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Transformation of lakes in mires

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Abstract

It has been presented relations among different types to lakes with respect to their morphometry, hydrodynamic, hydrochemistry, and biological properties of plants growing under various conditions of water depth, showing methods of their transformations in mires, as they become shallow. It has been explained too, how different lakes may be overgrown by vegetation and transformed in mires.

Key words: lakes, mires, macrohydrophytes, helophytes, immersion and emmersion vegetation, sorptive complex, lakes transformation

INTRODUCTION

Lakes have ephemeral character in a landscape, if they are considered in a long limit of time aspect. They appear and disappear leaving more or less distinct traces of their past being. Very rarely, we have to do with sudden disappearence of a lake, affected by a rapid flown down its water. More often, however, we may see how it changes its morphometic, hydrodynamical, hydrochemical, and biocoenotical character.

Lakes on account of their origin were classified by Hutchinson (1957). In Europe the lakes are predominantly of glacier origine, rarely here, they are of sea, river, karstic or volcanic origine. In Poland lakes classification in the Suwałki Lake Region has been presented by Stangenburg (1936), who built it up basing upon morphometic, hydrochemical and biocoenotical criteria. He modified and extended well known Thienamenn's (1928) classification. Stangenberg (1936) classified the lakes of the Suwałki Lake District in the oligotrophic, a. mesotrophic, b. mesotrophic, eutrophic, extremely calcitrophic

— jeziorka, dystrophic — suchary, and discussed the process of their aging. He detected the analogy between lakes ageing and the process of podsolation which occurs in soils, as well as showed the way of their evolution. He documented his point of view presenting a map of the Wigry Lake and little bodies of water of dystrophic character — suchary — situated near it.

Later on, it was Sobotko (1967) who focussed her interest on processes of endotheric lakes overgrowth in the Suwałki Region and gave valuable informations as to this topic in her doctoral thesis. From this region we have also very important investigations carried out on mechanismes of filling in the Mikołajskie Lake, Więckowski (1966).

History of lakes appearence in late glacial and holocen in Poland was a subject of Stasiak (1971) researches, who distinguished two periods of their origine, one being alleröd, and second one — atlantic. According to generally accepted by limnologists opinion (Naumann 1932, Thienemann 1928, Stangenberg 1936) there is a close connection among oligotrophic, mesotrophic, and eutrophic lakes, in which oligotrophic lakes are initial links in their farther developmenent, and the eutrophic represent one of the final link in the lakes evolution.

Different trophic levels of lakes correspond to plant communities which take part in becoming the lakes shallow and in their transformation in mires. On the other hand, we must not discuss the trophy of a lake without taking into account its hydrodynamic character which influence the rate of filling in a water basin and plant communities development.

In this paper I shall try to make use of well known facts which do not demand argumentations to be proved, as well as of my own investigations on plant successions within mires in Poland, to give a comprehensive explanation on how lakes are being transformed in mires. I am taking the following assumptions:

1. Lakes may be classified with respect to their trophic character in oligotrophic, mesotrophic, eutrophic and dystrophic.
2. Lakes are being aged — become old, their juvenile stage represent oligotrophy, meso- and eutrophy present adulescence, and dystrophy represents senescence — a senile, final stage of lakes existence.
3. As a lake is being aged, there appear changes in the amount of mineral elements, as well as in pH value of its water — there reveals a gradual decrease of mineral elements, and a change of the proportion between metallic cations — especially those of calcium — and hydrogen ions, in favour of the last.
4. As long as a lake has an inflow and outflow, it may keep its eutrophic character.
5. Lakes become shallow and are invaded by hydrophytes and helophytes.
6. A lake with differentiated bottom line, that having deep and shallow places splits in its ontogeny in several isolated deep water bodies.
7. There are the lakes with inflow and outflow, with outflow only, with inflow

only, and those which have neither inflow nor outflow with relatively stagnant waters.

