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Understanding common reed die-back: a phytocoenotic approach to explore the decline of palustrine ecosystems

L. Lastrucci[1], M. Cerri[2], A. Coppi[1], F. Ferranti[2], V. Ferri[2], B. Foggi[1], L. Lazzaro[1], L. Reale[2], R. Venanzoni[3], D. Viciani[1], D. Gigante[3]

[1]*Department of Biology, University of Florence, Florence, Italy.*

[2]*Department of Agriculture, Food and Environmental Sciences, University of Perugia, Perugia, Italy.*

[3]*Department of Chemistry, Biology and Biotechnology, University of Perugia, Perugia, Italy.*

Abstract

It is well known that since more than half a century, in Europe, *Phragmites australis* is suffering a process of decline, known in literature as 'common reed die-back'. Several hypotheses have been formulated but the actual causes of the phenomenon have been only partially understood. The several studies produced on this topic generally focused on the population approach and took seldom into account the floristic and vegetational features of the reed-dominated plant communities involved in die-back processes. The present study tries to fill this knowledge gap. Starting from a phytosociological approach, supplemented by the results of a recent three-year-long research project focused on morphological and ecological traits of dying-back reed beds, we analyzed the floristic and vegetational differences between declining and non-declining stands, based on a data set constituted by 80 relevés. Data refer to reed-dominated stands along the shores of five freshwater ecosystems in central Italy: the Lakes Trasimeno, Chiusi and Vico, the Fucecchio and Colfiorito Marshes. The statistical process, including cluster analysis and PCA, allowed to refer all the relevés to the association *Phragmitetum australis* Savič 1926, with eight variants differentiated from an ecological and floristic point of view. The indicator species analysis pointed out the *taxa* playing a diagnostic and/or differential role in each group, and provided useful information to understand pattern and processes occurring in the declining and non-declining reed-dominated phytocoenoses. As a general outcome, a clear inverse relation between number of species per relevé and intensity of the die-back process was showed. This supports the idea that the aquatic monospecific reed-beds are the most suffering ones, while the nitrophilous species-rich phytocoenoses, colonizing drier sediments and often in contact with disturbed areas, are the ones where common reed grows most healthily.

Key words: central Italy, common reed decline, indicator species, phytosociology, vegetation, wetlands.

Introduction

Since more than six decades ago, when the retreat of stands of *Phragmites australis* (Cav.) Steud. around several Swiss lakes was first reported by Hürlimann (1951), conspicuous phenomena of common reed decline have been observed in several areas of Europe and became the topic of a large scientific production (*e.g.* Den Hartog *et al*., 1989; Van Der Putten, 1997; Brix 1999; Ostendorp 1999; Rücker *et al*., 1999; Armstrong & Armstrong, 2001). In the last 15 years also several Italian wetlands have been the scene of drastic processes of reed die-back (Fogli *et al*., 2002; Gigante *et al*., 2011; Gigante & Venanzoni, 2012; Angelini *et al*., 2012; Reale *et al*., 2012). In particular, the recent detection of reed decline in three wetlands of conservation importance in central Italy, the lakes Trasimeno, Chiusi and Montepulciano (Gigante *et al*., 2011, 2014; Lastrucci *et al*., 2016), stimulated further surveys in other lakes to estimate the actual occurrence of this phenomenon in the Mediterranean Basin.

Although generally considered a strong and tolerant plant species, even invasive in some areas of the world, such as N-America (Chambers *et al*., 1999; Saltonstall, 2002; Kettenring *et al*., 2011), and occasionally also in its native range (Foggi *et al*., 2011), *P. australis* displays evident signs of suffering and decline in particular environmental conditions, bringing to wide-scale disappearance of palustrine ecosystems. Several hypotheses have been formulated, from chemical traits of the sediments to eutrophication, artificially stabilized water table, litter accumulation, parasitic attacks, mechanical damage, grazing and many others (*e.g.* Boar & Crook, 1985; Weisner & Graneli, 1989; Cízková *et al*., 1996; Hellings & Gallagher, 1992; Armstrong *et al*., 1996a, 1996b; Weisner, 1996; Clevering, 1998), however the ecological reasons behind such processes of reed decline remain hard to disentangle. Emphasis has been given to the role of artificial changes in the hydrologic regime (Ostendorp, 1989; Rea, 1996) and prolonged flooding has been repeatedly related to reed die-back (Gigante *et al*., 2011, 2014; Lastrucci *et al*., 2016). Recently, a clear correlation between permanent submersion, water depth and reed die-back occurrence has been proved (Lastrucci *et al*., 2017).

