Ecological Engineering 113 (2018) 52–60

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

On the use of macrophytes to maintain functionality of overgrown lowland lakes

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ARTICLE INFO

Keywords:
Lake recultivation
Overgrowth
Harvesting
Nutrient status

ABSTRACT

The presence of macrophytes is a key factor that determines good water quality in eutrophic lakes, and control of their presence is desirable to establish a clean water state. However, the subject is frequently discussed due to the intensive growth of aquatic plants that can restrict functioning of the reservoir (e.g., for swimming, fishing, etc.). Overgrowth of macrophytes also causes terrestrialisation processes of lakes, which occur very intensively in shallow and lowland artificial reservoirs. In order to analyse the contribution of macrophytes to nutrient reduction in lakes and investigate the possibility of using aquatic plants in reservoir recultivation, we investigated the nutrient budget of two artificial reservoirs located in Wielkopolska (Poland) with particular attention on macrophytes and nutrient pollution sources. To determine the loads with internal and external nutrients, we analysed the land use in the respective catchment areas, ground water quality, sewage management, quality and quantity of surface waters supplied to lakes (rivers and ditches), water, macrophytes and sediment quality in the reservoirs. Our results indicate that in both analysed catchments, the major source of nutrients is unregulated sewage systems. This demonstrates why improvement of sewage management is vital for increased water quality and more effective functioning of water reservoirs. We also propose methods to reduce the amount of nutrients directly supplied to lakes from agricultural lands. Our findings suggest that the mowing of macrophytes can reduce nutrient concentrations in the reservoirs. However, its impact is not particularly significant in comparison with the amount of nitrogen and phosphorus supplied from internal sources. Moreover, our study shows that growth limitation of particular species can stimulate growth of a desired species (e.g., charophytes). Controlled removal of macrophytes may also stimulate their intensive growth and possibly give rise to an increase in the amount of nutrients immobilised in the lake.

1. Introduction

The most important problems that disturb proper functioning of small lowland water reservoirs are sedimentation and overgrowth (Kondolf et al., 2014; Špoljar et al., 2017). Silting up is a result of sedimentation of the material carrier by the river influx and death of phytoplankton related to excessive trophy of the water. A consequence of large amounts of nutrients in shallow water reservoirs includes the abundant growth of macrophytes that restrict reservoir exploitation or abundant phytoplankton development, particularly blooming cyanobacteria (Lau and Lane, 2002; Fonseca and Bicudo, 2010). According to Scheffer's et al. (1993) and the theory of alternative stable states, a state dominated by macrophytes is more desirable, from the viewpoint of lake functioning, due to nutrient exclusion from the water and incorporation into plant biomass, which restricts phytoplankton bloom and increases water transparency. The clean and transparent water state is thus largely related to the contribution of vegetation in the lake (Hilt et al., 2006, 2010); Janse et al., 2008; Janse et al., 2010), which subsequently leads to limitations of the lake functionality (e.g., recreational swimming). On the other hand, a state of turbid water, characterised by excessive development of phytoplankton and especially toxic cyanobacteria, can be hazardous for human and animal health and restricts the lake's recreational use (e.g., swimming, fishing) (Fonseca and Bicudo, 2010, Dunalska et al., 2014).

In artificially established wetlands, the development of macrophytes is controlled by the introduction of selected species (Leung et al., 2017). In newly established water reservoirs, the succession of vegetation is spontaneous and determined by the seeds or buds/turions delivered by the influx current. The dynamics of vegetation development is much slower in natural lakes than in artificial reservoirs. The water depth, substrate type and influx volume influence the development of particular macrophyte species, while nutrient availability determines the vegetation productivity (Sand-Jensen et al., 2000; Hilt et al., 2006). The dynamics and persistence of migration and recolonisation of empty

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https://doi.org/10.1016/j.ecoleng.2018.02.003
Received 29 September 2017; Received in revised form 14 December 2017; Accepted 2 February 2018
0925-8574/

habitat patches also depend on competition between populations (Baastrup-Spohr et al., 2013). High pressure from periphyton, invertebrates and fish can contribute to a reduction or delay of macrophyte growth (Tóth and Palmer, 2016).

The presence of macrophytes not only affects the physicochemical properties of water and sediments, but also exerts a strong influence on phytoplankton through competition for biogenic compounds (Hilt et al., 2006; Janse et al., 2008; Janse et al., 2010). Selected macrophyte species have allelopathic effects on phytoplankton and restrict its development, as is particularly observed for Charophytes and some elodeids, e.g., rigid hornwort (*Ceratophyllum demersum*), spiked watermilfoil (*Myriophyllum spicatum*) (Kufel and Kufel, 2002; Borics et al., 2012). The intermediate effect of macrophytes on phytoplankton reduction is related to the presence of zooplankton and alevin in vegetation patches that provide shelter and food (Van Donk and Van de Bund, 2002). Macrophytes have a significant effect on the water state in reservoirs, but ambiguities exist regarding the size of the reservoir area that should be covered by submerged macrophytes, or an optimal plant volume to sufficiently reduce water turbidity (Hilt et al., 2006, 2010). On the one hand, high water quality is necessary for proper functioning of lowland water reservoirs, while on the other hand, excessive growth of macrophytes can transform shallow reservoirs into marshes with terrestrialisation features observed for high trophy lakes. In view of the above, it is clear that control of the volume and range of macrophytes is vital for the proper functioning of lowland lakes.

