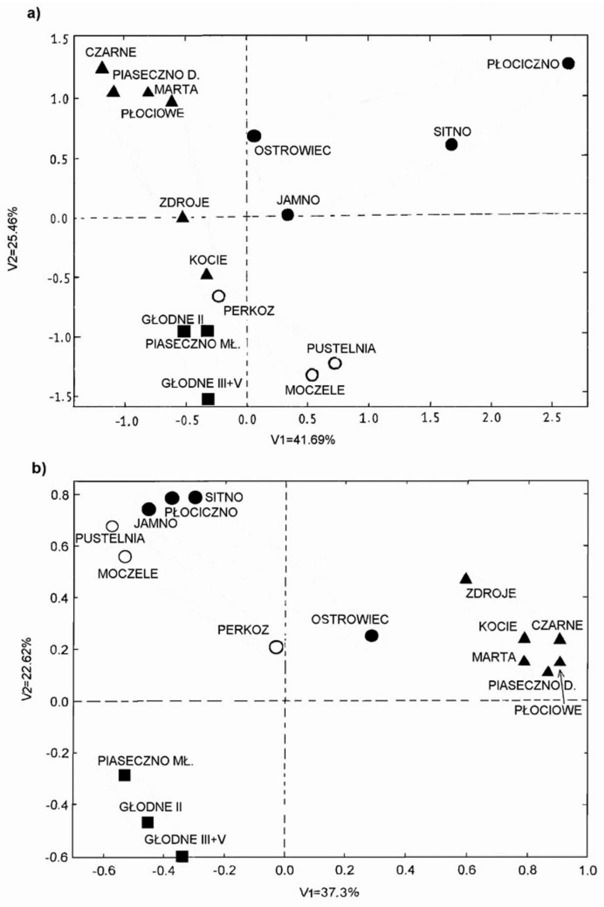


Fig. 3. Ordination (Factor Analysis) of lakes according to environmental variables (a) and structure of vegetation (b). The first two axis of the ordination ($V_1$ and $V_2$, respectively) are shown including their explanation of whole variations in percentages. Symbols indicate groups of lakes: ● – group 1, ○ – group 2, ■ – group 3, ▲ – group 4

ing, release or absorb different forms of nitrogen and phosphorus [35, 36].

Results of some multidimensional statistical analysis (FA) according to environmental variables included in Tables 1 and 2 (Fig. 3a) and the structure of vegetation (Fig. 3b) – bears the initial classification of lakes in the DNP into several groups out, but these drawings aren't identical. Differences can be caused, *e.g.*, with alternative states of the balance in shallow lakes – hypothesis 3. Lake Kocie and Zdroje are shallow lakes with clear water and abundant submerged plants. Other shallow lakes have turbid water and underdeveloped vegetation – group nr 2. These strongly contrasting ecosystems are stabilized with distinct feedback mechanisms. The submerged macrophytes prevent sediment resuspension, take up nutrients from the water, and provide a refuge for zooplankton against fish predation. In the turbid state, the development of submerged vegetation is prevented by low underwater light levels. The unprotected sediment frequently is resuspended by wave action and by fish searching for food, causing a further decrease of transparency. Since there are no plants that could serve as refuges, zooplankton is grazed down by fish to densities insufficient to control algal blooms [14].

This confirms the ecological principle of the synergistic interactions between biotope and biocoenosis, enabling us to draw conclusions on the spatial structure and composition of vegetation and processes of mutual vegetation-site effects on the basis of features of the site. Vegetation, equal to land relief, decides on the formation of a spatial system of site conditions. All 3 hypotheses were proven, but further research is necessary on the great differences in vegetation structure between years – especially in oligotrophic and mesotrophic lakes within the DNP. The explanation of the mechanisms underlying these differences may be very interesting and should help to increase our knowledge of these relations.

## References

1. FORMAN R. T. T., GODRON M., Landscape Limnology, J. Wiley and Sons, New York, **1986.**
2. RICHLING A. & SOLON J., Landscape Ecology, 2nd edition, Wyd. Nauk. PWN [In Polish]. **1996**.
3. KAJAK Z. Eutrofication of lakes, Wyd. Nauk. PWN, Warszawa, (In Polish), **1979**.
4. HAKANSON L., PETERS R. H., Predictive Limnology. Methods for predictive limnology, SPB Academic Publishing, Amsterdam. **1995.**
5. WETZEL R.G., Water as an environment for plant life. In: Vegetation of inland waters (Ed. J.J. Symoens), Kluwer Academic Publishers, Dordrecht, pp. 1-30, **1988**
6. GRANELI W., SOLANDER D., Influence of aquatic macrophytes on phosphorus cycling in lakes. Hydrobiologia, 170, 245, 1988.
7. DEN HARTOG C., SEGAL S., A new classification of the water plant communities. Act. Bot. Neerl. **13,** 367, **1964.**
8. PAWLACZYK P., The forest vegetation of the Drawa National Park, its anthropogenic transformation and current dynamic tendencies. In: (Ed. P. Pawlaczyk) Soils and vegetation of forest ecosystems in the Drawa National Park [In Polish], Idee Ekologiczne, **11**, 43, **1997**.
9. NIEDZIELSKI P., SIEPAK J., SIEPAK M., KRASKA M., Occurence of Arsenic, Antimony and Selenium in Surface Waters of Drawieński National Park., Polish J. Environ. Stud., **11(1),** 41, **2002.**
10. DEN HARTOG C, VAN DER VELDE G., Structural aspects of aquatic plant communities. In: Vegetation of inland waters (Ed. J.J. Symoens), Kluwer Academic Publishers, Dordrecht, pp. 113-153, **1988.**
11. KRASKA M., PIOTROWICZ R., KLIMASZYK P., Lobelian lakes in Poland. Chrońmy Przyrodę Ojczystą [In Polish], **52(3),** 5, **1996.**
12. KRASKA M., PIOTROWICZ R., RADZISZEWSKA R., Dystrophication as inthe chief factor of changes in the physico-chemical properties of water and vegetation of lobelian lakes of the Bory Tucholskie National Park (NW Poland). Acta Hydrobiol. **41**, **Suppl. 6,** 127, **1999.**

