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A CASE OF ECOLOGICAL RENATURATION IN A DRAINED MEDITERRANEAN PEATLAND: THE CASE STUDY OF THE MASSACIUCCOLI LAKE BASIN (TUSCANY, IT)

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The Massaciuccoli Lake floodplain is located in the Natural Park of San Rossore, Migliarino and Massaciuccoli (Figure 1), which is one of the most important residual coastal marshy areas of the Tuscany (Italy). Since the 1930s, a large part of the Massaciuccoli floodplain has been drained for agricultural purposes. To ensure a wate r table depth suitable for cultivation, a complex network of artificial drains and pumping stations has been used to drain the superficial aquifer and rainwater AA.VV.,1997). In the drained areas, cultivated peat soils (autri-sapric and endo-salic histosoils), with values of organic matter reaching up to 50% in some cases, are present (Pistocchi et al. 2012). Land use is characterised by conventional agriculture (covers 80% of the area) and periurban infrastructures, such as a wastewater treatment plant. In the peatland area, cropping systems are based on continuous production of maize (*Zea mays* L.), sunflower (*Heliantus annuus* L.), wheat (*Triticum spp.* L.) or maize-wheat rotations, while winter cereals are mainly cultivated in the remaining part of the basin. As a consequence of land use, several environmental concerns arose in the last 50 years. The most important concerns are those related to:

I. eutrophication of the lake due to nutrient enrichment (N, P) in the surface- and groundwater. Indeed, from the 1970s, the lake, from an initial oligotrophic status, progressively turned into an eutrophic/hypereutrophic system;

II. the subsidence rate (2-3 m in 70 years) due to compaction and increased mineralization of peat. This process, started since land reclamation, left the lake perched above the drained area, which is now 0 to 4 m below the sea level .

Fig.1 Geographical location of study area

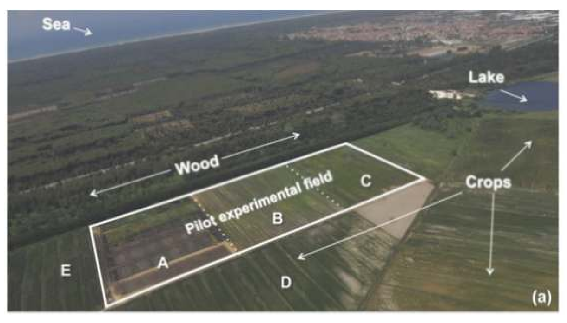

Fig.2 The area of study in the basin landscape

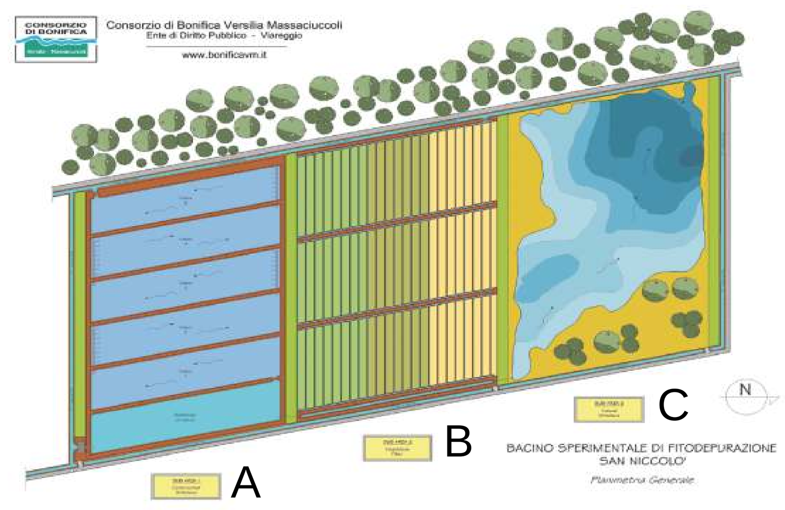

Fig.3 The pilot experimental field

Fig.4 Construction works

Fig.5 Overview of the subarea C after construction works

The project RestoMedPeatland (https://sites.google.com/site/restomedpeatland/) started in 2011, identified rewetting and setting-up a phyto-treatment system as the solution to improve water quality, and reduce soil organic matter (SOM) mineralisation, and, therefore, a method to restore the ecological functions of this site (Fig.2). A pilot experimental field of 15 ha was set-up and three different management systems, with increasing anthropogenic impact, has been tested (Fig. 3): constructed wetland (A), paludicultural system (B) and natural wetland (C).