In the huge literature about common reed decline, the large majority focused on the population level and only few studies took into account the floristic features of

Corresponding author: Lorenzo Lastrucci. *Department of Biology, University of Florence, Florence, Italy; e-mail: lastruccilorenzo73@gmail.com*

the reed-dominated ecosystems and the involved plant communities. Few authors investigated the effects on floristic diversity caused by the dynamic processes of reed expansion and decline (*e.g.* Lenssen *et al*., 1999; Greco & Patocchi, 2003; Mäemets & Freiberg, 2004; Van Geest *et al*., 2005), with the limit of no specific focus on die-back. In a recent paper based on a phytosociological approach, Gigante *et al*. (2013) reported about conditions of extreme floristic poverty in declining reed stands.

The present study is part of a three-years research project funded by the Italian Ministry of University and Scientific Research ("FIRB" 2013, grant number RBFR13P7PR), which took into account a wide set of morphological, ecological and physiological parameters with the aim to clarify and better understand the common reed die-back phenomenon, providing useful knowledge to be used as early warning monitoring tools. Some results of the project have already been published by Lastrucci *et al*. (2017) and Cerri *et al*. (2017a, 2017b). Here we discuss the floristic and vegetational features of the reed-dominated plant communities involved in die-back processes. Aims of the study were i) to point out the floristic differences between declining and non-declining stands based on a representative data set and ii) to give these floristic differences a phytosociological and, consequently, ecological interpretation, using species and communities as environmental indicators.

Materials and Methods

Study areas and data sampling

The vegetation of the reed-dominated stands along the shores of five freshwater ecosystems in central Italy has been sampled in September 2014. The five study areas were: the Lakes Trasimeno, Chiusi and Vico, the Fucecchio and Colfiorito Marshes (Fig. 1). All the sites are included in the Natura 2000 Network (SAC IT5210034, SPA IT5210072, SAC/SPA IT5130007, SAC/SPA IT5190009, SAC IT5210018, SPA IT5210070, SAC IT6010024, SPA IT6010057). Basic geographic, morphologic and ecological information about the sites is reported in Tab. 1.

The vegetation survey has been carried out applying the phytosociological methodology (Braun-Blanquet, 1979) in 80 plots (size: 3 m × 3 m), 18 per each wetland, located in correspondence of the sampling sites used for the study of the reed die-back symptoms in the above-mentioned "FIRB" project (for more details see Lastrucci *et al*., 2017). Each plot was characterized by flat slope. Each relevé consisted of the complete list of vascular species and the relative cover values, recorded by adopting Braun-Blaunquet's cover scale, modified in order to include the values 2m, 2a and 2b proposed by Barkman *et al*. (1964), better specifying the cover range referred to the value "2" and corresponding to ranges of: 5% with many individuals of small size (2m), 5-12,5% (2a), 12,5-25% (2b). Based on Lastrucci *et al*. (2017), declining and non-declining plots have been distinguished on the ground of several diagnostic traits, among which a key role was played by the clumping habit, *i.e.* the occurrence of an abnormal growth form caused by loss of apical dominance and development of dormant lateral buds, leading to the formation of clumps of culms (Armstrong *et al*., 1996b; Van Der Putten, 1997; Dinka & Szeglet, 2001; Gigante *et al*., 2011, 2014). This diagnostic trait was quantitatively measured by Lastrucci *et al*. (2017), and the reported values could be used to evaluate the level of decline of each plot.

Data processing

After a numerical transformation according to the conversion scale proposed by Westhoff & Van Der Maarel (1978), the 80 relevés were used to build a "species × relevés" matrix. A distance matrix was produced based on the Euclidean distance, by applying the function *vegdist* from the "vegan" package (Oksanen *et al*., 2017) in R environment (R Core Team, 2017). The distance matrix was then subjected to cluster analysis using the *hclust* function and applying the Ward method. For each resulting group, Pearson's *phi* coefficient was calculated (Chytrý *et al*., 2002) by applying the *multipatt* function from the "indicspecies" package (De Caceres & Legendre, 2009). Based on the results, the indicator species for each cluster have been pointed out. We considered a species as diagnostic of each group when $phi \geq 0.40$ and $p < 0.05$. In accordance with Illyés *et al*. (2007), we adopted as threshold value $phi = 0.40$, which results particularly suitable since it

