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SHALLOW POLESIE LAKES FROM THE VIEW POINT OF THE ALTERNATIVE STABLE STATES THEORY

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A b s t r a c t: Six Lubelskie Polesie shallow lakes Kleszczów, Rotcze, Długie, Sumin, Głębokie Uścimowskie and Syczyńskie were studied in summer, 2000 in order to check if the concept of the alternative stable states of lakes, invented in western European countries can be applied to Polish conditions. The lake waters were characterized by wide range of total phosphorus (19.7-436.0 g P dm^{-3}) and chlorophyll – *a* (1.28-357.0 mg dm^{-3}) concentrations.

The development of submerged and floating-leavedfloating-leafed macrophytes, expressed as PVI coefficient: 29.3, 34.5, 31.2, 3.3, 0.8 and 0.0%, respectively. The mean crustacean biomass ranged between 267 and 3623 g DW dm^{-3}, while that of fish: 2.57-19.82 kg $CPUE^{-1}$. Based on the analyses of the above parameters Lake Kleszczów and Lake Rotcze have been classified as macrophyte dominated, Lake Syczyńskie as phytoplankton dominated, while: Lake Długie, Lake Sumin and Lake Głębokie Uścimowskie are situated between the two extreme states. The mechanisms of various buffers responsible for the present status of the lakes are discussed.

K e y w o r d s: Polesie lakes, alternative stable states concept, nutrients, macrophytes, plankton, fish

INTRODUCTION

According to the announced almost ten years ago theory of alternative stable states of lakes [15] the communities of primary producers in the lakes over a wide range of concentrations of nutrients can be predominated by submerged macrophytes or by phytoplankton. A few years later, the authors proposed the existence of the intermediate states of lakes [16] – macrophyte-phytoplankton or phytoplankton-macrophyte dominated, depending on the superiority of a given community.

The concept of alternative stable states is mainly based on the results of the investigations carried out in the lakes of western European countries [13,12] where climatic and geological conditions, as well as the origin of lakes are different from those in Poland. Therefore the aim of the present paper was to check if the concept can be applied to the Polish lakes situated in the region of Western Polesie.

TERRAIN

The lakes studied are located in the western and middle part of the Łęczna-Włodawa Lakeland (Eastern Poland). All of them are characterized by flat lake basins and little mean (1.3-2.7 m) and maximum (1.3-7 m) depth [4,10]. Because of their small surface area (5.6-91.5 ha) they storehold relatively small amounts of water [11]. These parameters result in high dynamics of the water of the lakes which are polymictic.

The land use in the lake catchment areas is very diverse (Table 1). The ploughing fields take up from as little as 5.5% (Lake Długie) to over 60% (Lake Syczyńskie and Lake Głębokie) of their drainage areas, while forests from less than 1% (Lake Syczyńskie and Lake Głębokie) to 76.8% (Lake Długie). This points to a different potential load of nutrients to the lakes from their catchments, and consequently, also a different susceptibility of the lakes to degradation.

Table 1. Ohle's coefficient and structure of the land use (in percent) in the catchment areas of lakes investigated (after Furtak *et al.* [5], changed)

Land use	Lake					
	Kleszczów	Rotcze	Długie	Sumin	Głębokie	Syczyńskie
Ohle's coeff.	5.1	3.4	14.8	15.9	8.6	80.2
Lake	19.7	29.1	6.7	6.5	11.7	13.0
Forests and shrubs	25.5	10.5	76.8	9.5	1.0	0.3
Arable land	35.7	26.2	5.5	35.6	73.5	65.6
Others	19.1	35.5	11.0	48.7	13.8	32.8

METHODS

The investigations were carried out in July and August 2000, according to the commonly used limnological methods. Water for chemical and phytoplankton analysis was collected in the middle part of the lake. Analyses for total P and N were made according to the methods by Hermanowicz *et al.* [6] in unfiltered samples. Chlorophyll-*a* concentration was analysed by the ethanol method. Macrophytic communities in each lake were studied along 50 transects, and the plant abundance was expressed as percentage volume infested (PVI), calculated as the product of the percentage of coverage of the plants and their height divided by water depth. Samples for zooplankton analyses were obtained after pooling the 10-litre samples collected from 10 sites located along the longitudinal lake axis, and then sieved through a 50 m mesh. Fish were caught by means of electrofishing, fyke-nets and "Norden multimesh gill nets, and their biomass was calculated per CPUE (catch per unit effort = 12 hrs).