On endeavouring to join the above mentioned facts in a compact entity, I shall focus my attention upon: a) conditions affecting the lakes to become shallow as main factors causing their transformation in mires; b) biological properties of communities invading the lake water; c) methods of the hydrophytes and helophytes invasion and ways in which lakes are overgrown by plant communities; d) relations between water basins surrounding, especially that of peat bogs or *Pine* wood forests and sorptive properties of peat; e) relations between morphometry of lakes and methods of their overgrowing by plant communities.

CONDITIONS AFFECTING LAKES TO BECOME SHALLOW

A substantional factor affecting lake waters to become shallow up to depth, which enable an invasion of macrohydrophytes, and their rooting on the bottom, is filling in the water basin by material transported by rivers which discharge themself into the lake, restriction of salts weakly dissolved in the water, especially a formation of calcium bicarbonate due to liberation of CO_2 in the respiration process of living organisms, transport by water and deposition of silts, sands, clays and plant rests from the surrounding owing to abrasion processes, deposition of plant material of autochtonic origine in a form of coarse gyttia, fine detritus gyttia and various kinds of the algal gyttia.

After a deep lake has became shallow, up to about 4-3 m of depth, if it still maintains eutrophic character, it may be overgrown by underwater meadows made by *Chara, Potamogenton, Najas, Myriophyllum* or *Ceratophyllum*, which initiate the process of an upwards growth of lake biomass.

The rate of becoming shallow is modified by various human activity, especially by agrotechnology and fertilization. Fertilizers being in use in a big quantity in the vicinity of a lake bring about lake water eutrofization, thus affecting an increase of biomass production within the lake itself. The agronomic treatments intensify abrasion processes which silt up the lakes. The rate of an increase in thickness of lake sediments is about 0.8 mm per year (Żurek 1987).

BIOLOGICAL PROPERTIES OF THE PHYTOCOENOSES WHICH INVADE THE WATER ENVIRONMENT, AND THE METHODS OF LAKES OVERGROWTH

Plants which grow in the water basins as dependent of their depth may be divided in microhydrophytes, macrohydrophytes, and helophytes. All the three groups take part in making a lake shallow.

Helophytes occupy the peripheral parts of mezo- and eutrophic lakes. Macrohydrophytes enter deeper parts, among them nympheids are rooted up to the depth of about 3 m, and eloids enter still deeper into lake waters. Helophytes on account of their biological properties may be divided in emmersion and immersion group. The immersion plants form theirs root system in the lake bottom binding the stem of which a part streches out above water surface, plant bodies in this group are stiftly connected with the substratum. They are e.g. *Phragmites communis, Equisetum limosum, Scheonoplectus lacustris, Typha latifolia, T. angustifolia,* tall sedges and other helophytes rooted in the bottom.

The emmersion group is being characterized by superficially extending root and rhizome system, which is freely connected with a substratum. To this group belong e.g. *Menyanthes trifoliata, Comarum palustre, Calla palustris, Scheuchzeria palustris, Carex limosa.* The plants which belong here are able to form floating matts which may keep on the water surface, and they may be easilly detached from the substratum. They may give a support to water bryophytes, e.g. *Drepanocladus fluitans, Sphagnum cuspidatum.*

The processes of overgrowth the water basins are carried on, the most intensively in eutrophic, slowly flowing, or stagnant waters. In the first stages of an invasion in deep waters of eutrophic and mesotrophic character, they are nympheids and eloids which take part in this process. The remnants of these plants and died plancton, together with mineral deluvials from the neighbourhood, and calcium bicarbonate having been precipitated, form in depressions within a lake bottom various kinds of gyttia.

Within lake litorals which became shallow, there develop immersion helophytes producing reed and reed-sedge peats, which bring about farther shallow places formation.

If the shape of a lake bottom is symetrically developed, then after some time around the lake which became shallow there arises a fen. However, if within the lake bottom, deep and shallow places occur, then the shallow places are invaded by hydrophytes — nympheids, and helophytes of immersion character.