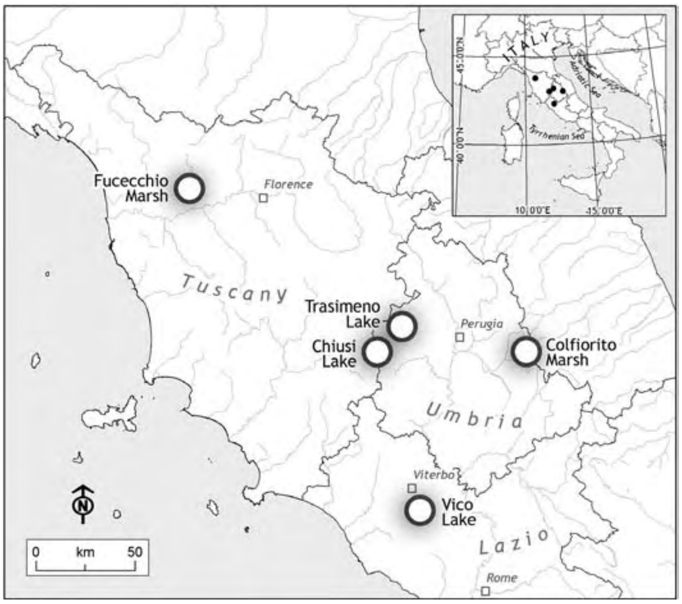

Fig. 1 - Location of the five study areas.

Tab. 1 - General information about the study sites (SAC: Natura 2000 Special Area of Conservation; SPA: Natura 2000 Special Protection Area). Maximum water depth sources are according to Lastrucci et al. (2017); geology derives from the geological map of Italy (source: http://www.pcn.minambiente.it/viewer/).

Site	Province, Region	Lat Long	Surface (ha)	Protected Areas	Altitude (m a.s.l.)	Max. water depth (m)	Bioclimate	Geology
Colfiorito Marsh (C)	Perugia, Umbria	43°01'23.00" 12°52'36'.00'	135	Wetland of International Importance (Ramsar Site); Regional Park of Colfiorito; SAC IT5210034 "Palude di Colfiorito"; SPA IT5210072 "Palude di Colfiorito"	756	1.6	Temperate Oceanic Submediterranean, lower supratemperate, lower humid	Limestone and pelagic marly limestone; Marl and marly limestone of pelagic facies; Micritic limestone and pelagic clay
Fucecchio Marsh, Le Morette (F)	Pistoia, Tuscany	43°48'30.38" 10°48'20.14"	102	Wetland of International Importance (Ramsar Site); Natural Reserve "Padule di Fucecchio" ; SAC/SPA IT5130007 "Padule di Fucecchio"	13	1.7	Temperate Oceanic Submediterranean, lower mesotemperate, upper subhumid	Debris, alluvial and fluvial-lacustrine deposits, actual beaches
Chiusi Lake (H)	Siena, Tuscany	43°03'22.11" 11°57'55.79"	360	SAC/SPA IT5190009 "Lago di Chiusi"	252	5.7	Temperate Oceanic Submediterranean, upper mesotemperate, lower subhumid [Mediterranean Pluviseasonal oceanic, upper mesomediterranean, lower subhumid]	Debris, alluvial and fluvial-lacustrine deposits, actual beaches; Sands and conglomerates
Trasimeno Lake (T)	Perugia, Umbria	43°08'05.50" 12°06'04.60"	12150	Regional Park of Lago Trasimeno; SAC IT5210018 "Lago Trasimeno"; SPA IT5210070 "Lago Trasimeno"	257	6.3	Temperate Oceanic Submediterranea,n upper mesotemperate, upper subhumid	Debris, alluvial and fluvial-lacustrine deposits, actual beaches; Debris, alluvial terraces, fluvial-lacustrine and fluvial-glacial deposits; Lacustrine and fluvial-lacustrine deposits; Sandstone and arenaceous-marly turbiditic units; Clay and clay-calcareous turbiditic units
Vico Lake (V)	Viterbo, Latium	42°18'58.40" 12°10'05.89"	1209	Natural Regional Reserve "Lago di Vico"; SAC IT6010024 "Lago di Vico"; SPA IT6010057 "Lago di Vico-Monte Fogliano e Monte Venere"	507	50	Mediterranean Pluviseasonal oceanic, upper mesomediterranean / lower supramediterranean, lower Subhumid [Temperate Oceanic Submediterranean, lower supratemperate / upper mesotemperate, upper Subhumid]	Debris, alluvial and fluvial-lacustrine deposits, actual beaches; Latites, trachytes, phonolites (lavas, ignimbrites, pyroclastic deposits); Phoidites, tephrites (lavas, pyroclastic deposits and ignimbrites)

produces neither too long nor too short lists of diagnostic species for each vegetation unit. The number of relevés of each cluster was virtually standardised to an equal size (Tichý & Chytrý, 2006) in order to eliminate dependency of the *phi* coefficient for presence/absence data on the relative size of groups within the data set.

A principal component analysis (PCA) was carried out in order to explore the groups with reference to three quantitative ecological variables: 1) average water depth, measured for each relevé at the moment of the sampling, that coincides both with the end of the vegetative season and the end of the dry period, 2) number of species per relevé, and 3) clumping rate per relevé, measured in a 1 m ×1 m located at the centre of the relevé plot. The values of the clumping rate, intended as the ratio between the number of stems in each clump and the total number of stems per square meter, were derived from Lastrucci *et al*. (2017) and refer to the same plots where the phytosociological relevés have been performed. This parameter has been proved to be a robust proxy to detect and quantify the occurrence of die-back, with a diagnostic role (Lastrucci *et al*., 2017). Finally, the geographical location was considered as an additional qualitative parameter. The PCA analysis was performed by using the *PCAmix* function from the package "PCAmixdata" (Chavent *et al*., 2014).

