Possibilities of a Saprotrophic Lake Recultivation Exemplified by Lake Długie in Olsztyn

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Abstract

This article presents the subsequent stages of Lake Długie recultivation. The lake has been completely degraded and has reached a saprotrophic state due to the discharge of domestic wastewater from the neighbouring living estate.

The lake's recultivation was initiated by cutting off the domestic wastewater inflow to the lake, and followed by the reduction of storm water inflow and artificial aeration with destratification carried out with modifications since 1987. Special attention was paid to the effects obtained in the reference years (i.e. without aeration) which allows determination of the durability of the recultivation results.

Keywords: saprotrophic lake, recultivation, artificial aeration

Introduction

Attempts to restore degraded reservoirs have been made since the mid 1950s. The great majority of lake recultivation techniques applied worldwide are based on artificial aeration with simultaneous thermal destratification or with no destruction of stratification [1, 2, 3]. Likewise, in Poland the highest number of lake recultivations is based on artificial aeration [4, 5, 6]. Artificial aeration with complete water mixing was initiated on Lake Starodworskie in Olsztyn, in 1967 [7]. This method has been gradually developed on the same lake [7, 8, 9, 10], also making use of wind energy [11], but moreover on lakes Mutek [12, 13], Skąpe [14], and on the shallow lakes: Jelonek [15], Łąck Wielki, and others.

The particular example of a lake restored with this method over many years under strictly controlled conditions and with constantly monitored effects is undoubtedly Lake Długie in Olsztyn. This has been achieved owing to model co-operation between the Department of Environmental Protection of the Olsztyn and the Department of Environment Protection Engineering, at the University of Warmia and Mazury the scientific supervisor of the recultivation. This has enabled rejuvenation of a once completely degraded reservoir.

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Material and Methods

Study Object

Lake Długie is situated on the western side of Olsztyn. The lake's surface area equals 26.8 ha. The reservoir has an elongated shape (Fig. 1). Its max. length (1,760 m) related to small width (240 m) makes elongation of 6.9. The lake bowl is distinctly divided into three sections: shallow (3 m) and small (2.3 ha) southern bay, the deepest (17.3 m) and largest (13.4 ha) middle section, and finally the northern section separated with a shallowness and a bridge of max. depth 5 m and 11.1 ha surface area.