As the lake become shallow, it loses step by step its inflow and outlow, attaining stagnant character, with water supply only in a form of rainfall. At this stage, when the lake have lost its inflow and outflow, if there is no disturbance by denudations which would bring about an additional mineral supply flowing down from the surrounding and which might have been deposed in the sedimentation basin (a case which may take place within little deep dales i the morain landscape, or at the contacts of a valley with steep edges of terraces) then in the waters of such lakes there is an initial (initial for farther consideration) concentration of nutrients. Let us sign it by C_{to}. As biocenoses grow, they consume the nutrients with a rate be it *a*. Thus let the initial amounts of the mineral element diminishes according to the rate during the time t_1. Then the amount of the nutrients after some time may be expressed in the equation: $C_{t_1} = C_{t_1}^{-at}$. The equation may express the relations with which we have to do while a lake of eutrophic character is being transformed in dystrophic one, as well as it may represent a decreasing amount of mineral elements in successive peat layers as peat bed (seam) is growing in thickness. When these relations are being considered, we should keep in mind the fact, that as biomass grow, there also changes the proportion between metallic cations and the hydrogen ions (Gorham 1966) (Fig. 4).

Because lakes may reveal different morphometic character, there are among them also ones which show unsymmetrical bottom line, with deep places situated both in a centre as well as in peripheral parts, and therefore it is not difficult to explain a formation of raised bogs within valleys, in their different parts, assuming that the rest of an eutrophic lake in a form of dystrophic water bodies may be directly overgrown by floating mat communities, which very fast may be transformed in raised bog. Thus in the above case the shallow places are transformed in fens, and the deep ones become inflowless and outflowless lake being surrounded by fen. Originated in this way the lake changes gradually its trophic character from eutrophy to mesodystrophy and begins to be overgrown from the shore by emmersion plant communities, building up floating mats.

RELATIONS BETWEEN WATER BASINS AND SORPTIVE PROPERTIES OF PEATS IN THE MIRES SURROUNDING WATER BODIES

Isolated deep places of lakes of which shallow places were transformed in mires receive their water supply from rainfalls. Plants which develope under such conditions, bind in their biomass certain amounts of mineral elements taken from the environment, causing their decrease in the water. The decrease is intensified by humic substances dissolved in the water, as well as, by peat mass around the deep places. They both, as in immense sorptive complex absorb certain amounts of metalic cations. As the mass of these complex grows, there increases gradually in it the amount of hydrogen cations. Decomposition under anaerobic condition of the lake, as well as, mire plants is the main source of the humic acids which dissolved in peat water may flow down into the lake, causing an icrease of the sorptive capacity. Thus, originally one water basin — widely extended lake, may be transformed, depending on its morphometric character, in one, or several, little dystrophic lakes.

OVERGROWTH OF THE DYSTROPHIC LAKES

This process was thoroughy described by Sobotko (1967), who investigated it within the same dystrophic lakes — suchary, which were previously characterized by Stangenberg (1936), who gave their hydrochemical features. An overgrowth of this type of lakes is affected chiefly by an invasion of emmersion plant communities which are able to form floating mats. The invasion goes on from the fringe of a lake towards its centre, like diaphragm in a photocamera does. Because in this stage of lakes developement their waters contain small amounts of mineral elements, especially that of calcium, but they are rich in humic acids, therefore, under such conditions may grow only specific, oligotrophic, acidophilous plants.

In the central Europe the overgrowth of distrophic lakes in their final stages of existence is caused by plant communities able to form floating mats, which belong to the *Scheuchzerio-Caricetea* class with such species as *Sphagnum cuspidatum, Drepanocladus fluitans* which may be interwoven by rhizoms of *Carex limosa, Scheuchzeria palustris, Calla palustris, Menyanthes trifoliata, Lysimachia thyrsiflora*. In such a way we have to do with a direct transsition from a body of water to transitional and raised bog.

In the light of the above presented arguments it is easy to understand and to explain the appearence and existence of raised bogs localized in somewhat strange, unexpected situation, namely, their occurence within a valley of which examples are given beneath.