The species nomenclature is updated according to the most recent reviews and matches with the database *AnArchive* (Lucarini *et al*., 2015). For the syntaxonomic framing, we followed the standards proposed by Biondi & Blasi (2013) and Biondi *et al*. (2014).

Results

The cluster analysis allowed to point out six main clusters, the second of which has been further subdivided in three groups due to prominent floristic differences which, being the relevés extremely species-poor, could not be detected by the indicator species analysis. The resulting dendrogram is reported in Fig. 2 and the indicator species per group are listed in Tab. 2. The phytosociological tables of the single groups are reported in the Tabs. 3-8, while a synoptic table is showed in Tab. 9. Based on their floristic, physiognomical and structural traits, all the groups have been referred to the association *Phragmitetum australis* Savič 1926. The different groups show clear differences which are hereafter described.

The results of the PCA analysis are illustrated in Fig. 3. The role of the three quantitative ecological variables is evident in the vectorial space with the relevés (Fig. 3c). The number of species ("num_spe") positively effects on the Groups V, VI and VIII, while the water depth ("wat_dep") and the clumping rate ("clu_rat") strongly influence the distribution of the Groups I, IV and VII (Figs. 3c, 3d). The Groups II and III ap-

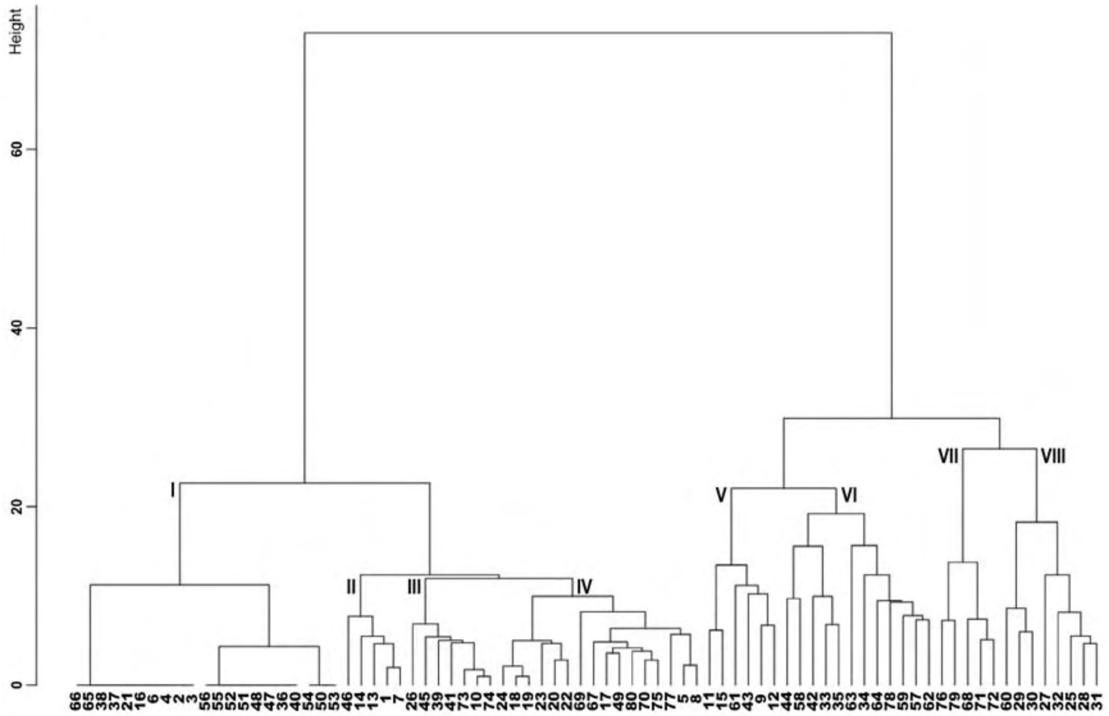

Fig. 2 - Dendrogram of the 80 relevés (*hclust* function, Ward method); the eight groups are indicated with roman numerals.

pear rather not related to those parameters.

In Fig. 4, the correlation between the average number of species per relevé in the eight groups and the average clumping rate per group (accounting for the level of die-back) is indicated, showing a robust inversed relation between the two variables (Spearman's R: -0.952, $p<0.001$).

