Polish Journal of Environmental Studies Vol. 12, No. 2 (2003), 171-179

Possibilities to Reduce Internal Loading to Lake Water by Artificial Aeration

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Received: 6 September, 2002
Accepted: 16 October, 2002

Abstract

The influence of artificial aeration on chemical composition of bottom sediments and nutrient exchange was investigated in heavily polluted Lake Długie. Analyzed were variations in the content of nitrogen and phosphorus compounds in near-bottom water, interstitial water and bottom sediments. The obtained results have confirmed a positive role of many years' artificial aeration in reducing the internal loading of nutrients. At the current stage of the survey, it is not possible to determine explicitly whether artificial aeration has had an effect on the chemical composition of bottom sediments.

Keywords: recultivation, artificial aeration, bottom sediments, exchange, nitrogen, phosphorus

Introduction

Bottom sediments play an important role in the eutrophication process not only by removing nutrients but also due to their recirculation [1, 2, 3]. Release to water of the elements previously deposited in the sediments increase their amount in circulation and therefore may stimulate eutrophication [4, 5]. Such a process plays a major role in highly eutrophic or heavily polluted lakes.

Nutrients released from sediments to water are regarded to be the main reason for lack of the lakes response to external loading reduction [4, 6]. In such cases, in order to improve water quality it is important to apply adequate recultivation techniques aimed to lessen the role of bottom sediments as a source of nutrients. It can be achieved through sediment removal, permanent nutrient (phosphorus) fixing in the sediments, or release reduction due to improved oxygen conditions in the near-bottom water resulting from artificial aeration.

Artificial aeration is one of the most popular lake restoration methods [7, 8]. Despite much popularity, investigations into the effectiveness of recultivation activities have been mostly confined to determination of an impact of artificial aeration on the aquatic conditions in the water body. In a few cases only, the surveys have comprised bottom sediments [3, 9, 10].

The objective of the present study was to determine the influence of a multi-year artificial aeration with destratification on the chemical composition of bottom sediments and nutrients exchange between sediments and water.

Material and Methods

The investigations have been conducted upon small (26.8 ha) but relatively deep (17.2 m) Lake Długie, recultivated since 1987 by the artificial aeration method with destratification. Detailed information regarding the lake's morphometric properties and the mode of restoration are contained in the papers by Lossow et al. [11]; Gawrońska, Lossow [12]; and Gawrońska, Lossow [13].

This paper contains the results of the near-bottom water, interstitial water and bottom sediment examinations of 1987 through 1989 (1st phase of aeration), 1995 (2nd phase of aeration), and 1996 (reference year - no aeration).

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The examinations were carried out on three research stations, situated at the deepest points of the three distinguished lake basins, differing not only in the morphometric properties but also in the degree of aeration impact:

- station 1 - southern bay (max. depth 3.5 m), not aerated
- station 2 - central basin (max. depth 17.2 m), aerated since July 1987
- station 3 - northern bay (max. depth 5 m), aerated since August 1991.

Samples were taken with a Kajak's bottom sampler. The near-bottom water was prepared by decantation of a 10-cm water layer over the sediments. Examinations of the bottom sediments comprised the upper (10 cm thick) layer, divided into two samples (0-5 cm and 5-10 cm). Sediments (after thorough mixing) were centrifuged 20 minutes at 3000 rpm. Water above the sediments was regarded as interstitial. Centrifuged sediments were dried at room temperature and powdered in a mortar.

In the near-bottom and interstitial water we determined ammonium nitrogen with indophenol test or distilation method, total nitrogen with Kjeldahl method, mineral phosphorus with colorimetric method with ammonium heptamolybdate and tin (II) chloride as reducer, and total phosphorus after mineralization in H_2SO_4 and HNO_3 using the colorimetric method with ammonium heptamolybdate and tin (II) chloride. Analyses were conducted according to the methods obligatory for hydrochemical examinations [14]. In the bottom sediments we determined content of organic matter and total nitrogen in accordance with the methods by Januszkiewicz [15]. Total phosphorus was determined with direct sediments burning method in the mixture of H_2SO_4 and $HClO_4$, and then using the colorimetric method with molybdenum-vanadium according to the methods by Golachowska [16].