We analysed two shallow artificial reservoirs that show intensive plant overgrowth. The aim of the present study is to perform reclamation projects, taking into account nutrient levels in the water, amount of sediments and macrophytes, as well as identification of pollution sources (e.g., land use, sewage management, agriculture). Special attention is given to the role of macrophytes in the maintenance of water quality, particularly on species composition and productivity. The results permit the conclusion that (i) macrophytes can be a good tool in lake recultivation and (ii) succession of macrophytes in artificial reservoirs should be controlled using appropriate nutrient levels and mechanical treatments.

2. Material and methods

2.1. Study area

Our study was carried out in the two artificial reservoirs, Przebędowo, Miedzichowo and their catchments, located in central and western Poland (Fig. 1). The Przebędowo reservoir was established by the damming of the Trojanka River from km 6915 to 8371 km of its course, and is located about 25 km north of Poznań (Murowana Goślina commune, Wielkopolska voivodeship) (Fig. 1). Its area and capacity are 15.04 ha and 229,450 m^3, respectively. Its maximum depth is 0.9 m, while its average depth is 0.4 m.

Additional morphometric data are given in Table 1. This reservoir was opened into service in November 2014. The aim of its construction was to retain water for agricultural use, as well as improve of the microclimate and water relations in the surrounding arable land. It is also used for flood control and as a fire-fighting reservoir for the village of Przebędowo and city of Murowana Goślina. It has also been used for recreational swimming and fishing, however, at present, due to the advanced process of vegetation overgrowth and poor water quality, it can no longer be open to public use.

The Miedzichowo reservoir is located in the village of Miedzichowo (Miedzichowo commune, Wielkopolska voivodeship), and was established as result of the damming of the Czarna Woda River at its km 6000. The reservoir is 5.5 ha and has been functioning since June 2013. Although initially 2.5 ha with capacity close to 16,000 m^3, the reservoir has since been enlarged to 70,500 m^3 capacity. As a result, large amounts of bottom sediments and excessive development of vegetation have been observed, and the reservoir has undergone substantial terrestrialisation processes. From the beginning of the 20th century, it was used as a retention reservoir for a local watermill and for about 20 years for a small hydroelectric power station. A decrease in water retention in the reservoir threatened the functionality of the watermill and flood control management of the reservoir. In order to prevent rapid overgrowth, as observed in the past, the water vegetation has been mowed once per year and removed outside the catchment.

2.2. Sampling

2.2.1. Surface waters

The field study was carried out between March and October of 2016. Water samples were collected monthly from two sites in the central parts of each reservoir (R1, R2; Fig. 2). Water samples were also collected from the rivers supplying the reservoirs: along two profiles of the both the Trojanka and Czarna Woda rivers (at the inflow and outflow); periodically appearing water from drainage outflows supplying the Przebędowo reservoir (I2, I3); at the tributary from the village of Miedzichowo (I2, I3) and an additional outflow from the Miedzichowo reservoir (O) (Fig. 2). The water flow velocity was measured using a Universal Wing F1 hydrometric mill.

Analyses of the water samples were carried out at the Department of Ecology and Environmental Protection, Poznań University of Life Sciences. Concentrations of total phosphorus (acid persulfate digestion method), orthophosphate (amino acid method), nitrite (ferrous sulfate method), nitrate (cadmium reduction method), organic nitrogen (Kjeldahl's method), ammonium (Nessler's method), sulfates (colorimetric method) and chemical oxygen demand (COD; dichromate method) were determined using a HACH DR/2800 spectrophotometer (HACH, 1992). In situ water temperature, pH and electrical conductivity were measured using digital potentiometers (Elmetron CP-401, CC-551) and oxygen concentration using a ProfiLine Oxi 3315. In the open water, chlorophyll *a* (spectrophotometrically; Elbanowska et al., 1999) and water transparency (measured by Secchi disk) were determined. The water quality of the investigated reservoirs was evaluated following the Regulation of the Minister of the Environment of 21 July 2016 (Regulation, 2016), Carlson's trophic state index (Carlson, 1977) and methods discussed in Vollenweider and Kerekes (1982), Forsberg and Ryding (1980) and Nürnberg (2001).

2.2.2. Groundwater

In order to evaluate the degree of influx of pollutants into the two reservoirs, underground water from the water-carrying I horizon was also analysed. Piezometers were installed in the coastal zone of the reservoirs neighbouring the urbanised area and arable lands. Seven wells were bored in Przebędowo and eight in Miedzichowo (Fig. 2). Additionally, water was also analysed from three wells under the control of the Wojewódzki Zarząd Gospodarki Wodnej (Regional Board of Water Management) in Poznań. Nitrate, ammonium, total nitrogen, orthophosphates and total phosphorus were measured. Groundwater analyses were performed as described above for surface waters.

2.2.3. Catchment

The catchment areas of the studied reservoirs were delimited on the basis of current topographic maps, the hydrographic atlas of Poland (Czarnecka, 2005), known terrain slope and verified actual direction of water outflow. Analysis of the catchment area use was made in terms of the Corine Land Cover 2012. Sewage management was characterised on the basis of the statistical data from the Central Statistical Office, Local Database (http://www.stat.gov.pl) and data from the relevant commune offices.

2.2.4. Vegetation

Aquatic plant species composition was evaluated using Braun-Blanquet methods. Additionally, macrophytes composition in Miedzichowo reservoir was analysed before lake reconstruction in