German Society for Limnology (DGL)
Extended Abstract from the Annual Conference 2014 (Magdeburg), Hardegsen 2015

Improvement in the ecological condition of a eutrophic lake through hypolimnetic phosphate precipitation

Tim Sebastian Epe[1]

[1] Institut Dr. Nowak, Mayenbrook 1, 28870 Ottersberg, te@limnowak.com

Keywords: Seenrestaurierung, Phosphatbindung, Nährstoffrücklösung, lanthan-modifiziertes Tonmineral

Introduction

The ecology of many lakes is under threat due to intensive land use in catchments and the associated inputs of nutrients that have occurred over many years. As a result, the capacity of lakes to function as a suitable environment for recreation and relaxation or as a supply source for fish and water for human consumption has been severely restricted. The Behlendorfer Lake was categorized for many years as a lake with elevated nutrient concentrations (eutroph2, 2004), recurring blooms of cyanobacteria (incl. *Planktothrix rubescens*) and a reduced diversity of macrophytes. As a first step towards restoring the lake, external inputs of nutrients were reduced to a minimum and biomanipulation measures undertaken. In particular, efforts were made to increase the population of predatory fish. In addition, acceptable sanitary facilities for recreational users were also installed. In November 2009, a further measure was undertaken which had as its aim the reduction of the trophic status of the lake hypolimnion (> 7 m depth) with a lanthanum modified clay mineral (Bentophos®). This material was developed by the Australian national research institute CSIRO (Douglas, 2002), and has been increasingly used over the past decade to immobilize phosphate in sediments and bind phosphate in the water column of eutrophic lakes. When applied to aquatic systems, the lanthanum contained in the clay matrix forms an ionic bond with PO_4, which is irreversible in all conditions found in natural aquatic systems. The lanthanum phosphate bond has a very high solubility product, is unaffected by redox potential and is formed across a very wide pH range (5 to 9) (Mackay et al., 2014; Meis et al., 2013; Zamparas und Zacharias, 2014).

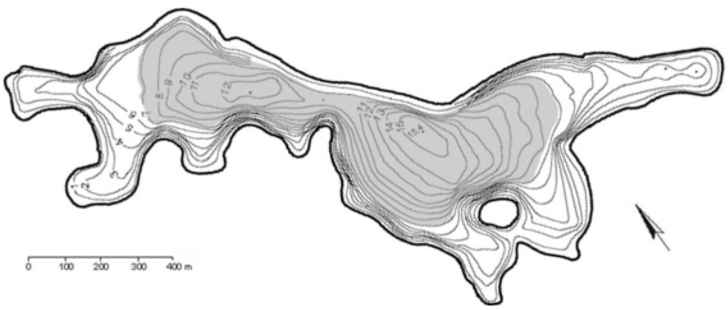


Diagram 1: Bathymetric Map (adapted from LANU 1991); Area > 7 m depth (shaded gray)

Material and Methods

Study Area

The Behlendorfer Lake is located near Ratzeburg in Schleswig Holstein in Northern Germany. It has a surface area of 0.63 km², an average depth of 6.2 m and a water volume of approximately $3.9*10^{-6}$ m^3. It is located within the „Lauenburgische Seen“ National Park at the edge of the „Schaalsee Biosphere Reserve”, is classified as a calcium rich, stratified deep lake (Lake Type 13), according to LAWA (1999) and has a small catchment.

.

Historical Data and Analysis

Studies undertaken in 1995 (Landesamt für Wasserhaushalt und Küsten, 1995) and 2002 (Arp and Koppelmeyer, 2003) showed that concentrations of both nutrients and chlorophyll-*a* in the Behlendorfer Lake were high. These studies also indicated that the ability of the sediments to act as a nutrient sink was reduced and that intensive release of nutrients from sediments was occurring during the summer months. In order to corroborate these studies and to establish a basis for efficient planning of restoration measures, a new monitoring program was undertaken in 2008. Water samples were collected and sediment cores taken using a Mondsee Corer (Uwitec, Austria). The sediment cores were used to conduct sequential phosphorus extraction (Hupfer et al., 1995; Paludan and Jensen, 1995).