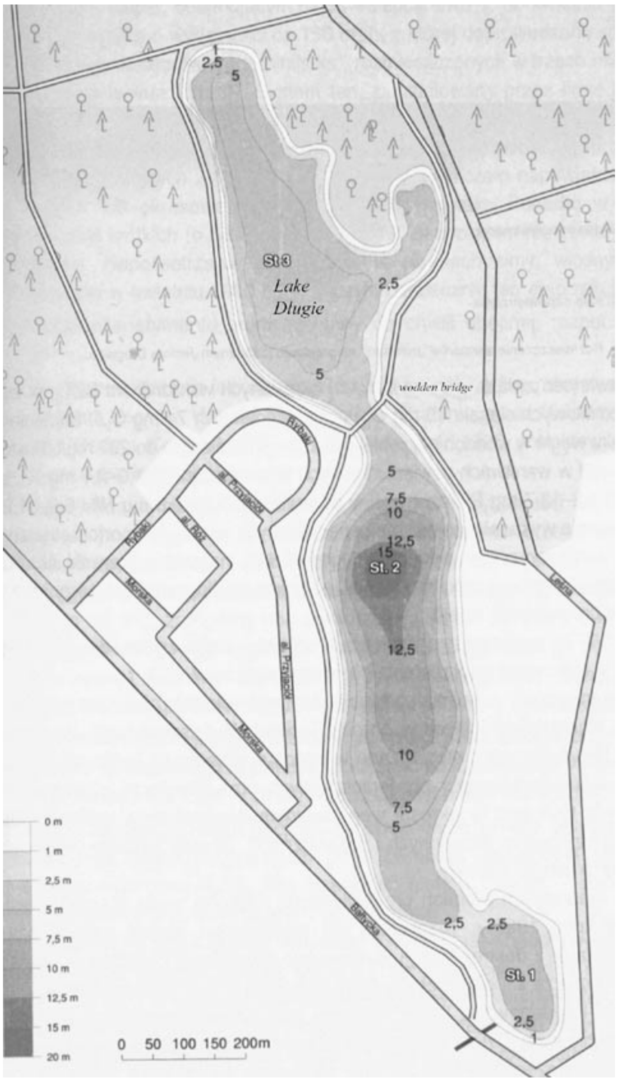

Fig.1. Distribution of water examination stations in Lake Długie.

Lake bowl volume amounts to 1,415,000 m^3. It has no natural surface outflows and inflows. The lake receives storm waters, and for over 20 years it had been also received water for sanitary sewage from western Olsztyn.

Water mass dynamics have been determined by bowl diversity and shielding of the shores. The shallow southern bay displays the properties of a polymictic reservoir, the middle section is evidently bradymictic, and the northern section (shielded by the forest) is characteristic of the dynamics typical for shallow lakes, though with hindered water turnover.

Methods

The artificial aeration of the lake was carried out in two phases. In phase one, i.e. since July 1987 till April 1990, an on-shore compressor of 150 m^3/h delivery was used, which served to distribute compressed air to three "minifloks" aerators placed in the middle section of the lake. The second phase was commenced in mid August 1991 and lasted until 2000. The aeration was executed with a compressor of 80 m^3/h delivery, and the compressed air was introduced through two "minifloks": the first placed over the deepest place in the middle section, and the second in the northern bay. In this phase aeration was carried out under strict control and operation time of the compressor was adjusted to observed aquatic conditions.

Effectiveness of the recultivation has been assessed according to physico-chemical analyses of the water, conducted in the monitored years (i.e. while artificial aeration was executed). The surveys were conducted on three research stations located over the deepest place of the distinguished basins of the lake (Fig. 1):

Station 1 – on the shallow, non-aerated southern bay;

Station 2 – on the deepest middle section of the lake, aerated since 1987;

Station 3 – on the northern bay, aerated since 1991.