This implies a gradient in regulation of water regime (from a strongly controlled system to a "quasi" natural rewetting), plant communities (from cultivated to native communities) and harvesting strategies. The soil-plant continuum systems are expected to reduce nutrient load. In addition, a conventionally cultivated (D) and an uncultivated drained (E) peat soil (the latter characterized by a natural vegetation succession), were used as controls (Figg . 4,5, 6).

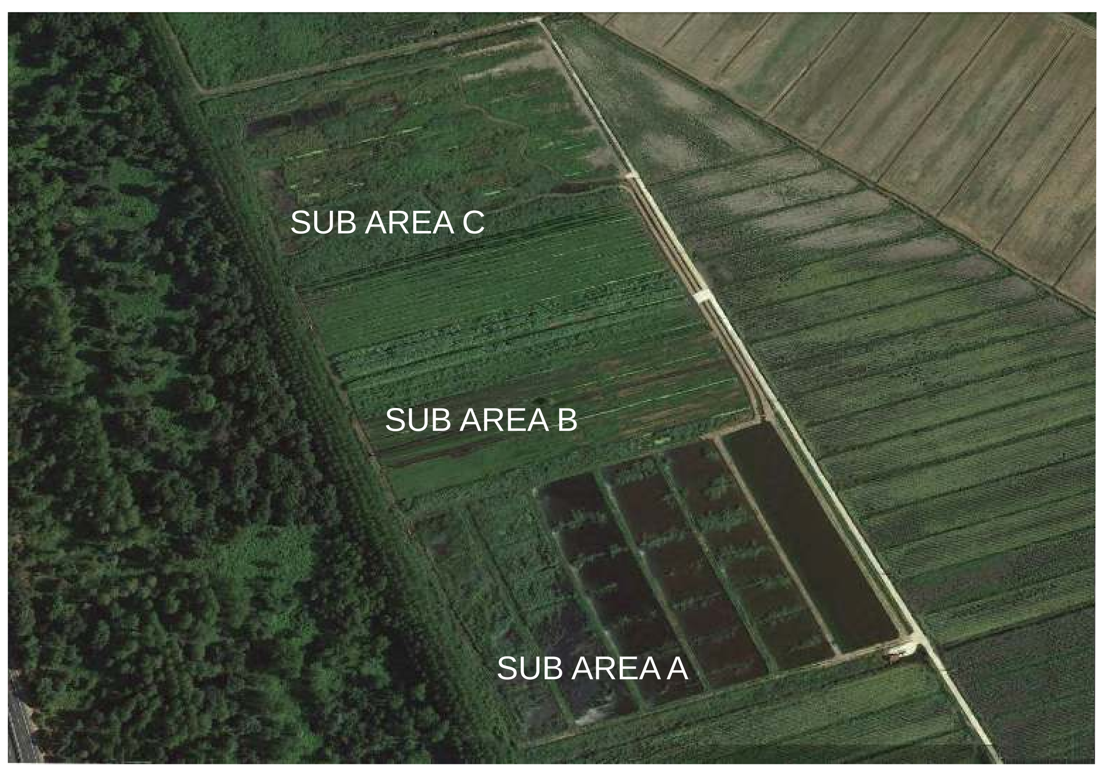

Fig.6 The pilot experimental field in 2012

The water capacity of the area C is about 8500-9000 m3, with a maximum depth of 50 cm. The flow is between 13 -15 L / s.

Before the beginning of the construction works, on the abandoned fields existing on the sub-area C, a floristic survey was carried out. In the natural wetland (C), after top soil removal, excavation and rewetting with drainage water, the vegetation has evolved naturally. Each year thereafter, a detection of the flora was performed in spring / summer.

In the summers of 2014 and 2015 phytosociological surveys, by Braun-Blanquet method (Tabb. 2,3,4,5)

The floristic surveys carried out highlighted the development of a spontaneous hydro-hygrophilous flora, partially similar to that Massaciuccoli banks, swhich strongly replaced the preexisting weeds (Tabb. 1 a, b) .