1. A raised bog situated within the Nowa Ruda mire complex — fen complex (Tołpa 1960).
2. Transitional and raised bog within the Pupkowizna mire complex (Tołpa 1960).
3. Transitonal and initial stages of raised bog development in the Kunice mire complex (Marek 1988).
4. Transitional and raised bog near the Brzeziczne Lake in the Włodawa-Łęczna Lake Region (Marek 1988).
5. The appearence of a raised bog in the successional stages in the centre of the Motarzyno mire (Marek 1988).
6. One can also show the examples of similar relations in papers published by Weber (1907), Kulczyński (1939, 1940), Mörnsjö (1968), Pacowski (1967), Grosse-Brauckmann (1976).

It has been long ago established the relations between the amount of accumulated biomass and pH value, pH and type of a mire (Gorham 1967).If we consider these facts, we can find distinctly expressed analogy between aging of lake waters with a tendency towards dystrophy and accumulation of a biomass, its quality in successive peat layers within a peat seam as it is growing in thickness in a central part of a mire. We must emphasize a close connection among amounts of mineral elements, hydrodynamic character of a body of water, as well as, an importance of humic acids dissolved in the lakes with stagnant water as a sorptive factor. In both two cases, namely, during aging of a lake without inflow, and during accumulation of organic materials there is a natural tendency to decrease of the mineral elements concentration, and to saturate the sorptive complex with hydrogen ions (Gorham 1967) (Fig. 4).

In the light of these relations we come to the following conclusions:

1. Shallow lakes of eutrophic character which have lost their inflows are overgrown very fast by nympheids and immersion helophytes to be directly transformed in fens (Fig. 1).

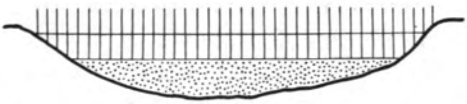

Fig. 1. A shallow eutrophic lake in a stage of an overgrowth by macrohydrophytes and immergent helophytes, after it lost its inflow

2. Deep eutrophic lakes with symmetrically built up bottom line — bottom profile are being transformed in their peripheral parts in fens while central part attaining a stage of dystrophy begins to be occupied by floating mat, which initiates a transitional and raised bog formation (Fig. 2).

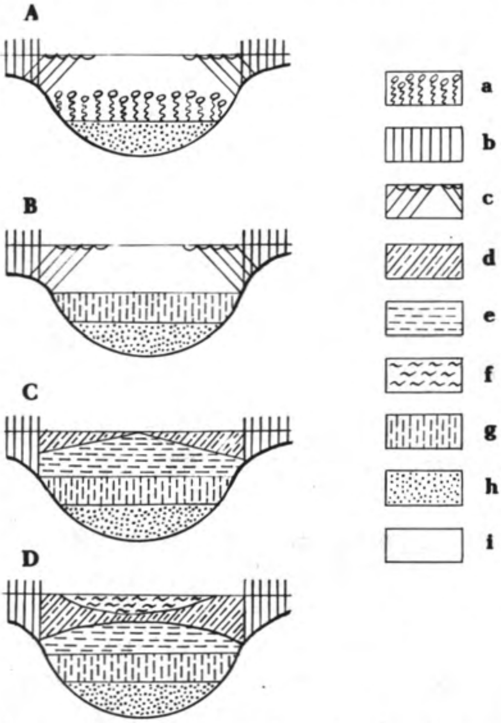

Fig. 2. A deep, eutrophic lake with symetrically formed bottom line in successive stages of its transformation, after it lost its inflow. A — an eutrophic stage, B — meso-dystrophy, C — dystrophy and an appearence of emmerged communities, D — an appearence of raised bog communities of the *Sphagnetea* class. a — eloids causing upwards overgrowth of water basins, communities which belong chiefly to the *Potamogetonetea* class, immerged, rooted in lake bottoms plants; b — helophytes, chiefly immergent plants of the *Phragmitetea* class, which cover peripheral and shallow places of eutrophic and mesotrophic lakes; c — nympheides, macrohydrophytes rooted in the bottom of lakes, with leaves floating on the water surface; d — emmergent plants of the *Scheuchzerio-Caricetea* class which appear when a lake attains a stage of dystrophy; they form floating matts giving rise to an invasion of raised bog vegetation; e — dy, a dystrophic lake sediment; f — raised bog communities of the *Sphagnetea* class, g — detritus gyttia; h — mineral substratum; i — free water or water closed in a form of lenses

3. Eutrophic lakes differentiated in shallow and deep places in their shallow parts undergo transformation in fens, however, deep places become isolated, smaller bodies of stagnant water, which attain a stage of dystrophy, those in turn, through a stage of a transitional bog, expressed in the *Scheuchzerietalia* order communities, are being transformed in raised bogs (Fig. 3).

