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Efficiency of a newly established in-stream constructed wetland treating diffuse agricultural pollution

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ABSTRACT

Diffuse agricultural pollution, especially from intensively managed agricultural land is a major cause of eutrophication, therefore it is important to reduce the diffuse load to surface water. Constructed wetlands (CW) are an effective measure for improving water quality and reducing nutrient runoff from agriculture by using natural water treatment mechanisms. We studied treatment efficiency of an in-stream free surface flow (FSW) Vända CW in southern Estonia from 16th of March 2017 till 11th of January 2018. Vända CW has a catchment area of 2.2 km^2 and of which approximately 62% is under intensive agricultural management. The CW consists of a sedimentation pond followed by two shallow water wetlands planted with cattail (*Typha latifolia*). Our analyses showed that the CW retained 17.5 kg phosphorus (P) ha^{-1} yr^{-1}. During the warm period phosphate removal was up to 41.8% whereas annually it was only 14.4%. Phosphate removal efficiency showed strong negative correlation ($R^2 = 0.58$, $p < 0.001$) with flow rate and therefore it can be seen that shorter retention time reduces significantly the overall P removal efficiency. The yearly reduction of total organic carbon was up to 3300 kg C ha^{-1} yr^{-1} while surprisingly the CW increased total nitrogen up to 1375 kg N ha^{-1} yr^{-1}. The results demonstrate that the acclimatization period of newly established in-stream FWS CWs in northern countries can be relatively long and after two years of establishment we still cannot see satisfactory treatment processes, especially in nitrogen.

1. Introduction

The increasing demand for agricultural products has expanded the use of fertilizers. Excessive or poorly timed fertilization results in nutrient runoff from fields to surface waters and causes algae growth, oxygen depletion and other problems. Eutrophication due to nutrient transfer from anthropogenic diffuse sources, in particular from agriculture, is well documented (Nõges et al., 2007; Asmala et al., 2011). Diffuse pollution is transferred from agricultural land to drainage ditches and larger water bodies, which causes significant degradation of water quality in rivers and lakes (Blankenberg et al., 2008). Diffuse pollution causes serious problems due to its large scale and its diffuse nature. Its movement in the environment is more difficult to control than point-source pollution (Anderson et al., 2002; Withers et al., 2014).

Land management practices such as constructed wetlands (CW) are one of the most effective measures to reduce nutrient runoff from agriculture to large water bodies and therefore preventing eutrophication. CWs are feature a variety of environments and a controlled water regime, that are necessary for water-purification, nutrient-absorption and -removal processes (Owenius and van der Nat, 2011). Previous studies in northern climate (Koskiaho et al., 2003; Koskiaho and Puustinen, 2005; Braskerund, 2002) have shown that free water surface flow (FWS) CWs can effectively reduce nutrient, especially nitrogen (N) and P runoff from agriculture, however they must meet certain requirements to function. For example, the wetland/catchment ratio should be at least 0.5% and flow velocity should be relatively low (Koskiaho et al., 2003; Koskiaho and Puustinen, 2005).

Based on the location in relation to the river or stream flow, there are two types of surface flow CWs – in-stream and off-stream. Off-stream wetlands are established outside a stream or river channel and only a part of the water is directed through the CW for purification (Kadlec and Wallace, 2009). In-stream CWs are located directly in the flow path and all the water from the river/ditch flows through the wetland, where flow rate is decreased and processes for nutrient reduction can take place for extended periods (Darwiche-Criado et al., 2017). Most of FWS CWs to reduce diffuse pollution are off-stream (Borin and Tocchetto, 2007; Zheng et al., 2014, 2015; Johannesson

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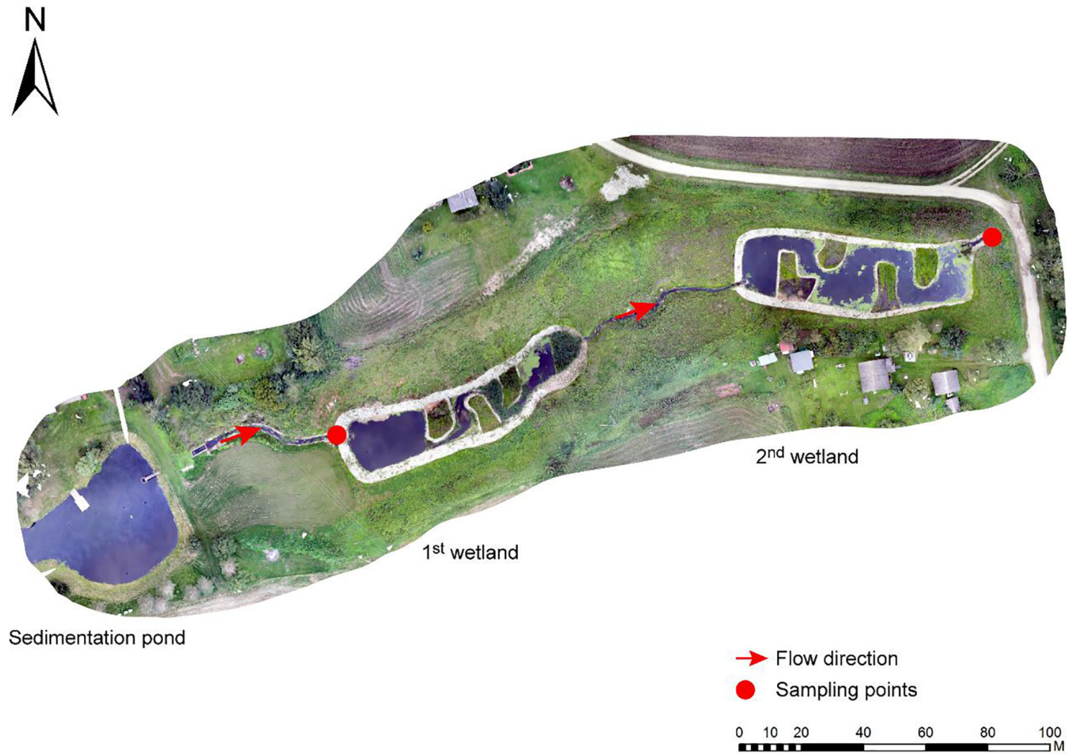