Tab 1 a Pre-processing floristic inventory (sub area C)

1. *Abutilon theophrasti* Medik	*Malvaceae*
2. *Amaranthus retroflexus* L.	*Amarantaceae*
3. *Arctium lappa* L.	*Asteraceae*
4. *Artemisia verlotiorum* Lam.	*Asteraceae*
5. *Bidens tripartita* L.	*Asteraceae*
6. *Bromus tectorum* L.	*Poaceae*
7. *Calystegia sepium* (L.) R.Br.	*Convolvulaceae*
8. *Datura stramonium* L.	*Solanaceae*
9. *Echinochloa crus-galli* (L.) P. Beauv.	*Poaceae*
10. *Linaria vulgaris* Mill.	*Plantaginaceae*
11. *Phragmites australis* (Cav.) Trin.	*Poaceae*
12. *Typha latifolia* L.	*Typhaceae*
13. *Lythrum salicaria* L.	*Lythraceae*
14. *Phytolacca americana* L.	*Phytolaccaceae*
15. *Rumex crispus* L.	*Polygonaceae*
16. *Silene alba* (Miller) Krause)	*Caryophyllaceae*
17. *Xanthium strumarium* L.	*Asteraceae*

The most abundant plant species were *C. sepium, P. australis, A. lappa and B. tectorum*

Tab 1 b. Three years after floristic inventory (sub area C)

1. *Alisma plantago-aquatica* L.	*Alismataceae*
2. *Apium nodiflorum* (L.) Lag	*Apiaceae*
3. *Aster squamatus* Spreng.	*Asteraceae*
4. *Bidens tripartita* L.	*Asteraceae*
5. *Calystegia sepium* (L.) R.Br.	*Convolvulaceae*
6. *Carex otrubae* Podp.	*Cyperaceae*
7. *Cirsium arvense* (L.) Scop.	*Asteraceae*
8. *Cyperus glomeratus* L.	*Cyperaceae*
9. *Datura stramonium* L.	*Solanaceae*
10. *Echinochloa crus-galli* (L.) P. Beauv.	*Poaceae*
11. *Epilobium hirsutum* L.	*Onagraceae*
12. *Holcus lanatus* L.	*Poaceae*
13. *Juncus articulatus* L.	*Juncaceae*
14. *Juncus bufonius* L.	*Juncaceae*
15. *Juncus effusus* L.	*Juncaceae*
16. *Lemna minor* L.	*Lemnaceae*
17. *Lycopos europaeus* L.	*Lamiaceae*
18. *Lytrum salicaria* L.	*Lythraceae*
19. *Matricaria camomilla* L.	*Asteraceae*
20. *Miriophyllum aquaticum* (Vell.) Verdc	*Haloragaceae*
21. *Paspalum dilatatum* Poir.	*Poaceae*
22. *Phragmites australis* (Cav.) Trin.	*Poaceae*
23. *Poa trivialis* L.	*Poaceae*
24. *Polypogon monspeliensis* (L.) Desf.	*Poaceae*
25. *Polypogon viridis* (Gouan) Breistr.	*Poaceae*
26. *Ranunculus sardous* Crantz	*Ranuncolaceae*
27. *Ranunculus sceleratus* L.	*Ranuncolaceae*
28. *Samolus valerandi* L.	*Samolaceae*
29. *Schoenoplectus tabernaemontani* (Gmel.) Palla	*Cyperaceae*
30. *Typha latifolia* L.	*Typhaceae*

The area C, was also periodically monitored through the use of a drone that, at average heights of 15 meters, has carried out photographic strips (Fig.7) through which, once assembled and imported into a GIS environment Map Info, it was possible to realize a dynamics map of the vegetation (Fig.8) .

Tab.2 Phragmites australis (Cav.) Trin. ex Steud. communities (Fig. 9)

Rel. no.	2	6	8	10	12	13	14
Surface (m²)	25	25	25	25	25	25	25
Coverage (%)	100	100	100	100	100	100	100
n° species	6	3	6	6	7	5	5
Phragmites australis (Cav.) Trin. ex Steud.	4	5	5	4	4	4	4
Calystegia sepium L.	+	+	+	+	+	+	+
Eupatorium cannabinum L.	.	.	.	+	+	+	.
Stachys palustris L.	.	.	r	r	r	.	.
Lythrum salicaria L.	+	.	.	+	+	.	r
Typha latifolia L.	.	r	r	.	.	.	.
Schoenoplectus tabernaemontani (Gmel.) Palla	r	.	.	.	r	.	.
Mentha aquatica L.	.	.	r	.	.	r	.
Iris pseudacorus L.	1	.	.	+	+	.	.
Oenanthe aquatica L.	.	.	+	.	.	.	+
Alisma plantago-aquatica L.	r	.	.	.	.	r	.
Polypogon monspeliensis (L.) Desf.	.	.	.	.	.	.	r