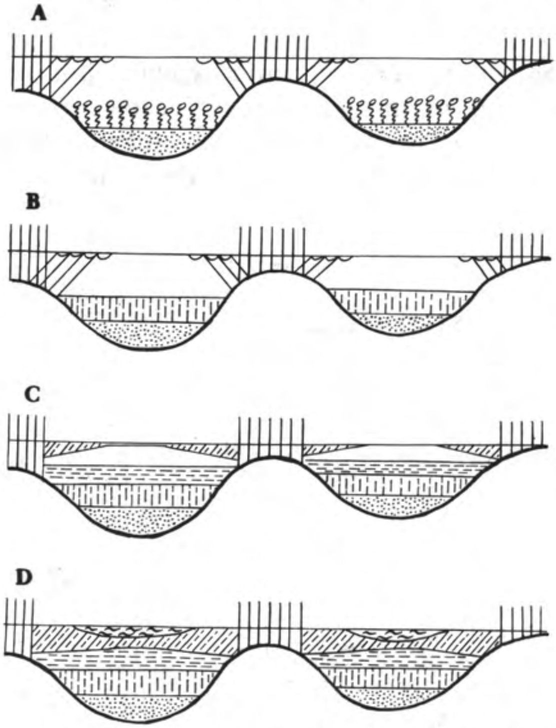

Fig. 3. Successive stages of an overgrowth of an eutrophic lake differentiated in deep and shallow places. Explanations as in Fig. 2

Within these lakes there are two kinds of sites which represent different environments, one being the places, shallow ones, which do not attain the stage of dystrophy, and there the developement of the lake — its existence, terminates in a stage of its eutrophy, and the other, deep places, where dystrophic waters appear. In the first case they are aquatic plants and immersion helophytes which terminate lakes existence, transforming them in fens (within their shallow places); in the second, however, they are the emmersion plants forming floating mats, which terminate the deep bodies of water existence, thus initiating a raised bog formation.

4. There are two main methods of filling in the lakes, one being the developement of plants rooted in the bottom, especially while the lakes are still in their eutrophic stage, and the depth allows macrohydrophytes to take roots. Then the process of invasion the lake is carried on by plant communities which

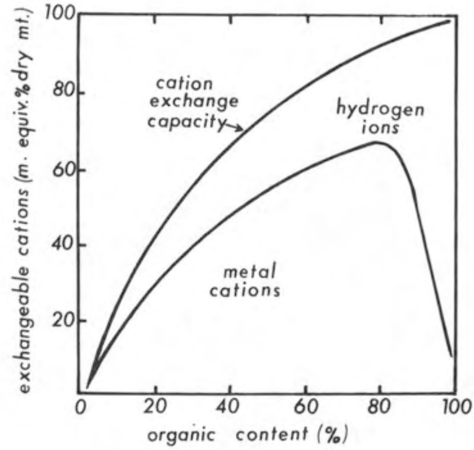

Fig. 4. Diagram showing a relation between organic matter content and exchengeable cations, in which a rapid decrease of metalic cations in a sorptive complex brings about its rapid saturation with hydrogen ions, as organic matter content increases above 90 %. After G o r h a m (1966)

belong chiefly to the class *Potamogetonetea*, and it is proceeding from the bottom upward.

The other way of invasion the water by plants is forming by floating vegetation — emmersion plants, surface platforms in a form of floating mats made up of roots and rhizoms which may support bryophytes. This vegetation belongs chiefly to the class *Scheuchzerio-Caricetea*. As the peat being formed by it is growing in thickness, it is sinking step by step in the lens of closed dystrophic water affecting ultimately its disappearence by filling it in.