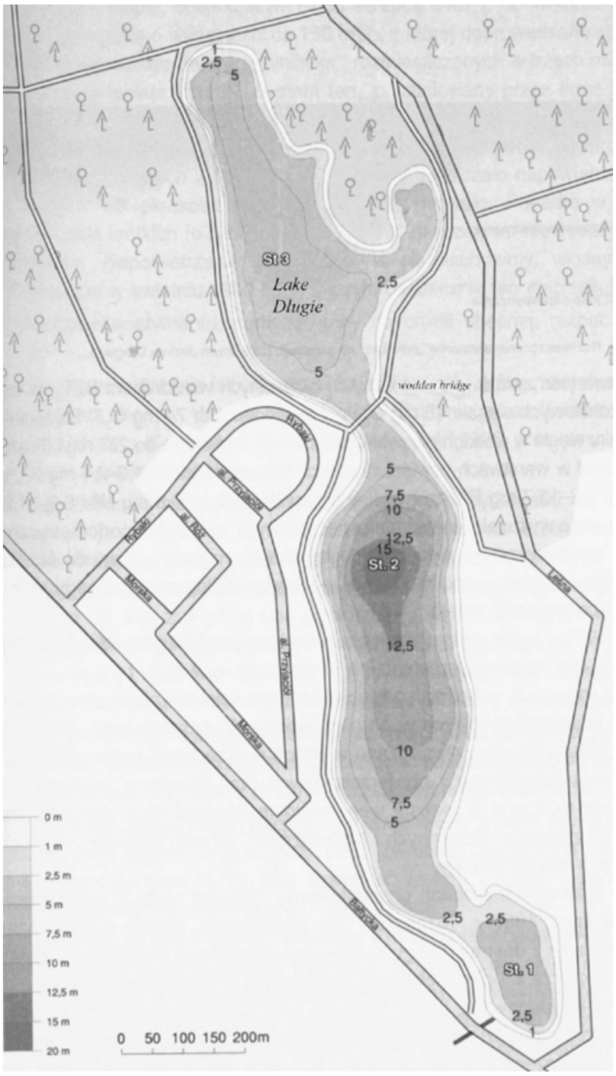

Fig.1. Distribution of bottom sediment examination stations in Lake Długie.

Results and Discussion

Using Lake Długie for domestic sewage receiving water has resulted not only in the heavy pollution of water [11, 17, 18] but was also manifested in the chemical composition of the bottom sediments. As revealed in the studies by Drozd [19], Januszkiewicz et al. [20], they were characterised by a very high content of organic matter, and of nitrogen and phosphorus compounds much exceeding the values reported for other eutrophic lakes [9, 21, 22].

However, detailed analysis of the results has revealed their considerable variation between the individual basins resulting first of all from the morphometry and the related water body dynamics, and to a smaller degree - from localisation of the pollution sources.

Sediments in the southern bay are characteristic for the highest content of silica (55% dry weight aver.) and the lowest content of organic matter (27% d.w.), nitrogen (1.5% d.w.) and phosphorus (0.35% d.w.). Sediments in the central section and in the shallow northern bay are characterised by a low content of silica (40% d.w.) and very high content of organic matter (45-50% d.w.), nitrogen (about 2.5% d.w.) and phosphorus (about 0.4-0.5% d.w.). The high content of silica in the sediments of the southern bay was explained by Januszkiewicz et al. [20] as caused by the localisation of the storm-water interceptors' outlets and the relatively good conditions for organic matter mineralization. The influence of domestic sewage on sediment composition was not displayed, most probably due to the small surface area and depth of this bay. Due to those factors, it can play mainly the role of settler for mineral suspended solids. Allochthonous organic suspended solids as lighter and non-settleable are carried over longer distances and settle in the deepest point of the lake. It has been confirmed by the composition of the bottom sediments of the central basin. An additional