Fig. 1. Vända free water surface constructed wetlands.

et al., 2017; Hernandez-Crespo et al., 2017), only few are reported as in-stream (Koskiaho et al., 2003). Main reasons behind that include incapacity of in-stream CWs to fully treat storm- or floodwater, or limitation of land available in intensive agricultural areas to achieve a suitable wetland/catchment ratio. Also, nutrient removal is significantly lower in in-stream CWs due to rapid flow rate changes (Darwiche-Criado et al., 2017). For example, TN retentions in off-stream wetlands have been reported to be 62.3–97% (Borin and Tocchetto, 2007; Zheng et al., 2014; Hernandez-Crespo et al., 2017) and 40–86% for TP (Zheng et al., 2014; Johannesson et al., 2017; Hernandez-Crespo et al., 2017) while TP removal efficiency of in-stream CWs have been 6–62% (Koskiaho et al., 2003; Johannesson et al., 2017) TN removal efficiency up to 36% (Koskiaho et al., 2003). However, if properly designed and if the recommended wetland/catchment ratio is achieved, in-stream wetlands can still achieve sufficient water treatment efficiency (Braskerund, 2002). Studied carried out in Sweden showed that only 30% of the river discharge was passing through the off-stream wetlands while the in-stream wetlands were reducing nutrient concentration from entire ditch/stream (Arheimer and Pers, 2017). In addition, in-stream wetlands have shown remarkably higher permanent plant cover (50–90%) compared with off-stream wetlands (10–20%) due to their permanent flood conditions (Darwiche-Criado et al., 2017), which is highly important for overall nutrient removal. Hsu et al. (2011) have also shown that in-stream wetlands are often much larger than off-stream wetlands and therefore are able to provide other important environmental benefits such as increasing biodiversity.

The aim of this study was to estimate the efficiency of a newly established in-stream FWS CW treating agricultural diffuse pollution in northern temperate climate and evaluate its acclimatization period.

2. Material and methods

2.1. Site description

2.1.1. Catchment

The Vända ditch catchment is located in the Porijõgi river catchment in southeastern Estonia. The Porijõgi river is 36.2 km long with a catchment of 298 km^2, which lies at the border between two landscape regions: the Southeast-Estonian till plain and Otepää Heights (Mander et al., 1997). The lower course of the Porijõgi river is an undulating moraine plain and the altitude is mainly between 32 and 75 m a.s.l. The Vända sub-catchment is 2.2 km^2 of which approximately 62% is arable land, 32% natural areas (forest and bog) and about 8% other land use types. According to the Tartu Observatory weather station in Tõravere (15 km from the site), annual precipitation is 726 mm per year during 168 days with rainfall per year. Annual mean air temperature is 6.3 °C. Compared to the previous decade, when 90% of the arable land became seminatural and cultivated grassland (Mander et al., 2000), between 2001 and 2006 the land use reversed and the grasslands were returned to the arable land raising it to 62% (Pärn et al., 2018). Nutrient runoff increased due to the changes in land use and increase in fertilization (Pärn et al., 2009). Previously the main problems in the Vända catchment were high concentration of NO_3-N in the shallow groundwater, relatively high runoff values for total inorganic nitrogen and erosion of ditch banks due to intensive agricultural management (Mander et al., 1997). Total nitrogen (TN) concentration in ditch water has risen over the years, for example in 2007 the concentration was 4.7 mg L^{-1}, which corresponds to medium water quality. In 2008 it was 5 mg L^{-1}, in 2011 and 2013 the concentration was over 8 mg L^{-1}, which corresponds to very bad water quality according to the Estonian Water Act. Average total phosphorus (TP) concentration was 0.06–0.1 mg L^{-1} in 2007–2013, but during higher flow rates the concentration rose up to 2.5 mg L^{-1}. The changes are associated with the land-use change and increased fertilization (Pärn et al., 2018).