Statistical Analysis

A Principal Components Analysis (PCA) and Components Ranking Test were conducted with the Analytical Program Origin 9.1 Pro (Origin Lab Corporation, Northampton, MA, USA) in order to plot the developments in the lake since the application and detect the relationships between environmental variables and the restoration measures.

Results

Pre-treatment monitoring of water and sediment

The water column of the lake contained a total of 550 kg P prior to the treatment. Sequential phosphorus extraction of sediment samples showed that there was 1,590 kg of release-sensitive phosphorus in the top 5 cm of sediment in the area of the lake that was deeper than 7 m. Based on the molar binding ratio of 1:1 between P and La (Haghseresht et al., 2009), it was calculated that a total quantity of 214 t of the clay material would be required to bind these two phosphorus pools.

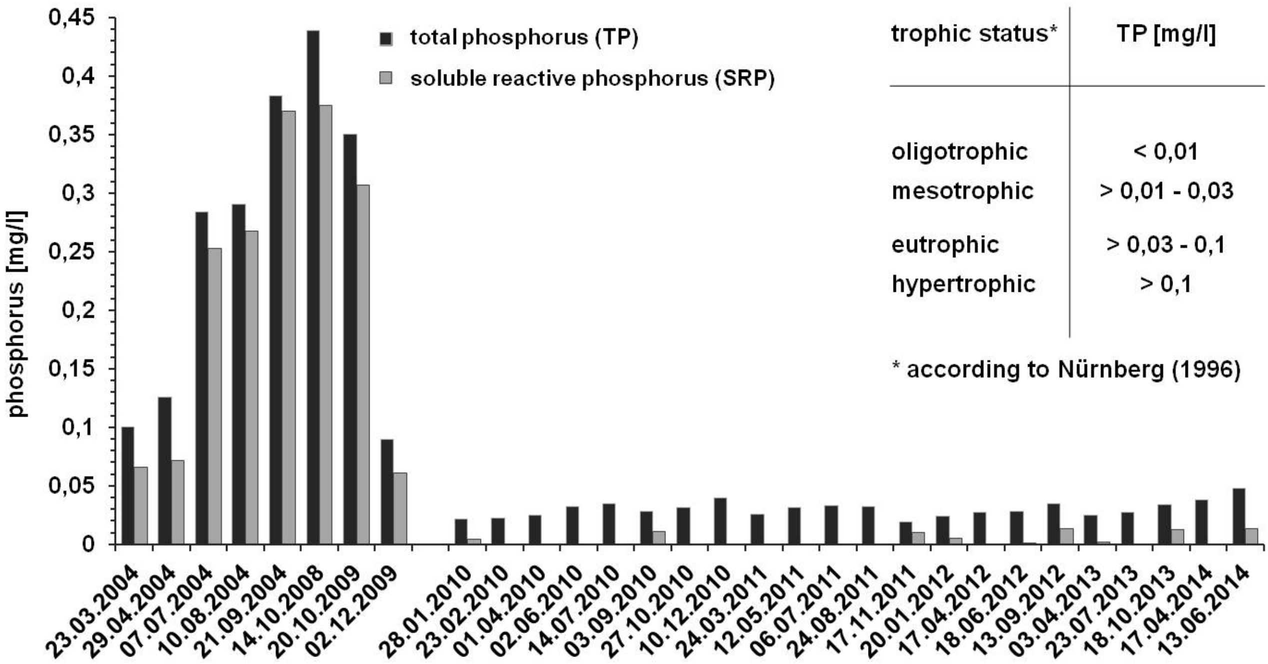


Diagram 2: Total phosphorus and soluble reactive phosphorus (SRP) concentrations in the Behlendorfer Lake. Plotted values are volume-based, weighted averages (n/sampling date = 7)