RESULTS

The lowest concentrations of total P were found in Lake Kleszczów and the highest in Lake Syczyńskie (Fig. 1). The concentrations in the latter (0.194-0.303 P mg dm^{-3}) were very similar or a little higher than in shallow Masurian lakes, described as strongly eutrophicated [3].

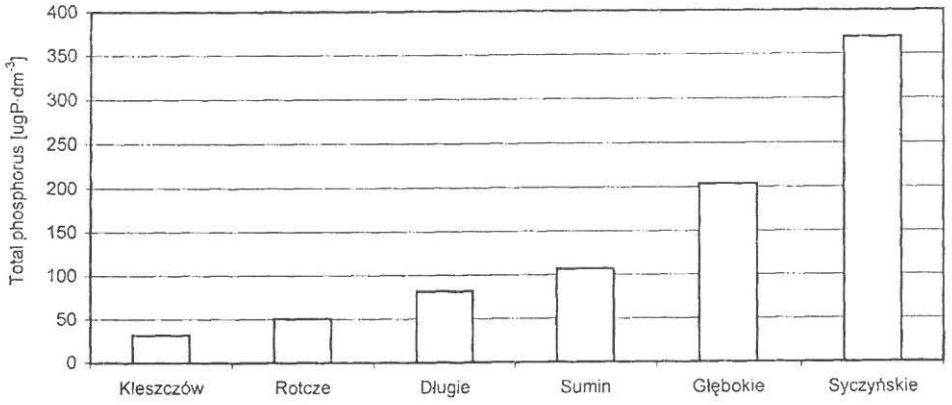

Fig. 1. Concentration of total phosphorus in the water of six shallow Polesie lakes

The concentrations of total N placed the lakes in the similar order, being the lowest in Lake Kleszczów (1.07 mg N dm^{-3}) and the highest in Lake Syczyńskie (2.26 mg N dm^{-3}). In the remaining lakes: Lake Rotcze, Lake Długie, Lake Sumin and Lake Głębokie the concentrations of total N amounted to: 1.19, 1.47, 1.56 and 1.41 mg N x dm^{-3}, respectively.

The abundance of phytoplankton expressed as chlorophyll-*a* concentrations were the lowest in Lakes Kleszczów and Lake Rotcze (Fig. 2), oscillating around 10 g dm^{-3} (range: 4.3-15.0 g dm^{-3}). The phytoplankton community was predominated by *Chlorophyta* (*Botryococcus braunii* in Lake Kleszczów and *Closterium tumidulum* in Lake Rotcze). The percentage of cyanobacteria in both lakes was very low, usually not exceeding 15%. The level of phytoplankton biomass in these lakes was clearly lower (1.0-9.2 mg dm^{-3}) than in the others (15.8 177.0 mg dm^{-3}).