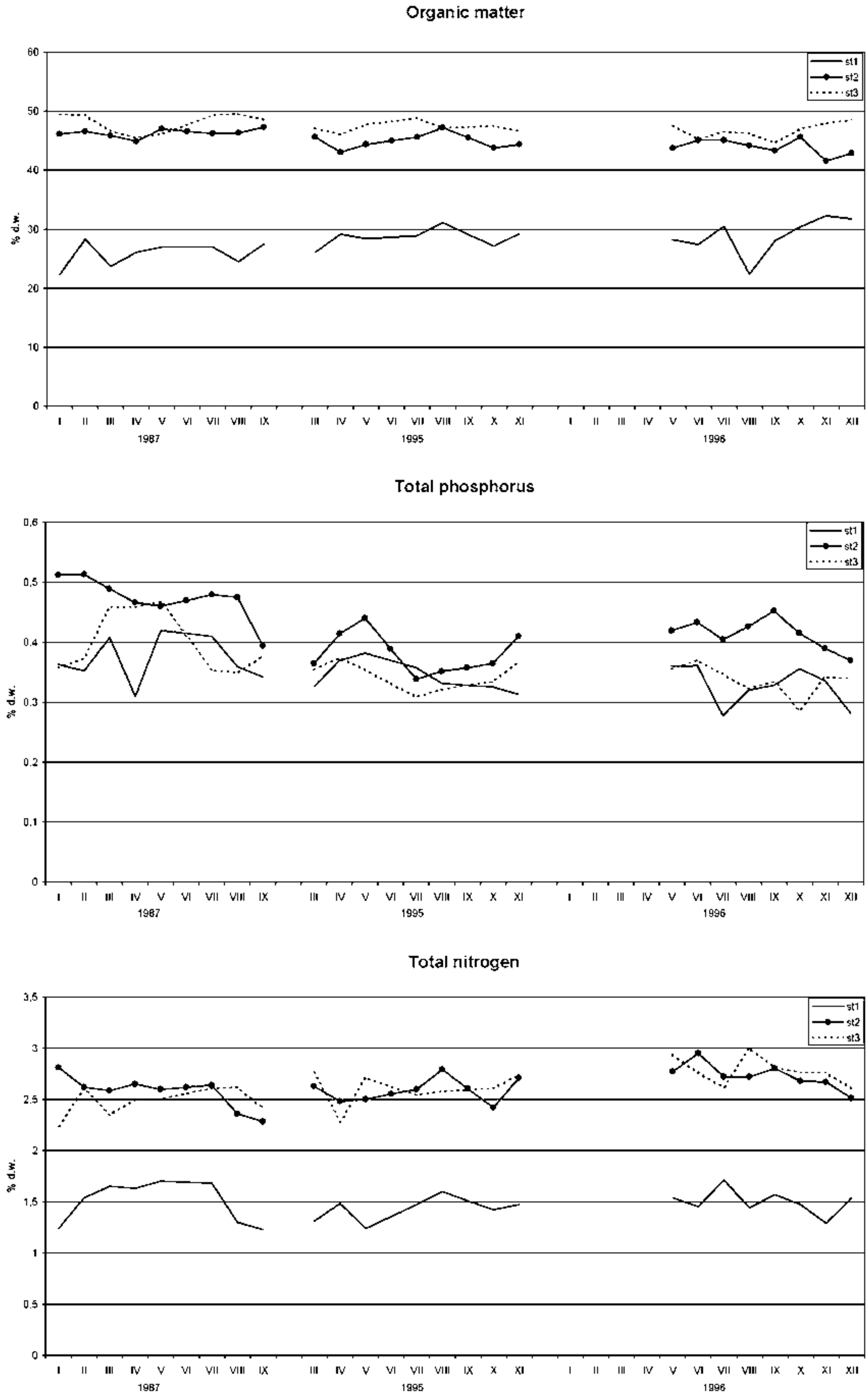

Fig.2. Chemical composition of the bottom sediments of Lake Długie over various years.