Tab. 3 *Typha latifolia* L. communities (Fig.10)

Rel. no.	25	26	27
Surface (m²)	9	9	4
Coverage (%)	80	80	100
n° species	4	6	3
Typha latifolia L.	3	2	4
Apium nodiflorum (L.) Lag	.	1	+
Calystegia sepium L.	+	+	1
Phragmites australis (Cav.) Trin. ex Steud.	1	1	.
Schoenoplectus tabernaemontani (Gmel.) Palla	.	+	.
Lythrum salicaria L.	+	1	.

Tab.4 *Myriophyllum aquaticum* (Vell.) Verdc. communities (Fig. 11)

Rel. no.	28	29	30
Surface (m²)	60	100	100
Coverage (%)	80	80	100
n° species	4	3	1
Myriophyllum aquaticum (Vell.) Verdc.	5	5	5
Juncus articulatus L.	+	.	.
Lythrum salicaria L.	+	+	.
Lemna minor L.	+	+	.

Tab. 5 Vegetation of wet meadow (Fig. 12)

Rel. no.	31	32	33	34
Surface (m²)	25	25	25	25
Coverage (%)	50	70	80	100
n° species	10	12	11	7
Phragmites australis (Cav.) Trin. ex Steud.	1	+	2	1
Echinochloa crus-galli (L.) P. Beauv.	2	1	+	3
Calystegia sepium L.	+	+	+	+
Eupatorium cannabinum L.	.	r	.	.
Poa trivialis L.	+	.	+	1
Juncus effusus L.	.	.	+	.
Juncus bufonius L.	.	+	+	.
Carex otrubae Podp	r	r	.	.
Lythrum salicaria L.	+	+	2	+
Schoenoplectus lacustris *Palla*	+	r	.	.
Iris pseudacorus L.	.	r	.	r
Paspalum dilatatum Poir.	+	+	+	.
Ranunculus sceleratus L.	.	+	+	.
Ranunculus sardous Crantz	+	+	+	.
Samolus valerandi L.	+	.	.	.
Epilobium hirsutum L.	.	.	+	+