Group I: *PHRAGMITETUM AUSTRALIS* "*nudum*"

The Group I (Tab. 3) includes relevés from all the five study sites. It groups together all the plots referring to monospecific stands, where *P. australis* is the only plant species in the community, with changeable cover values ranging from 3 to 5. Due to the extreme floristic poverty, a floristic-based classification was not possible. From the phytosociological and ecological point of view, the only feasible classification had to be grounded on the dominant role performed by *P. australis*, allowing the framing of these amphibian stands in the alliance *Phragmition communis* Koch 1926. The sampled plant communities should be considered as a basal phytocoenon, or as an extremely impoverished aspect of the association *Phragmitetum australis* Savič 1926, already typically species-poor (Landucci *et al.*, 2013). These monospecific stands are well known in literature and sometimes referred to as *Phragmitetum* "*nudum*", *e.g.* by Burian & Sieghardt (1979) and Sieghardt (1990). As pointed out by the PCA results (Fig. 3), this group is composed almost exclusively by permanently submerged stands. It includes the plots where the water depth at the end of the dry period is

Tab. 2 - Indicator species for the clusters of relevés produced by the dendrogram, and related phi coefficients with statistical significance. The groups 1-3, including from monospecific to extremely species-poor relevés, do not own any indicator species.

	phi coefficient	p value	
Group 4			
Myriophyllum spicatum L.	0.587	0.005	**
Najas marina L.	0.475	0.027	*
Group 5			
Echinochloa crus-galli (L.) P. Beauv.	0.743	0.001	***
Eclipta prostrata (L.) L.	0.683	0.001	***
Persicaria lapathifolia (L.) Delarbre	0.621	0.002	**
Bidens connatus Muhl. ex Willd.	0.552	0.009	**
Amorpha fruticosa L.	0.521	0.006	**
Xanthium orientale L. subsp. *italicum* (Moretti) Greuter	0.511	0.007	**
Group 6			
Urtica dioica L.	0.810	0.001	***
Galium aparine L.	0.620	0.001	***
Eupatorium cannabinum L.	0.552	0.001	***
Scutellaria galericulata L.	0.475	0.030	*
Limniris pseudacorus (L) Fuss	0.425	0.048	*
Group 7			
Schoenoplectus lacustris (L.) Palla	0.777	0.001	***
Nymphaea alba L.	0.607	0.007	**
Phalaris arundinacea L.	0.497	0.019	*
Group 8			
Juncus effusus L.	0.927	0.001	***
Galium palustre L.	0.683	0.001	***
Persicaria hydropiper (L.) Delarbre	0.587	0.003	**
Lycopus europaeus L.	0.573	0.003	**
Ranunculus repens L.	0.517	0.018	*