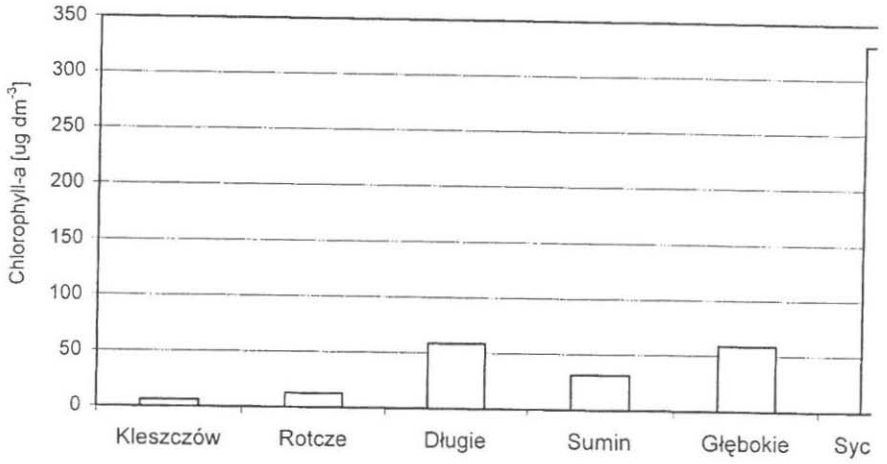

Fig. 2. Concentration of chlorophyll – *a* in the water of six shallow Polesie lakes

In Lake Długie, Lake Sumin and Lake Głębokie the concentrations of chlorophyll-*a* were much higher (Fig. 2), ranging between 20 and 90 g dm^{-3}. The most abundant group was cyanobacteria, whose contribution to the total biomass of phytoplankton usually exceeded 50%. The most important among them were Chlorococcales from the genus *Microcystis* and *Gomphosphaeria*, making large colonies. Occasionally also other taxa achieved high biomasses, e.g., *Ceratium hirundinella* in Lake Głębokie in July, and green-algae and diatoms in Lake Sumin in August. The total biomass of phytoplankton in the three lakes ranged from 15.8 to 69.9 mg dm^{-3}.

The highest values of both chlorophyll-*a* and the biomass of phytoplankton were found in Lake Syczyńskie (300-350 g dm^{-3} and 166-177 mg dm^{-3}, respectively) (Fig. 2). Cyanobacteria (with the most abundant *Planktothrix aghardii*) predominated the phytoplankton biomass amounting to 99 % during the summer.

The biomass of crustacean zooplankton was predominated by: *Ceriodaphnia quadrangula* in Lake Kleszczów and Lake Rotcze, *Chydorus sphaericus* in Lake Długie, *Bosmina coregoni* in Lake Sumin, *Daphnia cucculata* and *Mesocyclops leucarti* in Lake Głębokie and *M. leucarti* in Lake Syczyńskie. The mean crustacean biomass amounted to: 634, 958, 267, 1487, 3623 and 680 g DW dm^{-3}, respectively.

The ratio between the biomass of zooplankton and phytoplankton was the highest in Lake Kleszczów and Lake Rotcze, and the lowest in Lake Syczyńskie (Fig. 3).

The abundance of macrophytic communities, expressed as total PVI, was highly differentiated (Fig. 4). The macrophytes developed the most in Lake Rotcze (34.5%), Lake Długie (31.2%) and Lake Kleszczów (29.3%), being at least 10 times more abundant than in Lake Sumin (3.3%) and Lake Głębokie (0.75%). In Lake Syczyńskie there were virtually neither floating-leavedfloating-leafed nor submerged macrophytes, except for some singles shoots of *Ceratophyllum demersum* and *Potamogeton* sp.

The relative abundance of particular plant communities in the lakes studied differed, too (Fig. 4). Charophytes predominated in Lake Kleszczów (*Chara fragilis*) and Lake Rotcze (*Chara fragilis* and *Ch. hispida*), while elodeids in Lake

