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Patterns of macrophyte community recovery as a result of the restoration of a shallow urban lake

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ABSTRACT

Restoration of urban lakes becomes necessary to slow down unfavourable processes and to recover their-recreational role. Macrophyte communities are good bioindicators, thus they can be used to assess the effectiveness of restoration.

The aim of the study was to determine the dynamics and patternof macrophyte recovery as a result of the restoration measures in a degraded shallow urban lake characterized by strong cyanobacterial blooms. Annual changes in the composition and areal coverage of littoral macrophyte phytocoenoses, and in the Ecological State Macrophyte Indexwere recorded using a GPS and the ArcGIS programme and analysed in relation to changes in water quality for three years following restoration measures (phosphorus inactivation, aeration, and biomanipulation).

The shifts were statistically significant in the first two for total nitrogenconcentrationand three years for chlorophyll aconcentration, whereas total phosphorus concentration only decreased significantly in the third year. Changes in water transparency were not significant. The ecological status of the lakewas good or moderate. A characteristic pattern of recovery was observed. Phytocenotic richness increased (from 9 to 12 communities) and total phytolittoral area decreased (from 42 to 37 ha, i.e. 12%) during restoration efforts. The area of hypereutrophic plant communities (*Ceratophylletumdemersi*, *Hydrocharitetummorsus-ranae*, *Typhetumangustifoliae*) decreased, the former submerged community returned (*Potametumlucentis*) and the area of some existing communities (e.g. nympheids) increased.

Slow return of elodeidswas caused by low transparency andlack of submerged vegetation propagules, which are the most probable limiting factors of the recolonization process.

1. Introduction

Photosynthetically active radiation no longer reaching parts of the littoral sediments, deterioration of water and sediment chemical quality and the consequential retreat of submerged plants (i.e. elodeids and charophytes), often with a shift to a stable turbid-water state from a macrophyte-dominated clear-water state, are typical results of eutrophication and degradation of shallow lakes in all climate zones (Moss, 1990; Scheffer et al., 1993; Jin et al., 2006; Schallenberg and Sorrell, 2009; Klimaszyk et al., 2015).

Macrophytes influence the functioning of water ecosystems (Søndergaard et al., 2013), as they play a crucial role in the mobilization, transportation and accumulation of nutrients (Carpenter, 1980), and limit the resuspension of sediments (Ozimek et al., 1990; Zuccarini et al., 2011). They are responsible for a significant part of primary production in the littoral zone of lakes, provide a refuge for organisms (Schneider, 2007; Liu et al., 2014), reduce the penetration of pollutants from the catchment area to the pelagial zone (Sender, 2012), as they absorb and inactivate a variety of compounds, removing them from the water column (Trajanovska et al., 2014). The presence of macrophytes contributes to greater transparency (Mjelde and Faafeng, 1997; Zuccarini et al., 2011) and sustains clear water in lakes, as they can control phytoplankton growth (Scheffer, 1998). Their occurrence and structure depend on environmental factors, such as light conditions, availability of nutrients (Mjelde and Faafeng, 1997; Nagengast and Kuczyńska-Kippen, 2015), economic exploitation of the lake and use of its catchment area (Kissoon et al., 2013).

Macrophyte communities have well-defined ecological optima (Schneider, 2007; Trajanovska et al., 2014), that makes them good indicators of the eutrophication state of lakes (Hutorowicz and Dziedzic, 2008; Søndergaard et al., 2013; Ogdahl and Steinman,

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2014). They react slowly and gradually to changing environmental conditions (Penning et al., 2008; Søndergaard et al., 2013). Elodeids in particular are good but late-warning indicators of environmental disturbances (Sender, 2012; Trajanovska et al., 2014). Helophytes are less sensitive to changes in physicochemical qualities, nonetheless, they are more sensitive to water level fluctuations (Penning et al., 2008; Mjelde et al., 2013; Jusik and Macioł, 2014). Therefore the effectiveness of restoration measures could be evaluated based on the response of such communities.

Urban lakes come under intense human impacts that degrade their water quality due to the appearance of cyanobacterial blooms, as well as pathogenic bacteria, that may result from an influx of sewage and stormwater (Grochowska et al., 2015). Their recreational use becomes impossible. The increase in turbidity (e.g. due to the excessive growth of phytoplankton) leads to a deterioration of light conditions and significantly affects density and depth of the occurrence of elodeids (Horppila and Nurminen, 2003; Søndergaard et al., 2013), as well as lowering the biodiversity of emergent and floating-leaved plants.

To improve the water quality in lakes, which is required by the EU Water Framework Directive (Directive, 2000), restoration is necessary (Dunalska et al., 2015). The insufficiently understood processes and reactions of organisms occurring in aquatic ecosystems under the influence of restoration measures require further investigation. Observations usually concern the appearance and expansion of submerged vegetation but rarely include other plant groups (Hansel-Welch et al., 2003; Hilt et al., 2010).