Fig.9 *Phragmites australis* (Cav.) Trin. ex Steud. communities

Fig. 10 *Typha latifolia* L. communities

Fig.7 The aerophotographic moisaic of area C

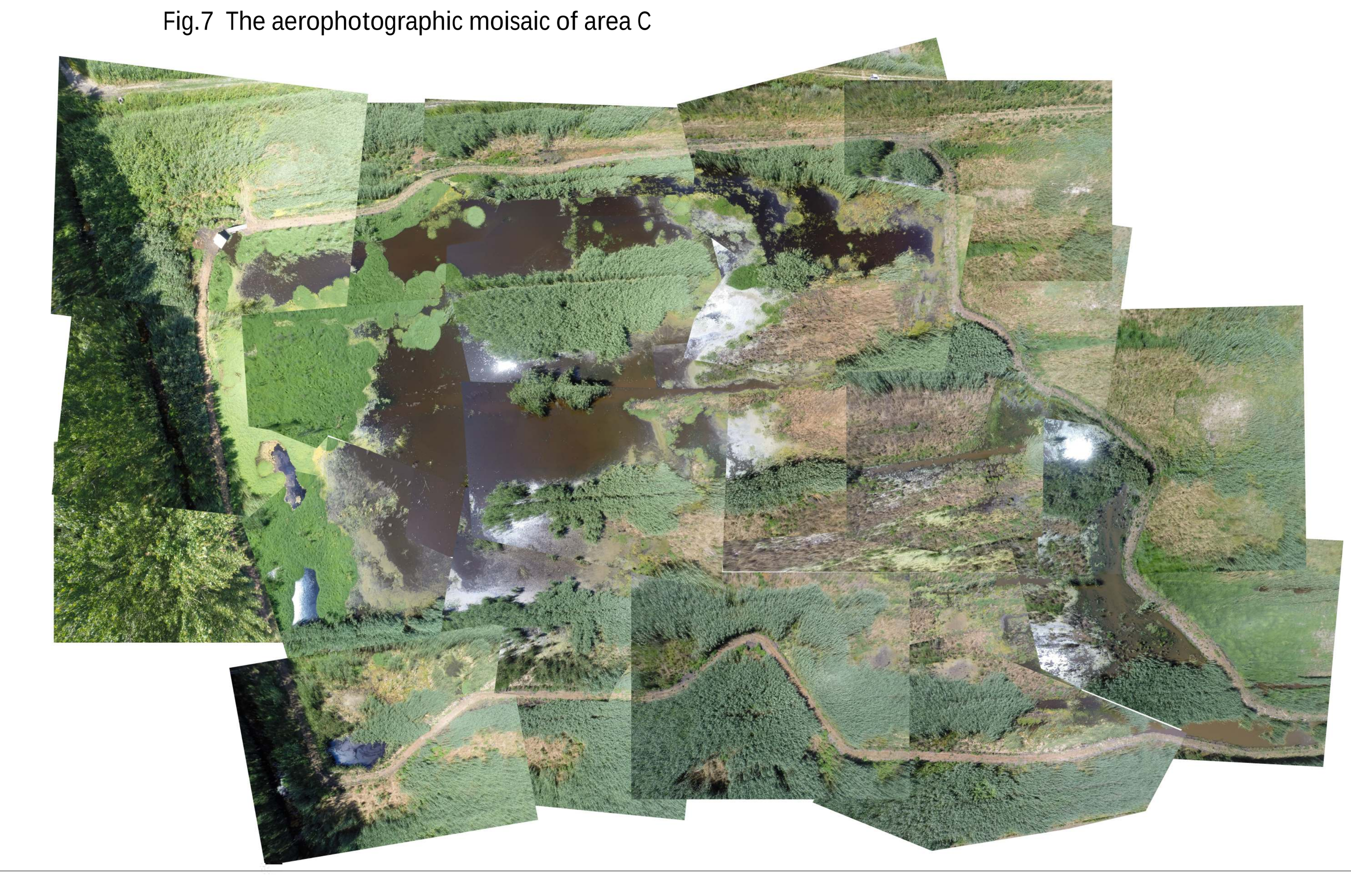

Fig.11 *Myriophyllum aquaticum* (Vell.) Verdc. communities

Fig.8 Vegetation map (spring 2015)