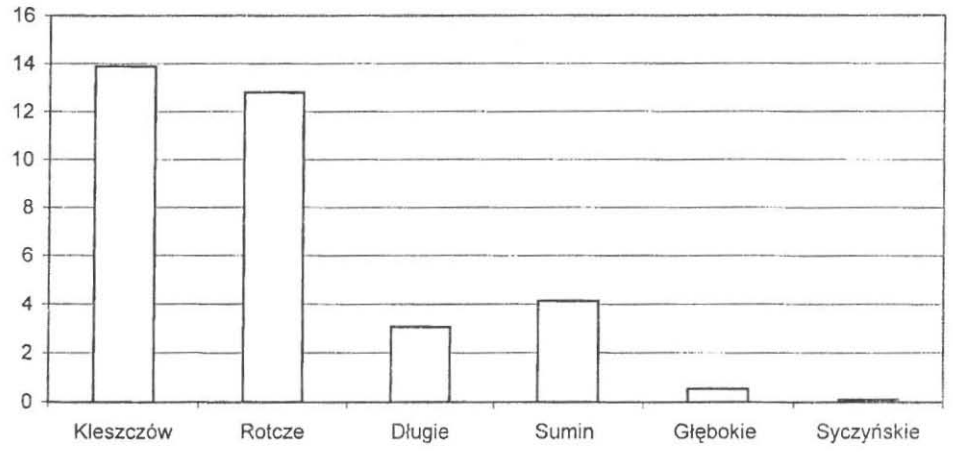

Fig. 3. Ratio between the biomass of zooplankton and phytoplankton in six shallow Polesie lakes

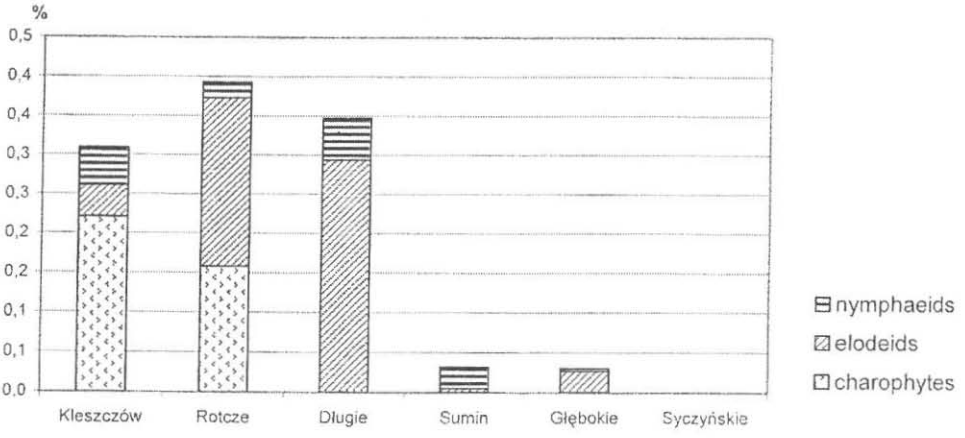

Fig. 4. Abundance of macrophytes expressed as PVI coefficient in six shallow Polesie lakes

Długie (mostly *Myriophyllum spicatum*), Lake Rotcze (*Ceratophyllum demersum*, *Elodea canadensis*, *Stratiotes aloides*) and Lake Głębokie (mainly *Elodea canadensis*). Nymphaeids prevailed only in Lake Sumin (*Nymphaea candida* and *Potamogeton natans*).

Fish achieved the highest biomass in Lake Głębokie (19.82 kg x $CPUE^{-1}$). Twice lower biomass was found in Lake Syczyńskie (8.96 kg x $CPUE^{-1}$), and was much lower, ranging between 2.57-4.8 kg x $CPUE^{-1}$ in the remaining lakes. The ratio between the biomass of predatory (mostly pike, pike-perch and perch) and unpredatorynon-predatory fish was highly differentiated, amounting from 0.05 in Lake Syczyńskie to 1.25 in Lake Kleszczów (Fig. 5). A similar relationship between the concentration of chlorophyll-*a* and the ratio between predatory and unpredatory fish werenon-predatory fish was found, e.g., by Persson *et al.* [14] and Jeppesen *et al.* [7].