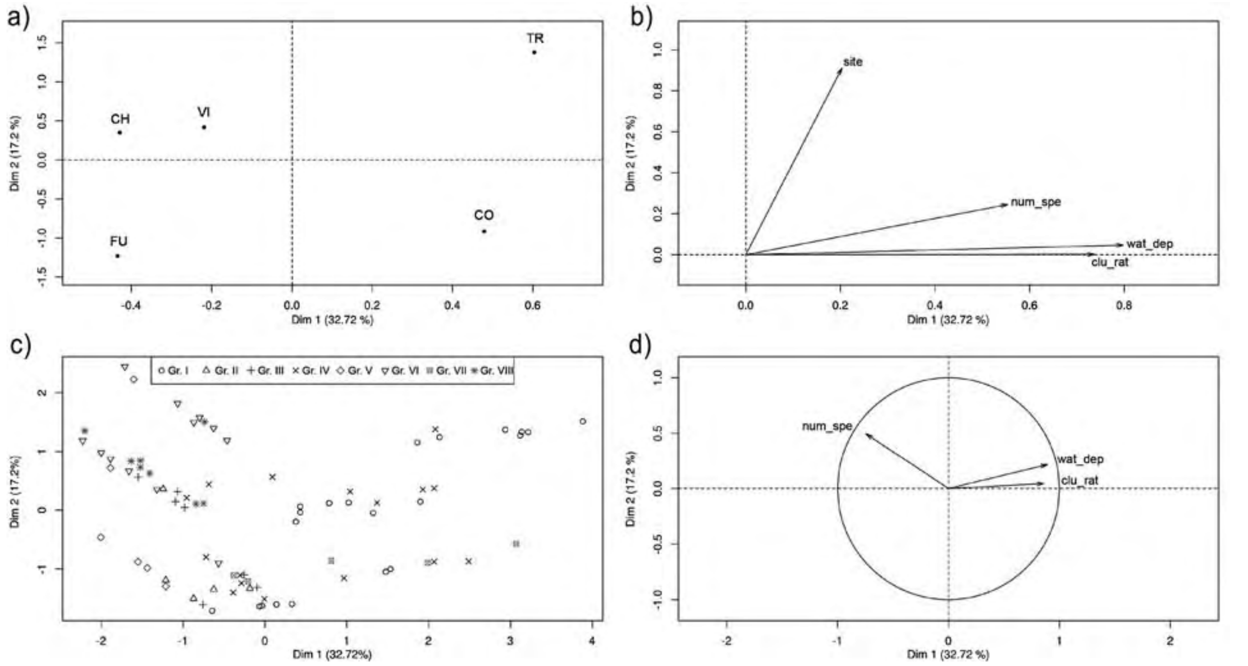

Fig. 3 - Results of the PCA analysis: a) levels component map; b) squared loadings; c) scattergram; d) correlation circle. CH = Lake Chiusi, CO = Colfiorito Marsh, FU = Fucecchio Marsh, TR = Lake Trasimeno, VI = Lake Vico; num_spe = number of species per relevé, wat_dep = water depth at the end of the dry season, clu_rat = clumping rate; the latter, expressed as ratio between the number of stems participating in clumps and the total number of stems per square meter, derives from Lastrucci *et al*. (2017).

the highest, with average values around 59.9 cm ± 8.9 (SE). The vector representing the clumping habit (Fig. 3), has also a prominent role for these relevés and indicates the occurrence of a condition of evident decline.

Group II: *PHRAGMITETUM AUSTRALIS* - species-poor variant with *Lythrum salicaria*

The Group II (Tab. 4) includes a small cluster of relevés, almost all carried out in Fucecchio Marsh, rather poor and including only 5 species per relevé on average ± 0.8 (SE). Besides *P. australis*, the only *taxon* in common is *Lythrum salicaria*, a frequent occurrence in the palustrine vegetation belonging to the class *Phragmito-Magnocaricetea*. Since this species was observed in several stands in all the study areas, it cannot be considered as an indicator species for Group II but only as a differential *taxon*, with respect to the other species-poor groups (Groups I, III and IV). The reed stands included in the Group II grow in areas where in summer the bottom sediment generally emerges, due to the lowering of the water depth (average values around 6.9 cm ± 5.5). The condition of decline is scarce or absent. From the phytosociological point of view, these plant communities are characterized by a co-occurrence of hygrophilous and nitrophilous *taxa* and represent a transition stage between typical and sub-nitrophilous reed beds. A certain level of disturbance is indicated by the presence of the alien *Cyperus odoratus*.

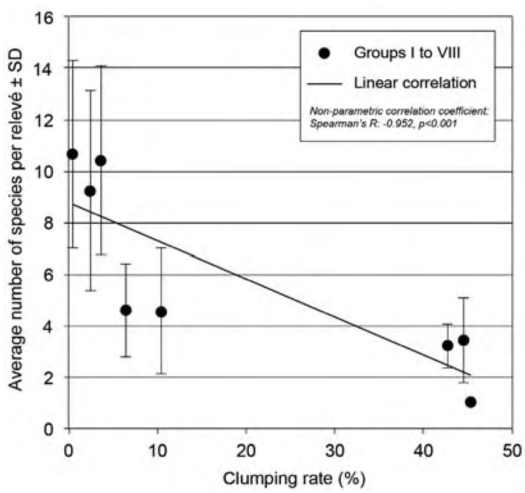

Fig. 4 - Correlation between average number of species per relevé in the eight groups vs. average clumping rate per group; for the latter parameter, values derive from Lastrucci *et al*. (2017).

Group III: *PHRAGMITETUM AUSTRALIS* - species-poor variant with *Calystegia sepium*

The Group III (Tab. 4) also puts together relevés very poor in species (5 on average ± 0.9), carried out in several study sites. It includes only reed beds in healthy status, without any sign of die-back, colonizing backward sites completely emerging in summer (average values of the water depth = 0.0 cm ± 0.0). Several hygrophilous species are present, although sporadically, such as *Mentha aquatica*, *Limniris pseudacorus*, *Lycopus europaeus*, *Carex riparia*. The only constant presence, although not suitable as an indicator species being also present in other groups, is *Calystegia sepium*,

Tab. 3 - Group I: *Phragmitetum australis* Savič 1926 “*nudum*”.