Floating platforms may also be sometimes formed by communities which belong to the *Phragmitetea* class, in which *Phragmites* communis tall tussock sedges such as *Carex elata, C. paniculata,* or *Cladium mariscus* may play an important role, which may grow in an intermediate zone, between reed communities and those of the *Scheuchzerio-Caricetea* class. They appear usually in the lakes where calcareous gyttia previously was deposed, and in these sectors of an overgrowing lake fringe, which are affected by spring waters.

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Przekształcanie się jezior w torfowiska

Streszczenie

W oparciu o znane, opublikowane również przez innych autorów wyjaśnienia procesów związanych z wypłycaniem i zarastaniem zbiorników wodnych oraz własne długoletnie badania biostratygrafii torfowisk jeziornego pochodzenia, uwzględniając czynniki: morfometryczne, hydrochemiczne, hydromechaniczne i fitocenologiczne, przedstawiłem teorię wyjaśniającą przekształcanie jezior w torfowiska.

Teorię tę można przedstawić następująco: Warunkiem przekształcenia jezior w torfowiska jest w nich stopniowy zanik przepływu pozwalający na spokojne ich wypłycenie i zarastanie. Wypłycaniu, spowodowanemu ograniczeniem dopływu wody oraz powstawaniem osadów nieorganicznych i różnorodnych sedymentów organogenicznych, towarzyszy zarastanie głównie przez makrofity

o różnorodnych przystosowaniach biologicznych i ekologicznych. Zarastanie może postępować od brzegów w kierunku środka jeziora, przy udziale roślinności wodnej i bagiennej zakorzeniającej się na dnie i opanowującej peryferia zbiornika wodnego — **zarastanie dośrodkowe**. Zarastaniu dośrodkowemu może towarzyszyć **zarastanie oddolne** spowodowane od pewnej głębokości przez roślinność wodną zakorzeniającą się na dnie zbiornika. Trzecim rodzajem zarastania jest **zarastanie odgórne**, pojawiające się pod sam koniec istnienia zbiornika wodnego, wtedy gdy wskutek zmian natury hydrochemicznej osiągnie on stan dystrofii. Na powierzchni wody pojawiają się darnie pływające utworzone przez mszaki wodne i emersyjne gatunki roślin bagiennych o skromnych wymogach pokarmowych. W zarastaniu różnych typów jezior i przekształcaniu ich w torfowiska zaznaczają się wyraźnie pewne prawidłowości.

Płytkie jeziora eutroficzne, które zatraciły przepływ, szybko zarastają przez nimfeidy i imersyjne helofity, przekształcając się bezpośrednio w torfowisko niskie. **Głębokie jeziora eutroficzne o symetrycznie wykształconej misie** rozwijają się w częściach peryferycznych w torfowiska niskie, w częściach centralnych natomiast osiągają stan dystrofii i tam przez zarastanie wolnej powierzchni wody przekształcają się w pływającą darń, która rozpoczyna fazę rozwojową torfowiska przejściowego i wysokiego. Proces zamykania wolnej powierzchni wodnej — lądowienia, odbywa się dośrodkowo na podobieństwo zamykania zwiększającej się przesłony w aparacie fotograficznym. **Jezioro eutroficzne o zróżnicowanej konfiguracji dna** na płycizny i głęboczki, wypłycając się ulega na płyciznach przekształceniu w torfowisko niskie, głęboczki natomiast stają się odizolowanymi jeziorkami osiągającymi stan dystrofii, a te, wykształcając darń pływającą, wchodzą w fazę torfowiska przejściowego i wysokiego.

W obrębie jednej misy jeziornej przeto, w zależności od ilości głęboczków w końcowym stadium jej zarastania, mogą występować wysepki torfowisk przejściowych i wysokich otoczone przez kompleks torfowisk niskich. W dalszym rozwoju takie odizolowane od siebie wysepki torfowisk wysokich mogą zlać się ze sobą poprzez pomost boru bagiennego, który zazwyczaj pojawia się na pierwotnych płyciznach oddzielających głęboczki.