13. REJEWSKI M., Lake vegetation of the Laska Region in the Tuchola Forests (Bory Tucholskie) [In Polish], Wyd. UMK, Toruń,, 178 pp. [In Polish], **1981.**
14. SCHEFFER M., Alternative attractors of shallow lakes, TheScientificWorld **1**, 254, **2001**.
15. Standard Methods for the Examination of Water and Wastewater, 18th edition., APHA, Washington, **1992.**
16. SOCZYŃSKA H., Dynamic hydrogeology, PWN, Warsaw, 371 pp. [In Polish], **1999**.
17. GIERCUSZKIEWICZ-BAJTLIK M., Predicting changes in the quality of stagnant waters, Institute of Environment Protection, Warsaw, (In Polish) **1990.**
18. SZYPER H., KRASKA M., Estimation of the nutrient input into the lakes of Drawieński National Park. In: Natural and anthropogenic lakes transformation (Eds: Choiński A. & Jańczak J.) Institute of Meteorology and Water Treatment, Warsaw. [In Polish], **1999.**
19. JONIAK T., KRASKA M., Contribution to the limnology of three dystrophic lakes of the Drawieński National Park, Northern Poland. Acta Hydrobiologica, **41, Suppl. 6,** 191, **1999**.
20. KRASKA M., PIOTROWICZ R., SZYPER H., SZELĄG-WASIELEWSKA E., GOŁDYN R., KLIMASZYK P., Variability of trophic state and vegetation in lakes of Drawieński National Park. Verh. Internat. Verein. Limnol. **28,** 900, **2002.**
21. STATISTICA for Windows [Computer program manual]., StatSoft Inc., 2300 East 14th Street, Tulsa, OK 74104, **1996**.
22. ELORANTA P., Water colour and Secchi disc visibility. In: Limnology of humic waters (Eds Keskitalo J., Eloranta P.). Backhuys Publishers, Leiden, p. 70, **1999**.
23. OECD., Eutrophication of waters. Monitoring assessment and control, pp.154, Paris,**1982.**
24. HESSEN D. O., Dissolved organic carbon in a humic lake: Effects on bacterial production and respiration. Hydrobiologia, **229**, 115, **1992.**
25. JONES R. I., The influence of humic substances on lacustrine planktonic food chains. Hydrobiologia, **229**, 73, **1992.**
26. COOPS H., HANGANU J., TUDOR M., OOSTERBERG W., Classification of Danube lakes based on aquatic vegetation and turbidity. Hydrobiologia **415**, 187, **1999**.
27. VESTERGAARD O., SAND-JENSEN K., Alkalinity and trophic state regulate aquatic plant distribution in Danish lakes. Aquatic Botany, **67**, 85, **2000**.
28. WILLBY N. J., ABERNETHY V. J., DEMARS B. O. L., Attribute-based classification of European hydrophytes and its relationship to habitat utilization, Freshwater Biology, **43**, 43, **2000.**
29. HEEGAARD E., BIRKS H.H., GIBSON C.E, SMITH S.J. & WOLFE-MURPHY S., Species-environmental relationships of aquatic macrophytes in Northern Ireland. Aquatic Botany, **70,** 175, **2001.**
30. KŁOSOWSKI S., Habitat conditions and bioindicator value of the main communities of aquatic vegetation in north-east Poland. Pol. Arch. Hydrobiol., **32,** 7, **1985.**
31. KŁOSOWSKI S., Ecology and bioindicator value of communities of helophyte vegetation in natural standing water bodies. Fragm. Flor. Geobot. (In Polish), **37**, 563, **1992**.
32. CARR G.M., CHAMBERS P.A., Macrophyte growth and sediment phosphorus and nitrogen in Canadian praire river. Freshwater Biology **39**, 525,**1998**.
33. SAND-JENSEN K., Influence of submerged macrophytes on sediment composition and near bed-flow in lowland streams. Freshwater Biology, **39**, 663, **1998**.
34. KARJALAINEN H., STEFANSDOTTIR G., TUOMINEN L., KAIRESALO T., Do submersed plants enhance microbial activity in sediments? Aquatic Botany, **69,** 1, **2001.**
35. ASAEDA T., NAM L.H., HIETZ P., TANAKA N. & KARUNARATNE S., Seasonal fluctuations in live and dead biomass of *Phragmites australis* as described by a growth and decomposition model: implications of duration of aerobic conditions for litter mineralization and sedimentation. Aquatic Botany **73**, 223, **2002.**
**36.** DĄBROWSKA B., Functioning of common reed stands in condition of diurnal fluctuations water level in lake Kwiecko and in natural conditions of River Debrzyca valley. In: Functioning of river catchments geosystems (Ed. A. Kostrzewski) 2, Bogucki Wyd. Nauk., Poznań: pp. 59-65, **2000**.