Rel. N.	66	65	38	37	21	16	6	4	2	3	56	55	52	51	48	47	36	40	54	50	53	
Plot ID	14ECo02	14ECo01	14ECh06	14ECh05	14EVi05	14EFu16	14EFu06	14EFu04	14EFu02	14EFu03	14ETr08	14ETr07	14ETr04	14ETr03	14ECh16	14ECh15	14ECh04	14ECh07	14ETr06	14ETr02	14ETr05	
Group N.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Water depth (cm)	70.7	61.0	59.3	58.0	53.3	0.0	9.3	7.7	12.0	10.3	114.7	101.0	103.0	89.3	18.7	53.3	63.7	59.9	98.7	82.7	131.7	
Clumping rate (%)	24.2	30.5	5.2	6.5	24.3	0.0	27.6	27.3	35.4	48.7	59.8	90.4	83.6	96.4	100.0	100.0	36.6	0.0	27.3	27.0	100.0	
Number of species per relevé	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Presences
Dominant species																						
Phragmites australis (Cav.) Steud.	5	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	3	3	3	21

Tab. 4 - Group II: *Phragmitetum australis* Savič 1926, species-poor variant with *Lythrum salicaria*. Group III: *Phragmitetum australis* Savič 1926, species-poor variant with *Calystegia sepium*. Group IV: *Phragmitetum australis* Savič 1926, aquatic variant with *Myriophyllum spicatum*.

Rel. N.	46	14	13	1	7	26	45	39	41	73	10	74	24	18	19	23	20	22	69	67	17	49	80	70	75	77	5	8	
Plot ID	14ECh14	14EFu14	14EFu13	14EFu01	14EFu07	14EVi10	14ECh13	14ECh08	14ECh09	14ECo09	14EFu10	14ECo10	14EVi08	14EVi02	14EVi03	14EVi07	14EVi04	14EVi06	14ECo05	14ECo03	14EVi01	14ETr01	14ECo16	14ECo06	14ECo11	14ECo13	14EFu05	14EFu08	
Group N.	2	2	2	2	2	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
Water depth (cm)	0.0	0.0	0.0	28.3	6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	68.7	65.0	22.3	20.0	38.7	19.3	40.0	62.3	79.0	0.0	59.7	0.0	0.0	15.3	9.7	
Clumping rate (%)	3.6	0.0	0.0	13.1	15.4	0.0	0.0	61.7	0.0	7.8	0.0	3.4	0.0	31.1	97.0	0.8	100.0	31.3	48.4	100.0	91.2	57.7	4.7	100.0	0.0	0.0	13.8	35.8	
Number of species per relevé	7	6	3	3	4	6	9	4	5	4	2	2	5	2	2	6	3	6	2	3	2	3	4	2	3	7	3	2	Presences
Dominant species																													
Phragmites australis (Cav.) Steud.	5	5	5	5	5	5	5	5	5	5	5	5	4	4	5	5	5	5	3	3	5	4	5	3	5	5	5	5	28
Differential species Group II																													
Lythrum salicaria L.	1	+	1	+	+	.	r	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7
Differential species Group III																													
Calystegia sepium (L.) R. Br.	.	.	.	.	.	+	+	+	1	+	+	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7
Indicator and differential (d) species Group IV																													
Myriophyllum spicatum L.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	1	+	.	.	.	.	.	.	.	.	.	.	6
Persicaria amphibia (L.) Delarbre (d)	1	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	+	1	5
Najas marina L.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	+	.	r	.	.	.	+	.	.	.	.	.	.	4
Potamogeton lucens L. (d)	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	+	.	r	.	.	.	.	.	.	.	.	.	.	3
Ceratophyllum demersum L. (d)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	+	.	.	.	.	.	.	3
Ricciocarpos natans (L.) Corda (d)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2b	.	.	.	.	+	+	.	.	.	3
Potamogeton nodosus Poir. (d)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1	.	.	.	.	.	.	.	.	.	.	2
Phragmito-Magnocaricetea																													
Mentha aquatica L.	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	+	.	.	4
Schoenoplectus lacustris (L.) Palla	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	+	.	.	.	3
Limniris pseudacorus (L.) Fuss	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
Lycopus europaeus L.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	2
Galio-Urticetea																													
Barbarea vulgaris W.T. Aiton	+	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
Bidentetea tripartitae																													
Cyperus odoratus L.	.	1	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3
Other species																													
Solanum dulcamara L.	.	.	.	.	.	1	r	.	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	4
Amorpha fruticosa L.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	2
Sporadic species	1	3	0	0	0	1	4	1	2	1	0	0	1	0	0	0	0	0	0	0	1	0	2	0	0	3	0	0	

which has an important ecological role indicating a slight nitrophilous character for this plant community. From the phytosociological point of view, this vegetation type can be interpreted as a typical aspect of the association *Phragmitetum australis*, where *Calystegia sepium* is generally frequent (Landucci *et al*., 2013).