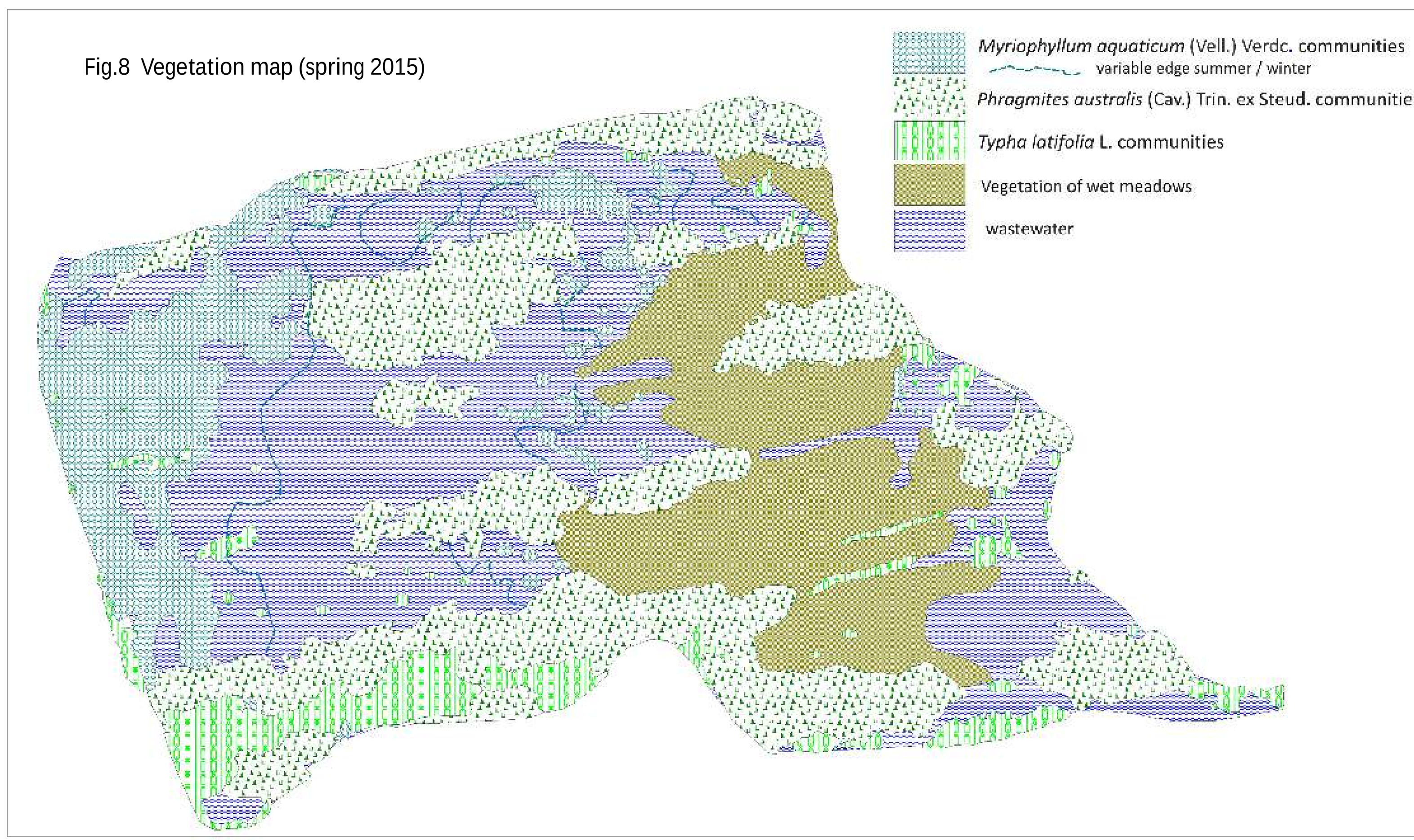

Fig. 12 Vegetation of wet meadows

In four years from the flooding, the area C has become a wetland with spontaneous hydro-hydrophitic populations. These, in part,were similar to the associations of helophytes of Lake Massaciuccoli (Tomei et al., 1997), partly dissimilar and yet others still in evolution. The populations of *Phragmites* australis appear floristically similar to *Phragmitetum australis* Gams 1927 of banks of Lake Massaciuccoli, while the populations of *Typha latifolia* here were differentiated from those of the lake instead made only by *Typha angustifolia*. This is probably due to a percolation of propagules and / or seeds from the ditches south of the lake where *T.angustifolia* is absent and instead *T.latifolia* is always present, as well as ecological conditions selective between the two species. The extensive population in *Myriophyllum aquaticum*, N-American exotic species , is only present in the reservoir and is, fortunately, absent from the lake and its massive coverage is likely linked to the particular conditions of low depth and high availability of nutrients. This area shows great potential for the study of the dynamics of colonization of hydro-hygrophilous species and has become a preferred site for nesting and a source of food for birds (Fig. 13)

During 2015, drainage waters treated in this system presented a reduction of about 50% of total phosphorus and of about 43% of total nitrogen compared to the coming drainage water, mainly characterized by the following characteristics: 5,9 mg/L of nitrogen and 0,10 mg/L of phosphorus (Giannini et al., 2015).

In the hypothesis of using this strategy for the phyto-treatment of the drainage waters of the Massaciuccoli Lake, 50 ha will be needed.

The efficiency of this system is related also to the higher volume of drainage water treated per surface unit, making it one of the more promising phyto-treatment solution for the low cost construction and the high level of biodiversity provided.

In the perspective of an integration of this system in the existing agricultural district, a series of investigations on the potential biomass produced and on the quality that it has will be performed.

Studying the maps created on the basis of photographic strips, biomass samplings on areas characterized of homogeneous vegetation (e.g. monophytic stands of *Phragmites*) will be carried out and qualitative analyses of biomass will be performed to verify the suitability to different valorization chains (e.g. combustion, biogas).

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(Fig. 13) The wetland has quickly developed into a refuge for nesting and as a source of food for birds

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