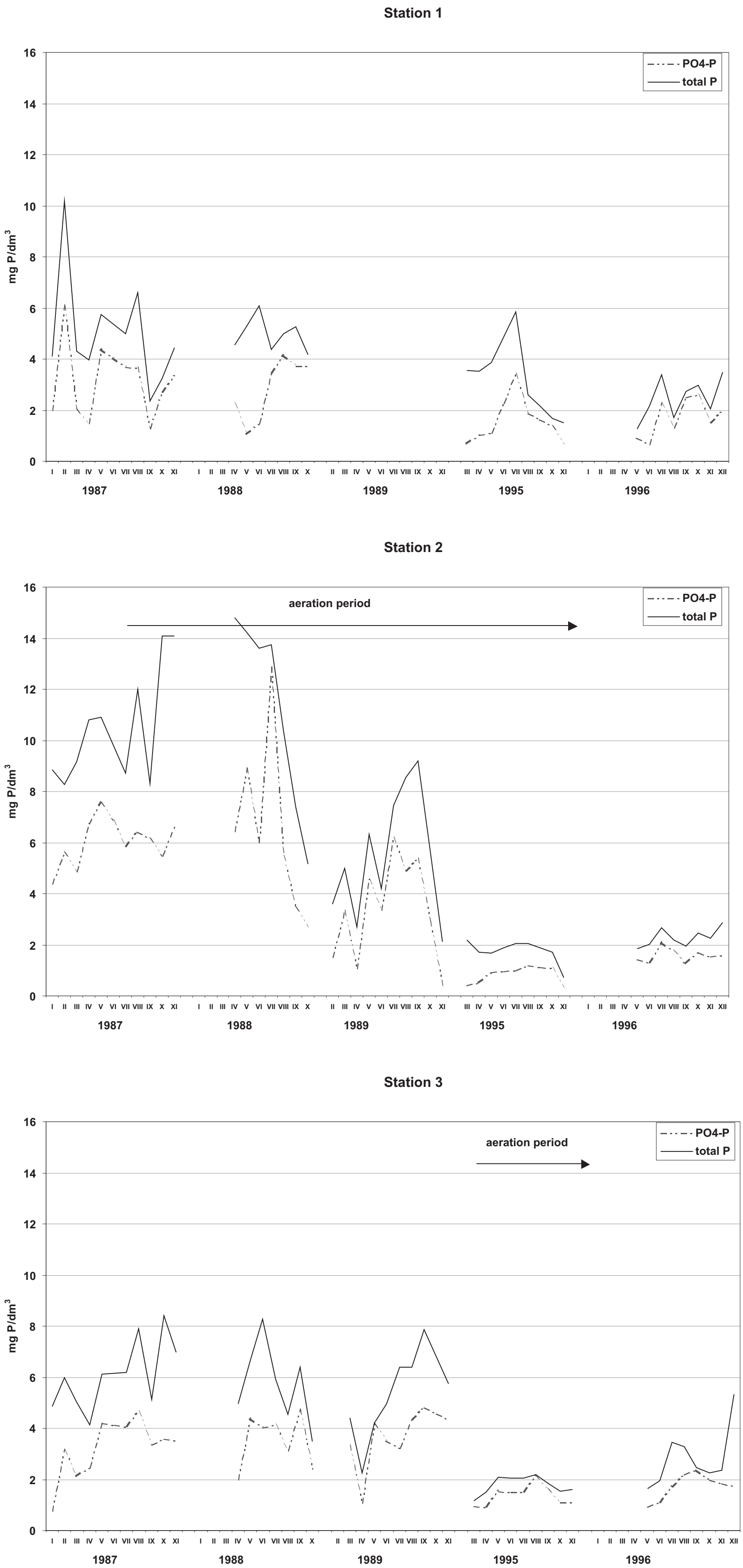

Fig.3. Changes of mineral and total phosphorus content in the interstitial water of Lake Długie.