Physico-chemical analyses of the lake's water were conducted in accordance using the Standard Methods [16]. DO was determined with Winkler method, BOD_5 – with direct method or dilution method, free carbon dioxide was titrated with sodium carbonate, chlorophyll "a" with Strickland – Parsons method, phosphate phosphorus and total phosphorus with colorimetric method with ammonium heptamolybdate and tin(II) chloride as reducer, ammonium nitrogen with indophenol test, nitrite nitrogen – with colorimetric method with phenolbisulfonic acid, organic nitrogen with Kjeldahl method, total nitrogen was calculated as a sum of the mineral forms (NH_4^+, NO_3^- and NO_2^-) and organic nitrogen.

Results and Discussion

At the end of the 1950s, the southern bay of this picturesque lake, used as a municipal bathing place, had begun to receive 300-450 m^3 of untreated municipal sewage from an emergency overflow on the sewage system serving the nearby neighborhood of single-family houses. The lake has shared the fate of numerous reservoirs located within municipal borders; however, the particular morphometry of the lake's bowl and the poor dynamics of mixing on one hand, and the substantial loads of the imported contaminants on the other, have resulted in accelerated transformation into a saprotrophic lake.

In 1972 total depletion of dissolved oxygen was detected in the water during ice-cover presence and strong variations in surface water oxygenation during the growing season (4.6 mg O_2/dm^3 in June to 13.1 mg O_2/dm^3 in August) (Fig. 2), at simultaneous complete oxygen depletion in the deeper layers [17]. Some physico-chemical indicators of the lake's water were similar to those of diluted sewage. BOD_5 in the surface water amounted up to 45 mg O_2/dm^3, and in the bottom water it varied between 17.3 and 74.2 mg O_2/dm^3 (Fig. 3). On the other hand, concentration of free carbon dioxide exceeded 240 mg/dm^3 [18]. Total phosphorus was present under the water surface in the amounts of 1.0-1.9 mg P/dm^3, and near the bottom: 1.2-12.5 mg P/dm^3 (Fig. 4); nitrogen concentrations were: 3.2-8.7 and 8.5-31.2 mg N/dm^3, respectively (Fig. 5) [19]. The amount of nutrients was determined by mineral forms content, i.e.: in the case of nitrogen - by ammonium nitrogen, and in the case of phosphorus - by phosphate phosphorus.