DISCUSSION

The nutrient load to the lakes was not measured in this study. One can suppose, however, taking into consideration both the proportions between the surface area of the lakes and their drainage area (expressed as Ohles coefficient), as well as the land use around the lakes (Table 1), that amounts of nutrients entering the lakes both from external and internal sources are highly differentiated [1]. This

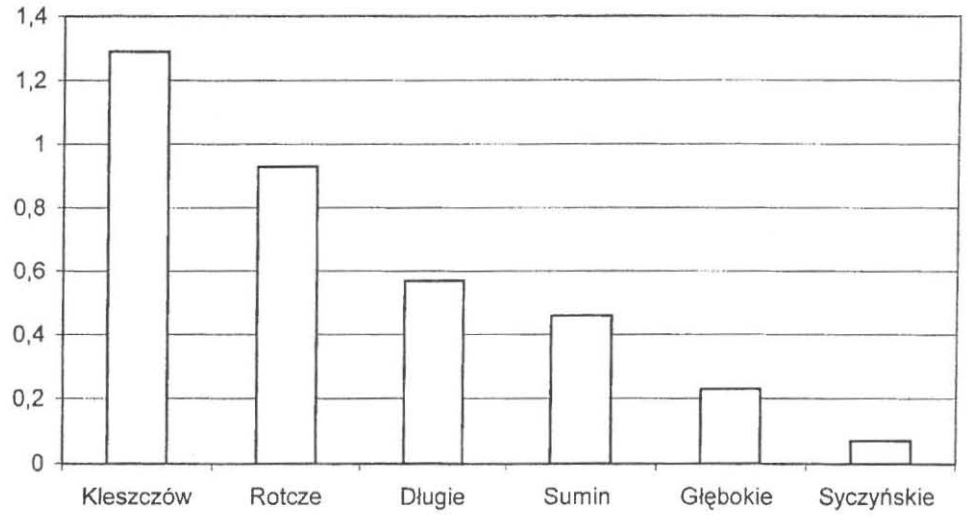

Fig. 5. Ratio between the biomass of predatory and unpredatorynon-predatory fish in six shallow Polesie lakes

might have resulted in the different phosphorus concentrations in the lakes, with two extremes – very low values in Lake Kleszczów and very high in Lake Syczyńskie. Thus, the described lakes are under a different nutrient influence from their catchments, which "at the start" could define their status, later on established by some internal buffer mechanisms presented in Fig. 6.

According to the concept of alternative stable states among the lakes studied four groups can be distinguished:

1. Macrophyte dominated in Lake Kleszczów and Lake Rotcze;
2. Macrophyte-phytoplankton in Lake Długie;
3. Phytoplankton-macrophyte dominated in Lake Sumin and Lake Głębokie;
4. Phytoplankton dominated in Lake Syczyńskie.

The conceptual model showing the position of lakes in the scheme and buffer mechanisms responsible for that are presented in Fig. 6.

In the first group of lakes (Lake Kleszczów and Lake Rotcze) the water is characterized by high transparency, which can be attributed to the high ratio between crustacean zooplankton and phytoplankton (Fig. 3), suggesting efficient control of algae by crustacean grazers [8,12]. The crustaceans were likely to find effective refuges against visually preying planktivorous fish provided by well developed macrophytic communities, and especially amongst the dense beds of charophytes, which are believed to be exceptionally important for establishing a