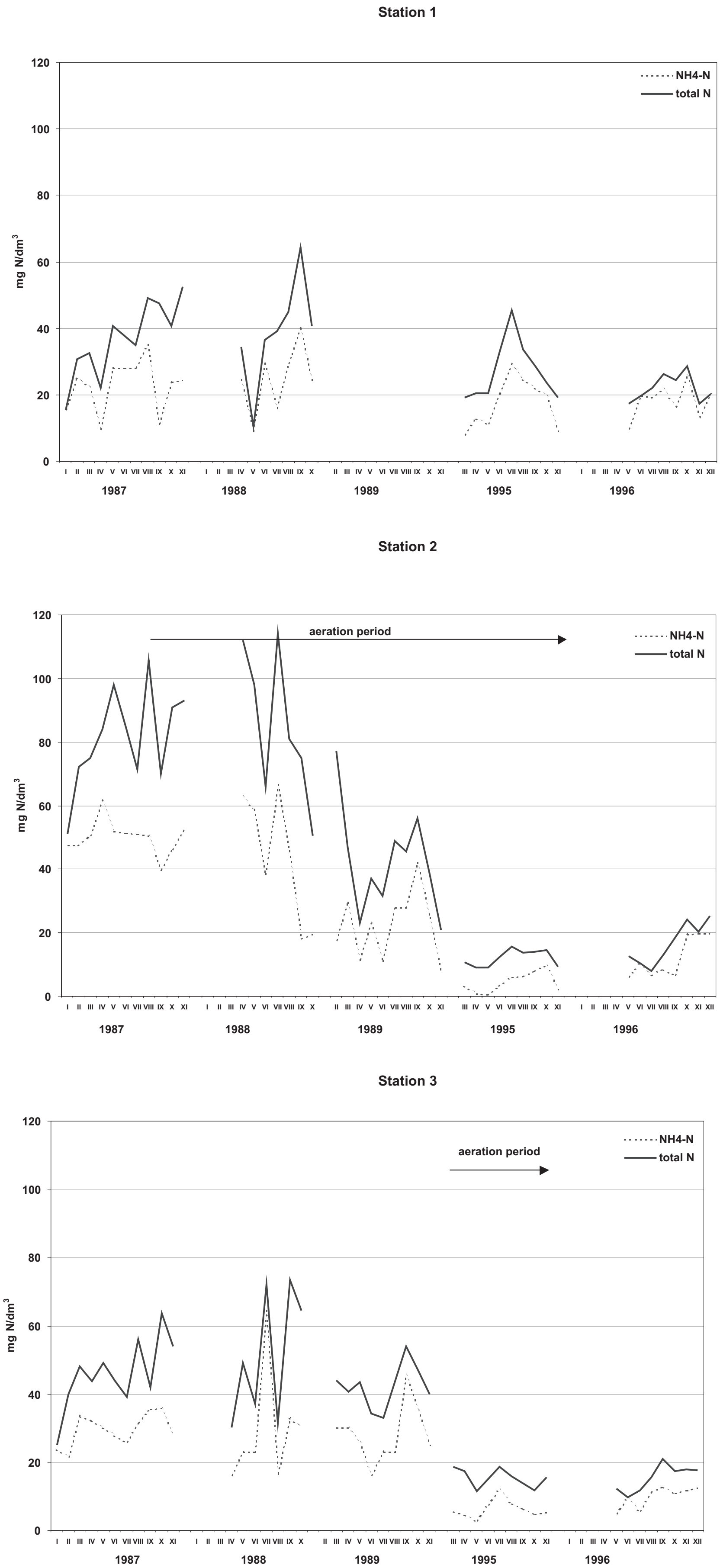

Fig. 4. Changes of ammonium and total nitrogen in interstitial water of Lake Długie.