Variations in the oxygen conditions and of the co-related primary production, typical for the saprotrophic state, resulted in rapid changes of the chlorophyll "a" content in the growing season, i.e. from 1.6 to 514 mg/m^3 (Fig. 3) [20].

The first phase of lake rejuvenation took place in the beginning of 1973 when the domestic sewage input

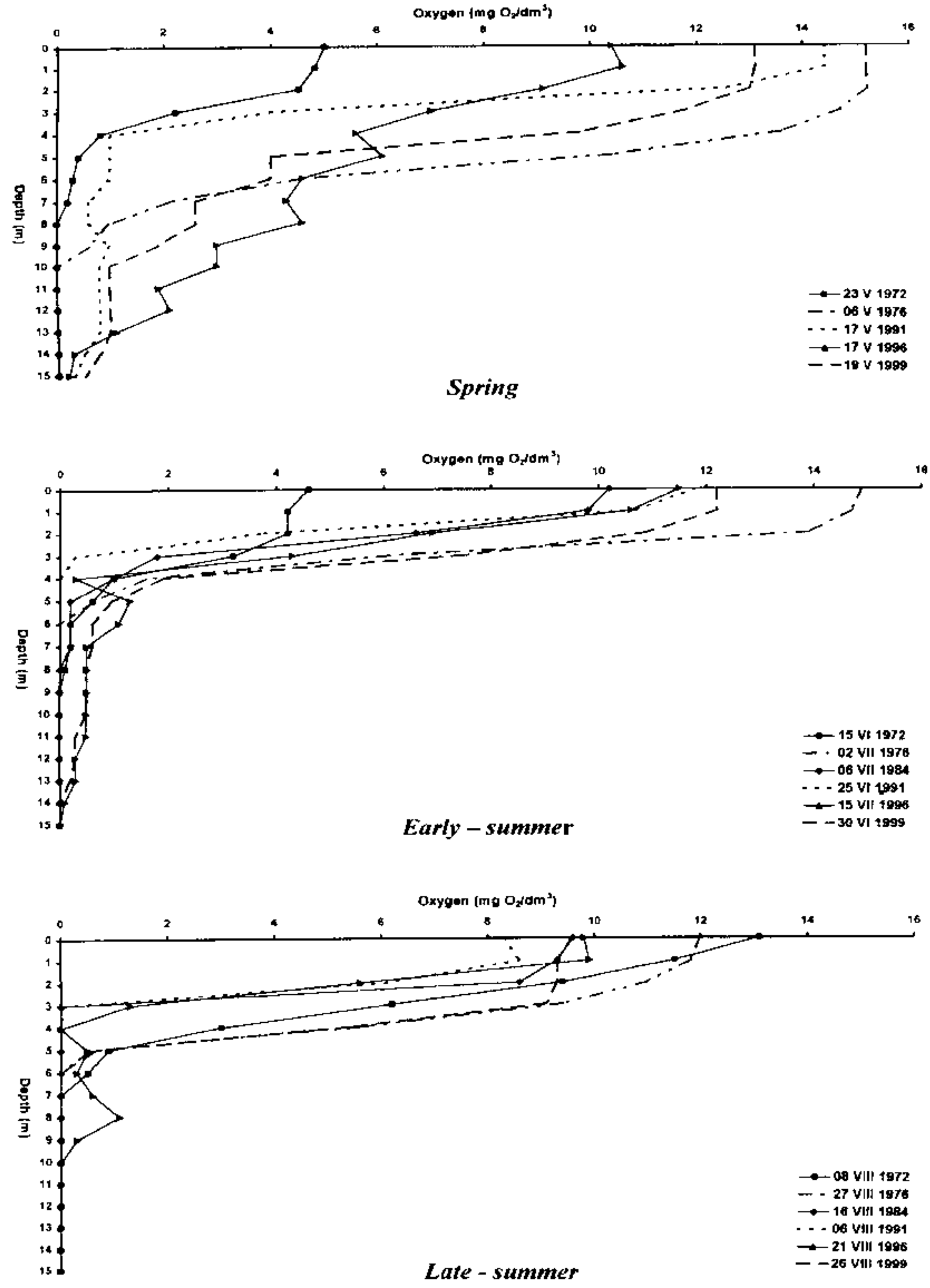

Fig. 2. Water oxygenation changes in Lake Długie in the summer stagnation period in various years.