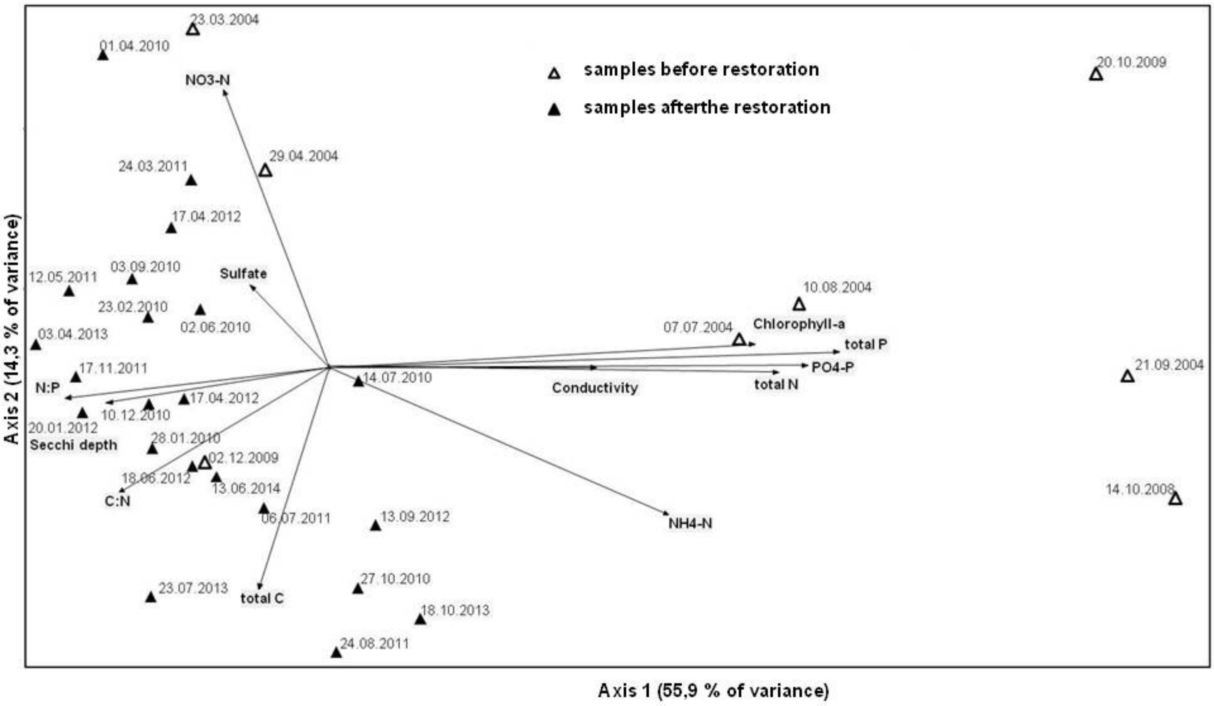
Since the restoration in December 2009, the Behlendorfer Lake has been in a stable, mesotrophic state, based on phosphorus concentrations. Total phosphorus concentrations have dropped by, on average, 75%

Table 1: Development of Macrophytes (Stuhr et al., 2013)

	2004 (n=4)	2010 (n=8)	2011 (n=8)	2012 (n=8)	2013 (n=8)
Ø no. of submerged vegetation species	3	5	4,6	5	4,5
Ø abundance submerged vegetation [%]	--	11	27	21	25
max. colonization depth [m ,depth]	3,5	4,4	4,9	4,4	4,5
Ø colonization depth [m depth]	2,6	3,6	4,2	4	4,1
Ø ecological status (accoring to PHYLIB 4.1)	4,5	3	3,2	3,2	3,3

Trends in the development of other environmental variables

The trends observed in terms of both macrophyte diversity and colonization depth have been positive since the restoration measures (Table 1) and have led to an improvement in the ecological classification of the lake, according to Stuhr et al. (2013). The multivariate comparison of the situation in the lake before and after the restoration confirms both a reduction in P concentrations as well as electrical conductivity, chlorophyll-a and ammonium and total nitrogen concentrations. These variables are all positively correlated with the 1st axis, which shows the changes that have occurred as a result of the nutrient immobilization. Additionally, secchi depth and the N:P ratio have also increased. The 2nd axis distinguishes the data according to N fractions and therefore contrasts the situation in the lake in spring and autumn.