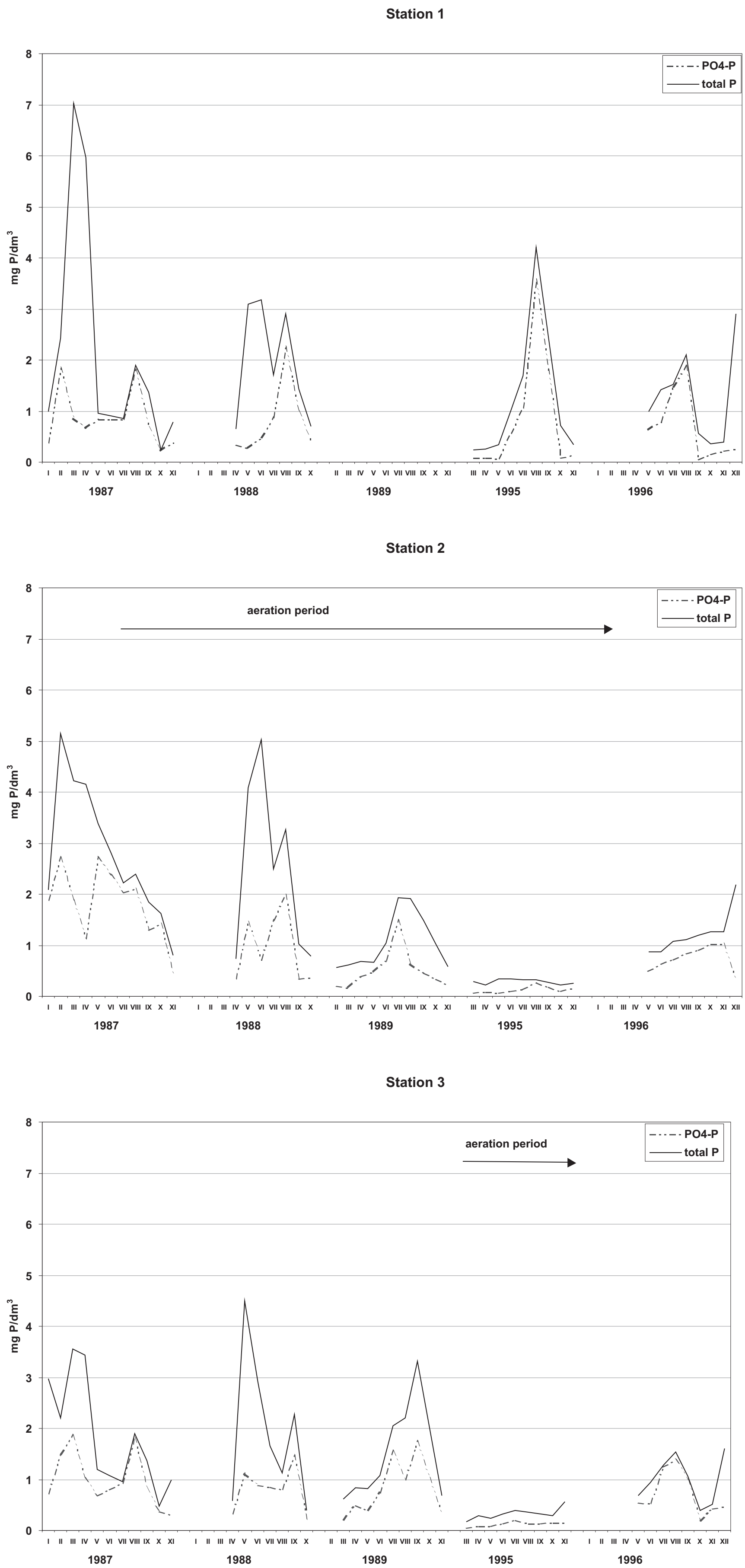

Fig. 5. Changes in mineral and total phosphorus content in near-bottom water of Lake Długie.