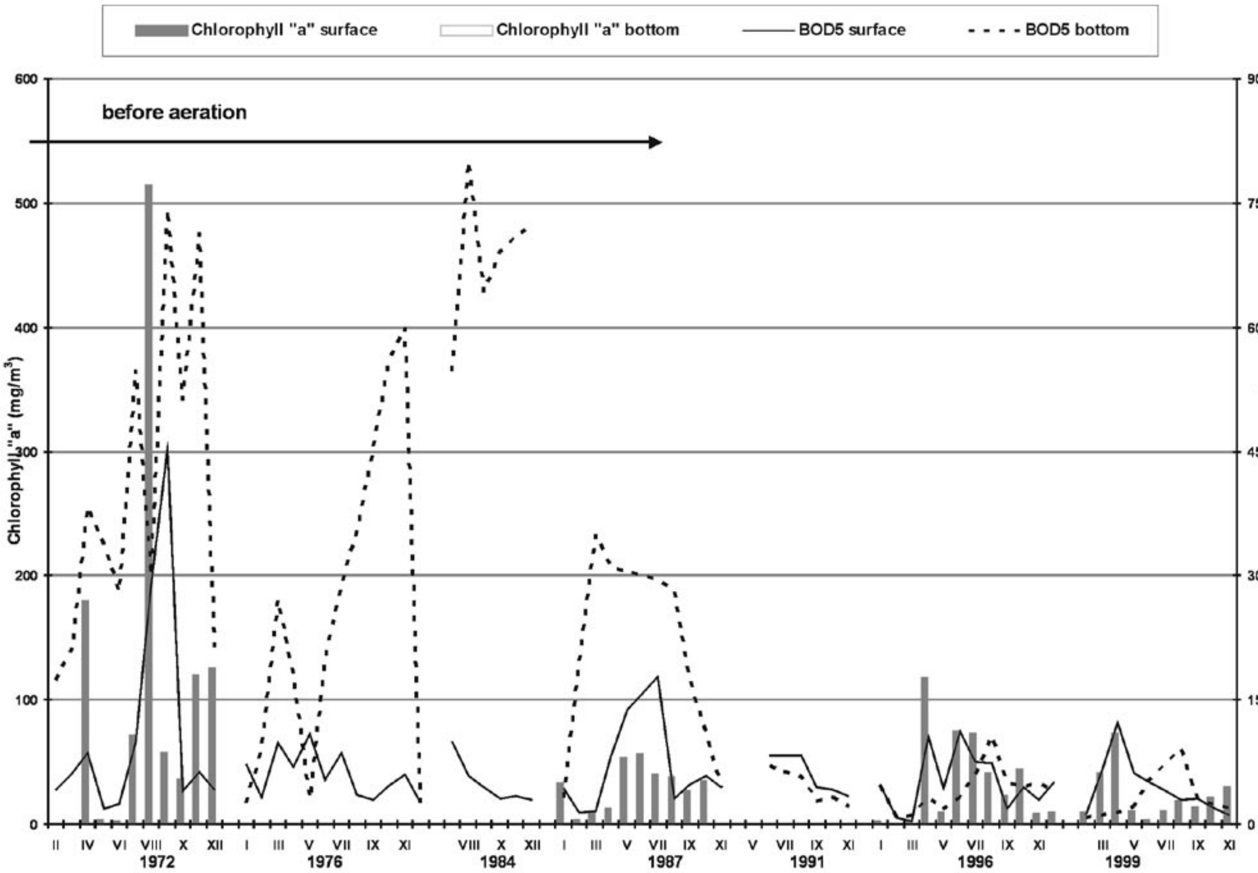

Fig. 3. BOD_5 and chlorophyll "a" changes in various years.

reduction had been commenced that in 1976 was eventually cut-down completely. As revealed in the studies by Gawrońska [21], although it resulted in some improvement of the aquatic conditions, the reduction of organic matter (Fig. 3) and nutrients (Figs. 4 and 5) had only a quantitative character, having no effect on qualitative changes. Once more, the data by Cullen and Forsberg [22] have confirmed an irreversible character of degradation in heavily polluted lakes. Cutting-down the sewage inflow has only resulted in the lake's transformation from a saprotrophic stadium into the hypertrophic state. Results of the surveys carried out in the following years have shown that without recultivation further improvement of the trophic state is not possible.

After unsuccessful attempts in 1984 to wash-through the lake which in fact resulted in deterioration of the aquatic conditions (Figs. 2, 3, 4, 5), at the end of summer 1987 artificial aeration was initiated with complete mixing of the waters.

This method, especially in the case of strongly stratified lakes, causes very distinct, nearly immediate changes in the physico-chemical settings and improvement of a lake's trophic state. Still, there is no answer to the question of whether through artificially achieved actuation of water masses, the trophic state of degraded lakes can be permanently improved. In other words: whether after the compressors have been switched down, the modified aquatic conditions in the lake will be sustained. The study by Lossow [7] has revealed that after short-term artificial aeration, a gradual return to the settings prior to aeration was observed. But in the experiment on Lake Długie artificial aeration was planned for a much longer period, which was meant to help determine the time indispensable to set new aquatic conditions that would not change after compressor switch-down. The durability of those conditions has been judged upon the results obtained during the purposely introduced reference years, i.e. without artificial aeration, and in two cases (1987 and 1991) it was initiated by the end of summer.

The results obtained hitherto have confirmed that recultivation using this method should be looked upon as a long-term process, gradually but very slowly improving the trophic state of the lake.

In the trophogenic layer, after a period of rapid increase of water oxygenation caused by the sewage cut-off, in the following years we observed a decrease of excessive oxygenation (Fig. 2) at much lower values of BOD_5 (Fig. 3), phosphorus compounds (Fig. 4) and nitrogen (Fig. 5). Lower and less variable were also the concentrations of chlorophyll "a" (Fig. 3). Nonetheless, especially in spring - there were relatively high points of considerable primary production in the lake's waters.