	Secchi depth	Con-ductivity	Chloro-phyll a	total P	PO4-P	NH4-N	NO3-N	total C	total N
Axis 1	**-0,60**	**0,55**	**0,83**	**0,79**	**0,66**	**0,73**	**-0,58**	0,03	**0,57**
Axis 2	-0,27	0,00	0,04	0,03	0,18	**-0,62**	**0,70**	**-0,67**	-0,19

Diagram 3: Distance based Biplot of the Principal Component Analysis. The Table shows the environmental variables included in the analysis and their relation to the axis values of the analysis. [Spearman Ranking Correlation Coefficient (bold = sig. < 0.01)].

Discussion

The results of the long-term monitoring (2009 - 2014) show that the measures to bind phosphate and interrupt the release of phosphorus from sediments have resulted in a sustained stabilization of the P-balance in the lake (Diagram 2) and created a suitable environment for further improvements in the ecological condition and ecosystem services (Table 1). The increase in macrophytes colonization depth and reduction in O_2 consumption have had a positive effect on the lake and led directly to an improvement in the oxygen budget. The population of charophytes, which are typical for a lake of this type and necessary for an increase in ecological classification, has until now not increased. Trials are however currently underway to seed charophytes and other desirable macrophyte species in lakes where nutrients loadings have been reduced through P precipitation measures, in an effort to establish sustainable populations of charophytes. These trials are being conducted as part of a PhD study being undertaken in cooperation with the Centre for Ecology and Hydrology (CEH), Edinburgh.

Despite the influence of important factors such as mixing / stratification and seasonality, which determine the distribution of the variables across the biplot, the positive effect of the phosphorus reduction is clear and explains the large variation in plotted values (cf. 1st axis, Diagram 3). The PCA consists of abstract axes, to which environmental variables contribute to varying degrees (Leyer und Wesche, 2007). Their importance can be seen by correlating them with the axes values of the PCA. The analysis shows that the decrease in chlorophyll-a concentrations, total nitrogen concentrations and electrical conductivity (reduced release of ions in the hypolimnion) were a consequence of the P reduction.

Since the nutrient precipitation, a shift in the phytoplankton community from domination by cyanobacteria to domination by green algae and diatoms has also been observed. Overall, the lake is now dominated by smaller algal types (per. comm. W. Arp). This shift may, to some degree, have also been the result of the biomanipulation measures that were undertaken in the lake prior to the phosphorus precipitation. Also noteworthy is the change in the N:P ratio which increased from an average of 33:1 (n=8) to an average of 154:1 (n=22), despite the reduction in total nitrogen concentrations. Such a significant change could also be a cause in the positive developments in the phytoplankton community, according to Smith (2003, 1983).

Summary and Conclusions

The measures undertaken on the Behlendorfer Lake (biomanipulation, reduction of external influences and P binding using Bentophos®) have led to positive changes in the ecological status of the lake. The phosphate precipitation and long-term reduction of P release from sediments have resulted in a sustainable increase in the N:P ratio, a shift in the phytoplankton community away from cyanobacteria towards green algae and diatoms and a desirable increase in the colonization area and colonization depth of macrophytes. Although no discernible increase in the charophyte community has been observed until now, the overall positive development of the lake has resulted in an improvement in ecological classification of the lake according to PHYLIB 4.1.

Acknowledgements

We would like to thank all government representatives (particularly Frau Gudrun Plambeck, LLUR Schleswig-Holstein) and all other colleagues who prepared and allowed us to use the additional data that have been incorporated into this study. These efforts and the data provided have been an invaluable contribution to our long-term monitoring of the lake and are gratefully acknowledged.

