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Research article

Rewetting in Mediterranean reclaimed peaty soils and its potential for phyto-treatment use

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ABSTRACT

A pilot experimental field combining rewetting of reclaimed peaty soils and water phyto-treatment was set up in the Massaciuccoli Lake basin (Tuscany, Italy) to reduce the water eutrophication and peat degradation caused by almost a century of drainage-based agricultural use.

In this paper, we investigated the restoration process occurring consequently to the conversion of a drained area in a natural wetland system (NWS) (the partial top soil removal, the realization of a perimeter levee to contain the waters, the rewetting with the drainage waters coming from the of surrounding cultivated areas) and the capability of the spontaneous vegetation to catch nutrients acting as a vegetation filter.

To follow the restoration process over time (2012–2016), we used a mixed approach merging phytosociological surveys with ortophotos taken by an Unmanned Aerial Vehicle (UAV). During the last year of observation (2016), we performed destructive sampling on the most widespread plant communities in the area (*Phragmites australis* and *Myriophyllum aquaticum* community) to quantify the biomass production and the uptake of nitrogen and phosphorus.

Stands of *Phragmites australis (Cav.) Trin. ex Steud.* yielded more than *Myriophyllum aquaticum* (Vell.) Verdc. (4.94 kg m-2 vs 1.08 kg m-2). *M. aquaticum* showed higher nutrient contents (2.04% of N and 0.35% of P), however *P. australis* was able to take up more nutrients within the NWS because of its larger cover and productivity.

In the perspective of maximizing the plant development and consequently the amount of nutrients extracted from treated waters, the authors suggest 4-5 year-long-harvesting turns, better occurring in spring-summer.

1. Introduction

Peatlands drainage and their following exploitation have severely compromised their ecological and biological status worldwide, because of the changes in the land use produced by agriculture, forestry and urbanization (Grootjans et al., 2012). We can estimate that nowadays less than 20% of the original, pristine wetland areas still remain (Verhoeven, 2014).

By altering groundwater patterns and compositions, extensive peatland drainage has determined significant changes on the physics and chemistry of peats, leading to: i) acceleration of organic-matter oxidation (Oleszczuk et al., 2008), with a consequent increase in greenhouse gases (GHG) emissions into the atmosphere of up to 25 t CO_2 equivalent $ha^{-1}y^{-1}$ (Wichtmann and Wichmann, 2011; Couwenberg et al., 2011); (ii) enhancement of mineralization and nitrification of organic N due to higher oxygen availability and consequent increase of NO_3^- concentrations in porewater (Tiemeyer et al., 2007) and (iii) mineralization of organic P compounds and increase of absorbed and Fe-bound P pools (Zak et al., 2004). The continual recurrence of these phenomena has negatively affected the status of peatlands, lowering the soil level (subsidence), increasing nutrient availability and loads delivered to receiving water bodies (eutrophication) and decreasing ecosystem biodiversity and functionality (loss of resilience) (Smolders et al., 2006; Pistocchi et al., 2012; Lamers et al., 2015).

Moreover, these deeply drained areas are becoming unsuitable for modern agricultural production requirements (Pfadenhauer and

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Grootjans, 1999) and almost inaccessible for the ordinary machines used in agriculture.

From a merely biodiversity perspective, peatlands are unique, complex ecosystems of global importance, since they contain many species found only or mainly in peatlands thanks to the water regime of these areas (Tanneberger and Wichtmann, 2011).

For all these above-mentioned factors considered, stopping the peatland drainage and planning the consecutive management represent an environmental priority to face.

From literature, we can derive that there are different reasons leading to the change by moving from the traditional drainage-based management of peatlands: stimulating the restoration of land portion deteriorated from prolonged drainage (e.g. restoring) or recovery of the agricultural productivity of the areas (e.g. paludiculture).

Regardless the aims behind the restoration, we can assume that to achieve the rehabilitation of at least some of the functions supplied by these ecosystems, two main conditions have to be met i) rewetting (e.g. constructing dams or filling in drainage ditches) and ii) reduction of trophic status (e.g. by mean of the top soil removal) (Van Dijk et al., 2007; Klimkowska et al., 2010a,b; Zak et al., 2014).

Both are not without side effects. Raising water level and flooding organic soils can lower the soil nutrient availability (mainly released as ammonium), but can at the same time boost phosphorus mobilization (Lamers et al., 2002; Meissner et al., 2008; Zak et al., 2004).

Top soil removal, i.e. the removal of the upper and most degraded peat layers responsible of the higher mobilization of phosphorous during the rewetting phase (Zak and Gelbrecht, 2007; Zak et al., 2017) causes the removal of the reproductive organs of plant species (seeds, stolons, rhizomes, etc.) (Lepš, 1999) delaying the time of re-naturation.