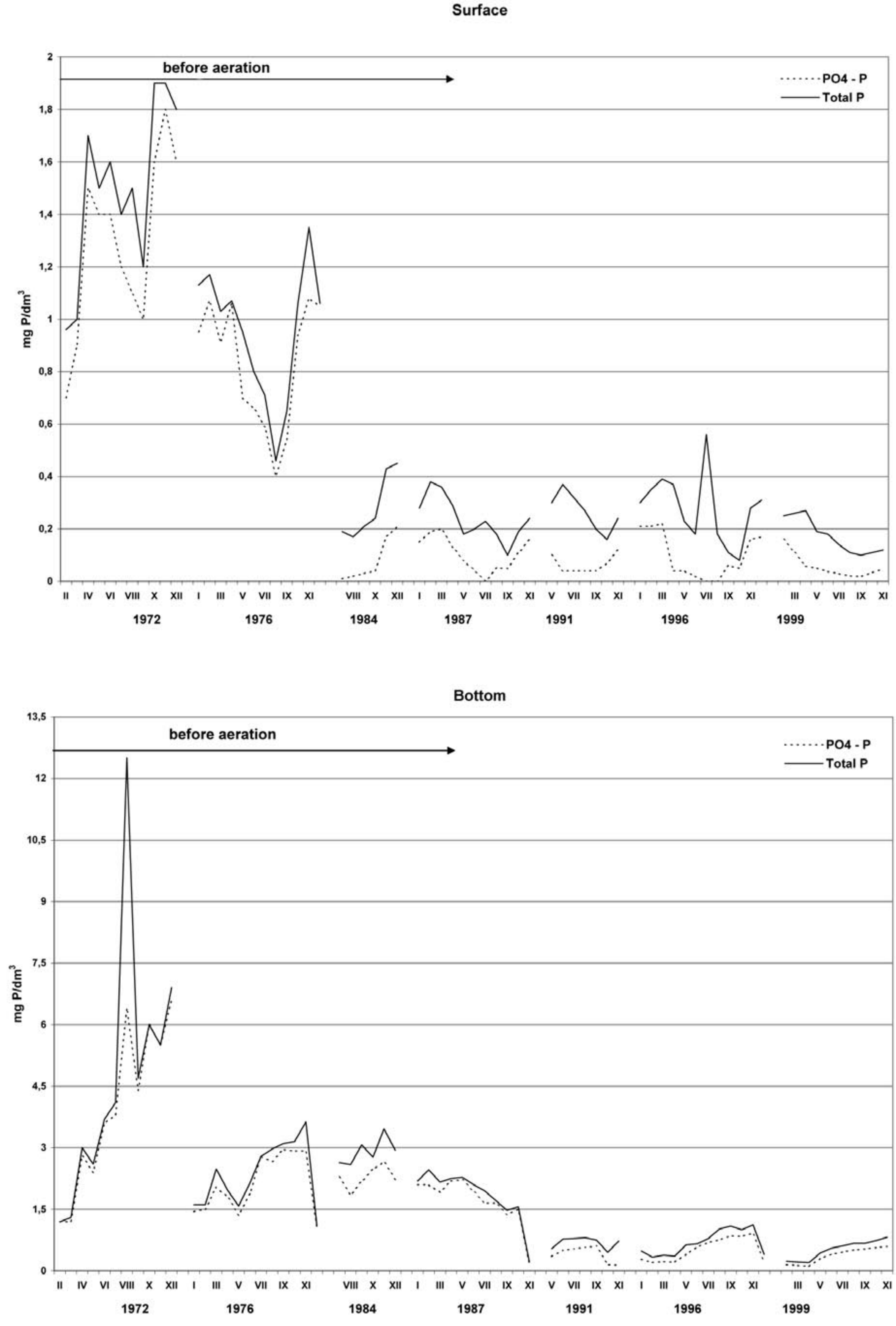

Fig. 4. Changes of phosphorus compound content in central part of Lake Długie in various years.

Water of the tropholytic layers was in the summer period still deficient in dissolved oxygen. Nevertheless, clearly visible was the gradual slow-down of oxygen reduction in these layers along with summer stagnation stabilisation (Fig. 2). Observed was also reduction of organic matter in the deeper waters (Fig. 3) and reduction of both main nutrients. Detected was also, and sustained in the following years, the limitation of internal loading to the near-bottom waters (Figs. 4 and 5) despite dominating anaerobic conditions over the bottom deposits. This points at the gradually proceeding changes in the bottom deposits caused by good oxygenation sustained forcefully over the years of aeration. This has been proven by the results obtained by Gawrońska et al. [23], showing radi-