Literature

Arp, W., Koppelmeyer, B., 2003. Vorkommen der Burgunderblutalge (Planktothrix rubescens) in drei ausgewählten Gewässern Schleswig Holsteins (Endbericht für das Landesamt für Natur und Umwelt Abteilung 4 - Gewässer Hamburger Chaussee 25 24220 Flintbek). Berlin.

Douglas, G., 2002. Remediation material and remediation process for sediments. US Patent Nr. 6350383.

Haghseresht, F., Wang, S., Do, D.D., 2009. A novel lanthanum-modified bentonite, Phoslock, for phosphate removal from wastewaters. Appl. Clay Sci. 46, 369–375. doi:10.1016/j.clay.2009.09.009

Hupfer, M., Gächter, R., Giovanoli, R., 1995. Transformation of phosphorus species in settling seston and during early sediment diagenesis. Aquat. Sci. 57, 305–324. doi:10.1007/BF00878395

LANU, 1991. Seenkurzprogramm: Überblick über Zustand und Belastung von Behlendorfer See, Cilpiner See, Grammsee, ...; Landesamt für Natur und Umwelt des Landes Schleswig-Holstein. Flintbek.

LAWA, (1999): Gewässerbewertung - stehende Gewässer. Vorläufige Richtlinien für eine Erstbewertung von natürlich entstandenen Seen nach trophischen Kriterien. Länderarbeitsgemeinschaft Wasser, Kulturbuchverlag. Berlin.

Leyer, I., Wesche, K., 2007. Multivariate Statistik in der Ökologie - Eine Einführung.

Mackay, E., Maberly, S., Pan, G., Reitzel, K., Bruere, A., Corker, N., Douglas, G., Egemose, S., Hamilton, D., Hatton-Ellis, T., Huser, B., Li, W., Meis, S., Moss, B., Lürling, M., Phillips, G., Yasseri, S., Spears, B., 2014. Geoengineering in lakes: welcome attraction or fatal distraction? Inland Waters 4, 349–356. doi:10.5268/IW-4.4.769

Meis, S., Spears, B.M., Maberly, S.C., Perkins, R.G., 2013. Assessing the mode of action of Phoslock® in the control of phosphorus release from the bed sediments in a shallow lake (Loch Flemington, UK). Water Res. 47, 4460–4473. doi:10.1016/j.watres.2013.05.017

Nürnberg, G.K., 1996. Trophic state of clear and colored, soft- and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. Lake Reserv. Manag. 12, 432–447. doi:10.1080/07438149609354283

Paludan, C., Jensen, H.S., 1995. Sequential extraction of phosphorus in freshwater wetland and lake sediment: Significance of humic acids. Wetlands 15, 365–373. doi:10.1007/BF03160891

Smith, V.H., 1983. Low Nitrogen to Phosphorus Ratios Favor Dominance by Blue-Green Algae in Lake Phytoplankton. Science 221, 669–671. doi:10.1126/science.221.4611.669

Smith, V.H., 2003. Eutrophication of freshwater and coastal marine ecosystems a global problem. Environ. Sci. Pollut. Res. 10, 126–139. doi:10.1065/espr2002.12.142

Stuhr, J., van de Weyer, K., et., al., 2013. Monitoring der Qualitätskomponente Makrophyten für die WRRL- und FFH-Richtlinie in schleswig-holsteinischen Seen. Vegetation des Behlendorfer Sees, des Bültsees, des Garrensees, des Großen Plöner Sees, des Großen Pönitzer Sees, des Ihlsees (Krs. Segeberg), des Schluensees und des Wittensees im Auftrag des Landesamtes für Landwirtschaft, Umwelt und ländliche Räume. Kiel.

Zamparas, M., Zacharias, I., 2014. Restoration of eutrophic freshwater by managing internal nutrient loads. A review. Sci. Total Environ. 496, 551–562. doi:10.1016/j.scitotenv.2014.07.076