The hypothesis was that sustainable restoration (not destructive for most of the biota, e.g. using small doses of chemical compounds) improves water quality in shallow urban lakes, which causes the return of elodeids and increases the biodiversity of macrophyte communities. The aim of study was to determine the response of particular plant communities and the pattern of their recovery in a shallow urban lake under the influence of restoration measures in relation to changes in the physicochemical parameters of water quality, such as transparency, concentration of chlorophyll *a* and nutrients (total nitrogen and total phosphorus). Additionally the factors, which may limit the development of macrophytes, were defined.

2. Material and methods

Swarzędzkie Lake (52°24′49″N 17°03′54″E) is a relatively shallow, postglacial, polymictic, medium-sized, elongated, flow-through lake, located on the border of the cities of Poznań and Swarzędz (Poland) (Table 1). The north-eastern part of the lake is wider and deeper, while the south-western part is shallower (ca 2 m depth) (Szyper et al., 1994; Kowalczewska-Madura and Gołdyn, 2006).

Swarzędzkie Lake was strongly eutrophic (Kowalczewska-Madura and Gołdyn, 2006; Kozak et al., 2014), because it was subject to intense human pressure having been the receiver of untreated urban waste water from the city of Swarzędz for nearly 50 years. Water quality had steadily deteriorated. Although water and sewage management have been practised in the catchment for the last twenty years in an attempt to eliminate the external loading of nutrients (Kowalczewska-Madura and Gołdyn, 2006), there had been no visible improvement in water quality. Indeed, cyanobacterial water blooms were still present (Table 1) as a result of internal nutrient loading from the bottom sediments as well as the nutrient rich tributaries. As a consequence, the lake could still not be used for recreation (Kowalczewska-Madura and Gołdyn, 2006).

Therefore restoration measures were begun in autumn 2011. To reduce phosphorus concentration, improve water transparency and oxygenate the bottom waters three methods were used: phosphorus inactivation using small doses of iron sulphate and magnesium chloride (dosage: 200–300 kg/lake – 9 times/2012, 5 times/2013, 5 times/2014), aeration of water above the bottom sediments with the use of a wind-driven aerator and biomanipulation (ca. 5% of cyprinids removal and stocking of pike *Esox lucius* L. and pike-perch *Sander lucioperca* L. fry) (Kozak et al., 2014; Rosińska and Gołdyn, 2015). The reactions of the ecosystem were monitored throughout the restoration measures.

Analyses of syntaxonomic composition, distribution and size of patches of the macrophyte communities in Swarzędzkie Lake were carried out during the peak of the growing season – July 2013 and August 2014, in the second and third year of restoration measures. The data were supplemented with the results from the first year of restoration in 2012 (Rosińska and Gołdyn, 2015) and compared with previous data collected prior to the restoration (Jenek et al., 1979; Gołdyn et al., 2005). The study was carried out using pontoons from the open water and by walking along the shoreline. The syntaxonomic composition of the macrophyte communities was determined directly in the field, based on the dominant species in accordance with the phytosociological method adapted for lakes (Podbielkowski and Tomaszewicz, 1996). The presence and coverage area of submerged vegetation communities were estimated with a three-pronged rake (weed anchor) 20 cm wide. The bottom was checked every 20 m around the lake. Raking was repeated 3 times in each place, throwing rake in different directions at a distance of about 3 m from the boat and dragging the bottom stretch along. When submerged plants were found in each case the size of their patch was determined by marking the extreme points with a GPS device (the resolution was *ca.* 2 m). The abundance of plant communities was estimated in square metres. The data collected in the field were analysed using the ArcGIS for Desktop 10.2.2 programme, which allowed the production of maps of the distribution of macrophyte communities and calculations of the surface of macrophyte patches (the surface of small patches of vegetation was estimated in the field, larger ones were calculated *posteriori* using ESRI ArcGIS). Aerial photographs obtained from the Central Documentation Centre of Geodesy and Cartography in Warsaw from

Table 1
The characteristics of Swarzędzkie Lake (Jenek et al., 1979; Szyper et al., 1994; Kowalczewska-Madura and Gołdyn, 2006; Stefaniak et al., 2007; Gołdyn and Kowalczewska-Madura, 2008; Kozak et al., 2014).

Parameter	Value
Maximum depth	7.2 m
Surface area of the lake	93.7 ha
Area of two islands	2.0 ha
Length of the shoreline	6 650 m
Total catchment area of the lake	178 km^2 (75.5% – is agricultural land)
Direct catchment area	5.58 km^2 (consists mainly of urban areas of the cities of Swarzędz and Poznań)
Tributaries	River Cybina – polluted by water from fish ponds located upstream of the lake
	Mielcuch Stream – contaminated by stormwater
Cyanobacterial blooms	*Aphanizomenon gracile* Lemm.
	Pseudanabaena limnetica (Lemm.) Kom.