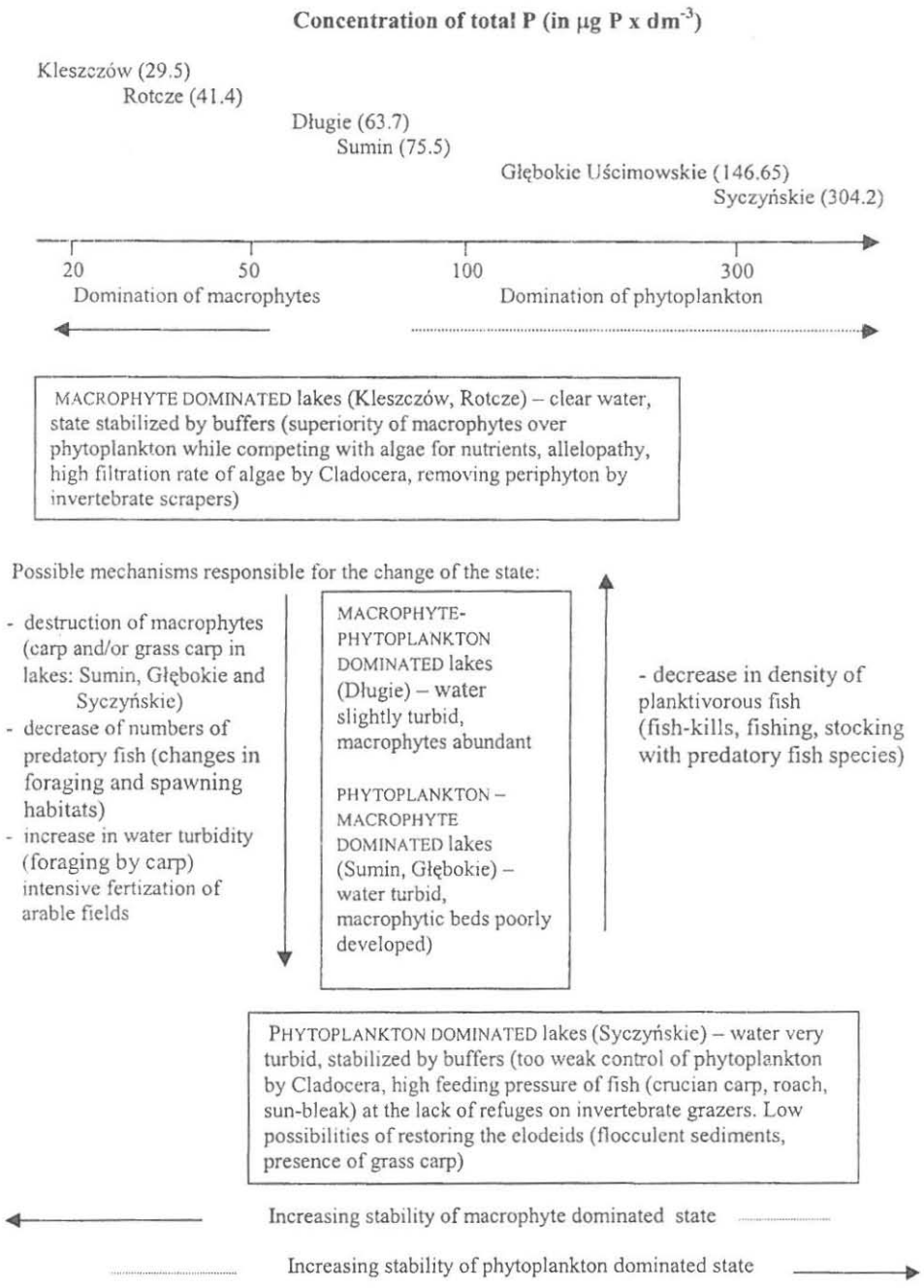

Fig. 6. The conceptual model of alternative stable states and buffer mechanisms in six shallow Polesie lakes. (Based on Moss [12], changed)

clear-water state in lakes [2,10,17]. In turn the populations of cyprynid fish are, most probably, well controlled by predatory fish as suggested by the very high ratio between predatory and unpredatorynon-predatory fish in these two lakes (Fig. 3).

The second group of lakes macrophyte-phytoplankton dominated – is represented solely by Lake Długie, which was more or less turbid depending on the season. The macrophytes, composed mainly by *Myriophyllum spicatum*, developed a dense carpet covering almost the whole lake bottom area. Nevertheless, there were occasional algal blooms in the lake, affecting high chlorophyll-*a* concentrations (Fig. 2). This might have been due to relatively low ratio between the biomass of crustacean grazers and phytoplankton. It can be assumed that this unfavourable situation was caused by very high population of small zooplanktivorous fish – sun-bleak.

In the third group – phytoplankton-macrophyte dominated in Lake Sumin and Lake Głębokie – the water was more or less turbid depending on the season. The macrophytes were poorly developed, with obvious consequences for relationship between zooplankton and phytoplankton, and between predatory and unpredatorynon-predatory fish.