The case study reported in the present paper is linked to a project realized in Tuscany (IT), which compares three different management strategies aimed to combine the peatland rewetting and the water phyto-treating action.

In this paper, we focused on the Natural Wetland System (NWS). The first objective was to follow the restoration process after rewetting of lowlands to evaluate the dynamics driven by the re-established vegetation. According to literature, the ecological restoration perspective is highly dependent on the zero-point condition before starting the restoration process (Klimkowska et al., 2010b). Indeed, while Tanneberger and Wichtmann (2011) report that top soil removal in combination with rewetting can lead to the restoration of soft-water pools and small sedge marshes within 5 years, Poschlod (1992) shows that in the case of peatland severely used for peat extraction mostly monospecific stands of non-peat-forming species could develop even for 20 years after the rewetting. Joosten (1995) even reports that in the cases of severe anthropogenic impact on the environment, it is not possible to observe any change within a human time perspective.

The second important research goal was to evaluate the capability of the NWS to work as phyto-treatment system thanks to the capability of plants to take up nutrients from waters proportionally to the biomass production and nutrient contents in the vegetative tissues.

2. Material and methods

2.1. Site description

The study was carried out over 5 years (2011–2016) in Vecchiano, about 10 km from Pisa, Italy (43° 49′ 59.5″N; 10° 19′ 50.7″) in the Migliarino, San Rossore, Massaciuccoli Natural Park, within a 15 ha experimental area (Fig. 1a and b).

This site was used to compare the efficiency of three different strategies in treating the eutrophic drainage water coming from a cultivated sub-watershed within the reclamation district around the Massaciuccoli Lake. In this area, phosphorous has been recognized as the primary cause of the eutrophication and the losses of this nutrient from cultivated fields (dissolved + particulate fractions) are estimated in 2–4 kg $ha^{-1}y^{-1}$ (Pensabene et al., 1997; Bonari et al., 2013).

The NWS was set up as natural rewetted area with a surface area of 2.7 ha and surrounded by small embankments built with the top soil (~10 cm) removed long the area's borders. Natural elevation changes within the NWS helped in creating zones with a different bottom height in order to promote the colonization from a large variety of plant species.

The soils of this experimental area has been classified as Histosol according to the USDA system and as Rheic Histosol according to the FAO system (Pellegrino et al., 2015).

The climate is classified as Mediterranean (Csa) according to Köppen-Geiger climate classification map (Kottek et al., 2006). Summers are dry and hot, while rainfall is mainly concentrated in autumn and spring (mean annual rainfall = 910 mm) and mean air

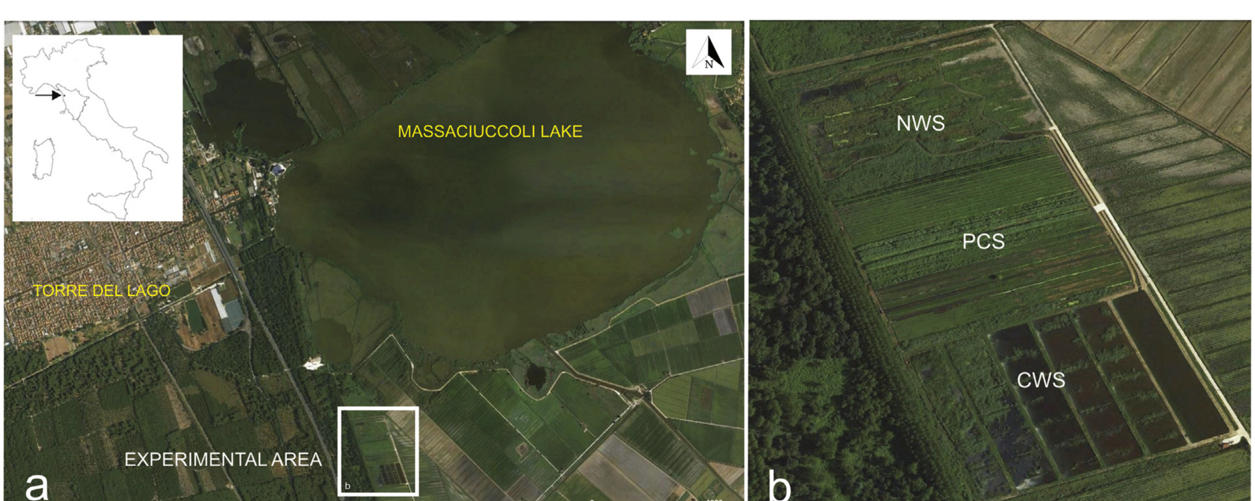

Fig. 1. (a) Aerial view of the Massaciuccoli Lake catchment (Tuscany, IT) and (b) zooming on the experimental area.