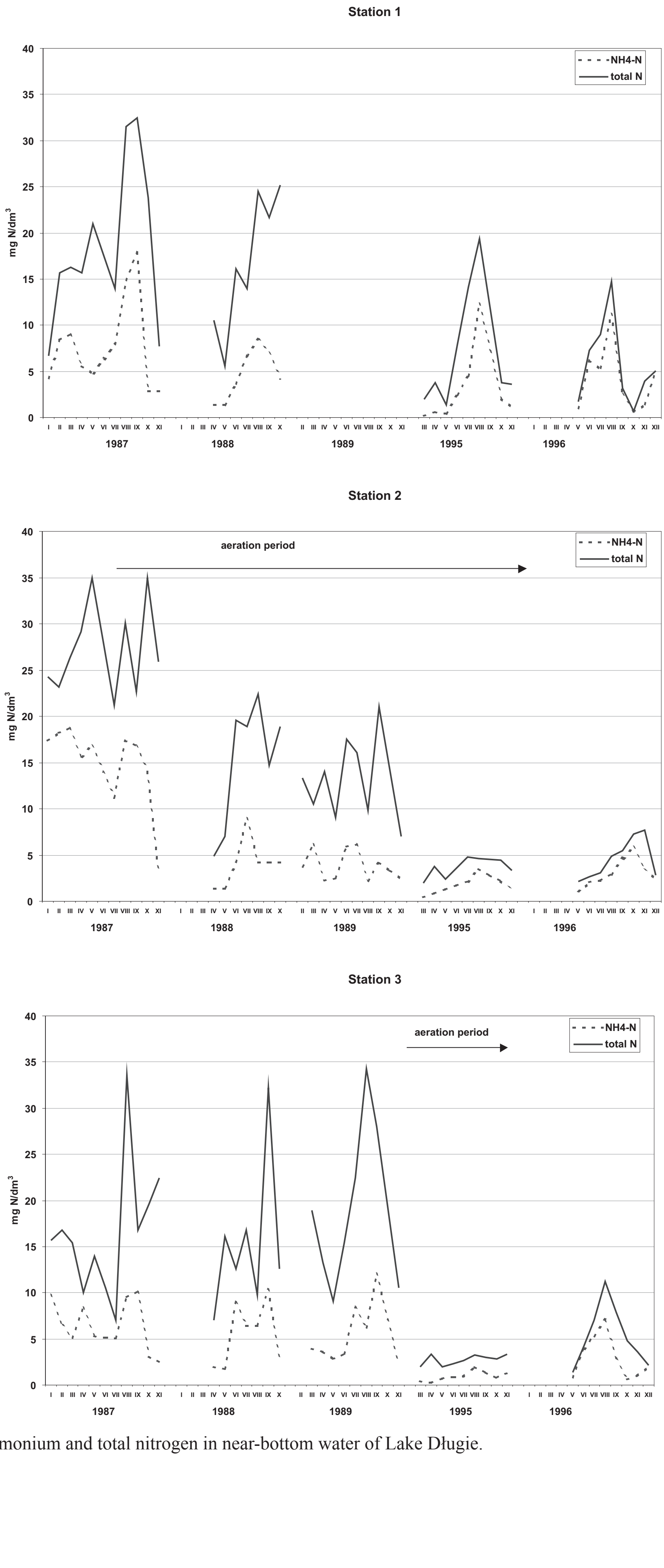

Fig. 6. Changes of ammonium and total nitrogen in near-bottom water of Lake Długie.

factor stimulating the deposition of organic matter in the sediments of the two deepest basins was the full oxygen depletion in the near-bottom waters, observed for most of the year [12, 18].

The cut-down of the sewage input and the artificial aeration of the lake commenced in 1987 have radically changed the conditions for deposition and influenced the chemical composition of the sediments. Organic matter and phosphorus content decreased while the amount of nitrogen increased (Fig. 2). The biggest changes though, were observed in the longest-aerated central basin, the smallest in the southern bay. While the decrease of organic matter content may be explained by the improvement of the oxic conditions and the temperature increase in the near-bottom waters, stimulating the mineralisation processes, the reduction of phosphorus content is completely unexpected. Some explanation may be sought in the creation of a new layer of the sediments, displaying the modified aquatic conditions, whose formation was much influenced by the lake's artificial aeration.

The artificial aeration had a larger and more visible effect on the exchange of nutrients between the sediments and water. The evidence comprised changes of nitrogen and phosphorus content in both interstitial water and near-bottom water.