The fourth group phytoplankton dominated – is represented by Lake Syczyńskie. Its biocenosis is strongly simplified, the water is very turbid, with almost constant blooms of cyanobacteria and a lack of submerged and floating-leavedfloating-leafed macrophytes. Taking into account the criteria of trophic lake typology it was classified as hypertrophic [9].

One may suppose that the position of the lakes in the classification presented is rather stable in the case of the first and the fourth groups of lakes (Fig. 6). The first group (Lake Kleszczów and Lake Rotcze) is well buffered by the abundant development of macrophytes, the fourth one – phytoplankton dominated Lake Syczyńskie – by predomination of phytoplankton and the nature of the bottom sediments, which are flocky and do not provide a suitable substrate for the recolonization of macrophytes [13]. These lakes seem to be in the state "without alternative" because of the nutrient load. The macrophyte dominated Lake Kleszczów and Lake Rotcze which have low TP concentrations and are well buffered by the abundant development of macrophytes, because their phytoplankton communities are nutrient limited. Lake Syczyńskie, in contrast, is phytoplankton dominated because of the high phosphorus concentrations which have contributed to the luxuriant algal development. The possible shift of Lake Syczyńskie into a macrophyte dominated state, with the consequent improvement of the water quality, is likely to be obtained (after the substantial reduction in the nutrient load

from the catchment area) as a result of a very severe fish-kill (Fig. 6), or, more likely, by complex restoration measures.

In the case of lakes representing the intermediate state (macrophyte-phytoplankton or phytoplankton-macrophyte dominated) the situation may change from year to year, depending, e.g., on the weather or other external factors. The possible mechanisms which can switch the lakes in the direction of phytoplankton or macrophyte dominated lakes may include macrophyte and/or fish management, and the way of the land use, too (Fig. 6). This category of lakes seems to be the most susceptible to the human impact, and the proper management is very important in order not to deteriorate that the environmental situation does not deteriorate.

CONCLUSION

Concluding, the theory of alternative stable states of lakes allowed for classification of the lakes studied for identifying the threads to the lakes. At the moment, however, it is difficult to say if the concept can be fully applied to shallow Polesie lakes. In order to answer this question, the bigger data set of further data on the lakes should be investigated.

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PŁYTKIE JEZIORA POLESIA Z PUNKTU WIDZENIA TEORII STABILNYCH STANÓW ALTERNATYWNYCH

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S t r e s z c z e n i e. Latem 2000 zbadano ekosystemy sześciu płytkich jezior Polesia Lubelskiego (Kleszczów, Rotcze, Długie, Sumin, Głębokie Uścimowskie i Syczyńskie) w celu zweryfikowania hipotezy, czy sformułowana w krajach Europy zachodniej teoria alternatywnych stanów stabilnych jezior może być stosowana w odniesieniu do jezior polskich. Wody jezior cechował

szeroki zakres stężeń fosforu całkowitego (19.7-436.0 3 mg P dm^{-3}) oraz chlorofilu-*a* (1.28-357.0 mg dm^{-3}). Stopień rozwoju makrofitów wyrażony współczynnikiem PVI wynosił odpowiednio: 29.3, 34.5, 31.2, 3.3, 0.8 i 0.0 %. Biomasa planktonu skorupiakowego zawierała się w przedziale od 267 do 3623 g s.m. dm^{-3}, zaś ryb od 2.57 do 19.82 kg $CPUE^{-1}$. W oparciu o analizę powyższych czynników, jeziora Kleszczów i Rotcze zostały sklasyfikowane jako makrofitowe, jezioro Syczyńskie jako fitoplanktowe zaś Długie, Sumin i Głębokie Uścimowskie jako położone pomiędzy dwoma ekstremalnymi stanami. W pracy przedyskutowano wpływ użytkowania zlewni oraz wewnętrznych mechanizmów buforowych opartych o interakcje troficzne w jeziorach i decydujących o przynależności jezior do poszczególnych stanów.

S ł o w a k l u c z o w e: jeziora poleskie, teoria alternatywne stanów stabilnych, substancje odżywcze, makrofity, plankton, ryby