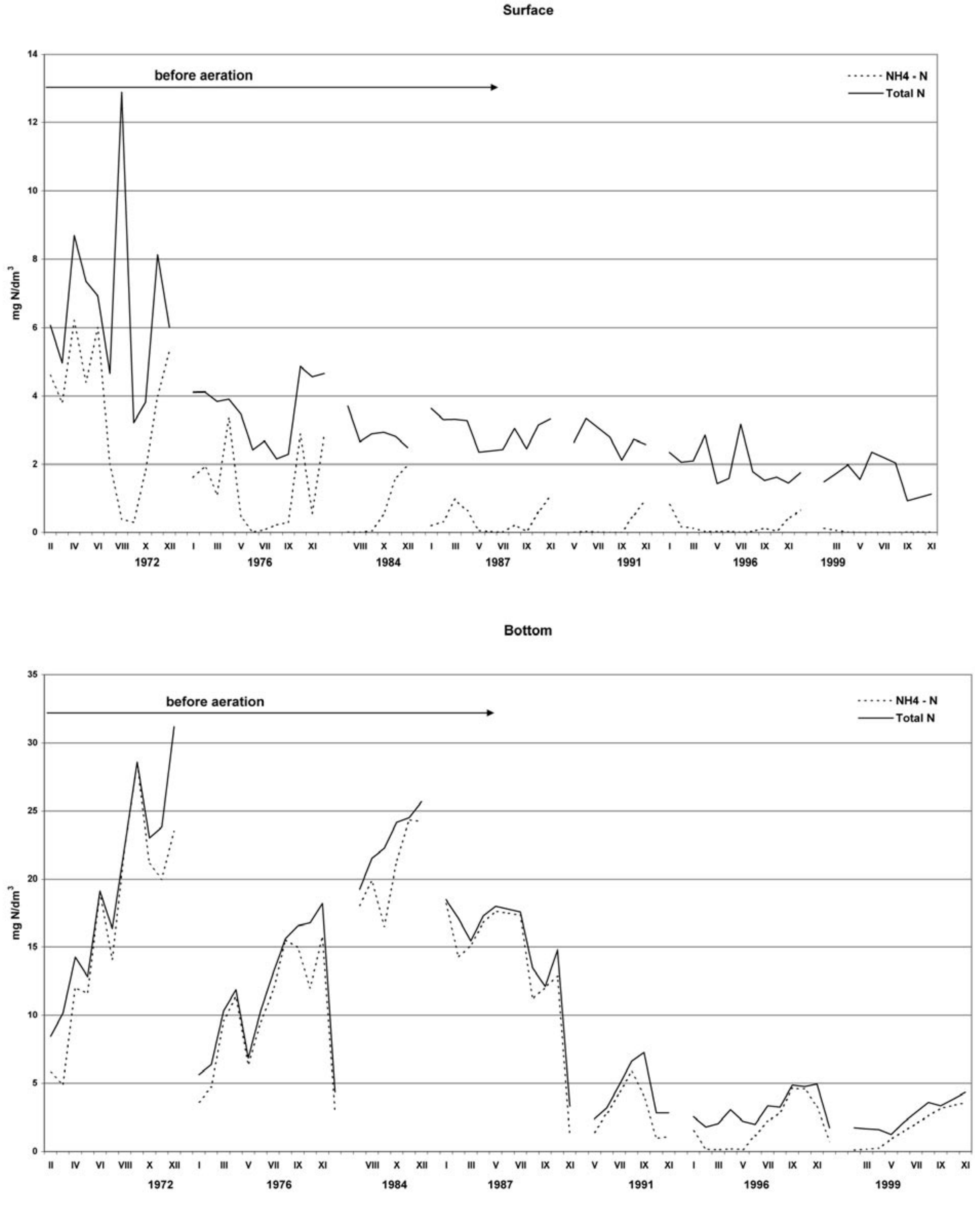

Fig. 5. Changes of nitrogen compound content in the central part of Lake Długie in various years.

cal reduction of phosphorus and nitrogen content in the near-bottom waters as compared to the period prior to aeration. Simultaneously detected by these authors was a gradual change in the chemical composition of bottom deposits which appear to point at the actual possibilities of permanent improvement of the trophic state by multiyear artificial aeration.

Acceleration of these processes may only be achieved in the case of additional method application, e.g. phosphorus inactivation through precipitation to bottom deposits.

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