The max. concentrations of both nutrients were measured in the interstitial water. Before recultivation (i.e. 1987) total phosphorus concentrations varied between 2.4 mg P/dm^3 and 10.2 mg P/dm^3 on station l, 8.3 mg P/dm^3 and 14.1 mg P/dm^3 on station 2, 4.1 mg P/dm^3 and 8.4 mg P/dm^3 on station 3 (Fig. 3), whereas nitrogen concentrations ranged from 15.4 to 52.5 mg N/dm^3, 51 to 105.6 mg N/dm^3, and 25.2 to 63.7 mg N/dm^3, respectively (Fig. 4). In both cases the mineral fraction was dominant. Average mineral phosphorus concentration, depending on the station, was from 53 to 62% total P, whereas average ammonia nitrogen concentration was from 63 to 66% total N.

Artificial aeration caused a considerable decrease of nutrient concentrations in those waters. Max. variations were observed in the longest-aerated central basin, and the min. in the non-aerated southern bay.

The influence of artificial aeration on nutrient content in the interstitial water can be best investigated on the example of the central basin. In the first year of recultivation (1987/88) aeration had stimulated a considerable increase of the total amount of phosphorus (Fig. 3) and nitrogen compounds (Fig. 4) as a result of organic fractions increase at the parallel minimal decrease of the mineral fractions. In the second year of aeration, concentration of both fractions (mineral and organic) decreased, and the total amount of nitrogen and phosphorus was much lower than before recultivation. The decline tendency was observed in the following years of recultivation. In 1995 phosphorus and nitrogen concentrations in the interstitial water in both aerated basins were similar and not higher than 2 mg P/dm^3 and 20 mg N/dm^3. In the non-aerated southern bay changes of their content were minimal, and the max. concentration of phosphorus amounted up to 6 mg P/dm^3 and 45 mg N/dm^3.

The changes presented above are not permanent. Termination of the aeration in 1996 again resulted in the increase of both nutrients' concentration in this water, although the increase was relatively small and unlike in the period before recultivation when max. concentrations were detected in the southern bay.

Variations in nutrient concentrations in the interstitial water were displayed by their content in the near-bottom water.

Before recultivation, concentrations of nitrogen and phosphorus in this water had also been very high (max. about 7 mg P/dm^3 and over 30 mg N/dm^3) (Figs. 5, 6). Likewise, in the case of interstitial water, the highest amounts were usually detected in the central basin. The total content of phosphorus and nitrogen was decided by mineral forms (70% of total P was in phosphate form, 55% of total N - in ammonia form).The quantitative differences regarding the other two shallow basins were minimal.

Artificial aeration has stimulated reduction of nitrogen and phosphorus concentrations, mainly as a result of the mineral fractions decrease (ammonium nitrogen and phosphate phosphorus) and to a smaller degree the organic fractions. However, the course of the alterations was not just a simple exhibit of the changes in the interstitial water which in turn was undoubtedly influenced by such factors as oxygen conditions and temperature in the near-bottom water and the concentration gradient at the sediments-water interface. In 1995 concentration of total phosphorus at station 2 reached max. 0.35 mg P/dm^3, at post 3: 0.57 mg P/dm^3 and at post l up to 4 mg P/dm^3 whereas in the case of total nitrogen the values were, respectively: 4.76 mg N/dm^3, 3.36 mg N/dm^3 and 19.32 mg N/dm^3. Thus, the reduction of concentration in the longest-aerated central basin amounted to 90% in the case of phosphorus and 87% in the case of nitrogen.

The changes presented above regarding the content of phosphorus and nitrogen in the interstitial and near-bottom waters, as well as the decrease of their overall amount in the whole lake [12, 23] confirm the previously submitted point that artificial aeration effectively reduces internal loading. The parallel changes in the chemical composition of the bottom sediments may point to the fact that a multi-year aeration (in a non-defined precise period) can result in the creation of the sediments in balance with conditions in the lake water.

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