Group IV: *PHRAGMITETUM AUSTRALIS* - aquatic variant with *Myriophyllum spicatum*

The Group IV (Tab. 4) includes 16 relevés from the Lakes Vico and Trasimeno and Fucecchio Marsh. It refers to reed beds with a prolonged submersion, with average values of the water depth at the end of the dry season around 33.3 cm ± 7.1. The sampled stands are generally species-poor (3 species per relevé on average ± 0.4), however the analysis of the Pearson’s *phi* coefficient points out two indicator species: *Myriophyllum spicatum* and *Najas marina* (Tab. 2). Besides these two taxa, a relevant number of other hydrophytes can be sporadically found in the relevés of Group IV, such as *Persicaria amphibia*, *Potamogeton lucens*, *P. perfoliatus*, *P. nodosus*, *Ceratophyllum demersum*, *Najas minor* and the aquatic bryophyte *Ricciocarpos natans* (Tab. 4). Their presence is a clear indication of the prolonged condition of submersion for this vegetation type. Few other hygrophilous species are sporadically present, such as *Mentha aquatica* and *Schoenoplectus lacustris*. The reed population generally shows clear symptoms of decline, the more prominent as the longer is the submersion period. From the phytosociological point of view, they can be considered as a variant of the association *Phragmitetum australis*, representing the contact with the aquatic communities of the classes *Potametea* and *Lemnetea*.

Group V: *PHRAGMITETUM AUSTRALIS* - hygro-subnitrophilous variant with *Echinochloa crus-galli*

The Group V (Tab. 5) is composed by relevés rather rich in species (11 on average ± 1.5). As pointed out by the analysis of Pearson's *phi* coefficent, especially the annual hygro-subnitrophilous species are diagnostic for this cluster, *e.g. Echinochloa crus-galli* and *Persicaria lapathifolia*, together with several alien *taxa* such as *Xanthium orientale* subsp. *italicum*, *Bidens connatus*, *Eclipta prostrata* and the perennial *Amorpha fruticosa*. *Calystegia sepium* is also very frequent and performs a differential role, although it cannot be considered a diagnostic species, being present also in other groups (*e.g.* Groups III, VI, VIII). The relevés of the Group 5 refer to healthy stands, not showing any symptom of die-back. They have been performed along the shores of Fucecchio Marsh, Lake Chiusi and Lake Trasimeno, in stands flooded only temporarily, which in summer appear totally emerged (average values of the water depth = 0.0 cm ± 0.0). The reed individuals do not show any sign of decline. The annual hygro-nitrophilous component of the vegetation in the floristic spectrum is typical of the amphibian environments affected at the end of summer by natural disturbance, due to the accumulation of sediment and vegetal rests, with a consequent increase of nutrients. From the phytosociological point of view this community represents the contact with the annual pioneer hygro-subnitrophilous vegetation of the class *Bidentetea* and can be considered as a variant of the association *Phragmitetum australis*.

Tab. 5 - Group V: *Phragmitetum australis* Savič 1926, hygro-subnitrophilous variant with *Echinochloa crus-galli*.

Rel. N.	11	15	61	43	9	12	
Plot ID	14EFu11	14EFu15	14ETr13	14ECh11	14EFu09	14EFu12	
Group N.	5	5	5	5	5	5	Presences
Water depth (cm)	0.0	0.0	0.0	0.0	0.0	0.0	
Clumping rate (%)	0.0	0.0	3.3	0.0	0.0	0.0	
Number of species per relevé	13	6	16	12	8	9	
Dominant species							
Phragmites australis (Cav.) Steud.	5	5	5	5	5	5	6
Indicator and differential (d) species Group V							
Calystegia sepium (L.) R. Br. (d)	1	.	1	1	1	1	5
Echinochloa crus-galli (L.) P. Beauv.	1	1	+	.	1	.	4
Xanthium orientale L. subsp. italicum (Moretti) Greuter	1	+	.	.	+	.	3
Persicaria lapathifolia (L.) Delarbre	1	+	.	.	.	+	3
Eclipta prostrata (L.) L.	+	.	.	.	1	+	3
Amorpha fruticosa L.	+	.	.	.	1	+	3
Bidens connatus Muhl. ex Willd.	1	.	.	.	.	+	2
Phragmito-Magnocaricetea							
Lythrum salicaria L.	3	3	+	r	.	1	5
Oenanthe aquatica (L.) Poir.	+	.	.	.	.	1	2
Bidentetea tripartitae							
Bidens frondosus L.	.	.	.	+	+	+	3
Cyperus odoratus L.	r	.	.	.	+	.	2
Potametea pectinati							
Persicaria amphibia (L.) Delarbre	1	+	.	.	.	.	2
Sporadic species	1	0	12	8	0	0	

Group VI: *PHRAGMITETUM AUSTRALIS* - nitrophilous variant with *Urtica dioica*

The Group VI (Tab. 6) mainly refers to the Lakes Chiusi and Trasimeno. The stands are very rich in species (10 per relevé on average ± 1.1). The Pearson's *phi* coefficent points out a statistically significant presence of five species: two perennial nitrophilous (*Urtica dioica*, *Galium aparine*), one hygro-subnitrophilous (*Eupatorium cannabinum*) and two hygrophilous *taxa* typical from palustrine vegetation (*Limniris pseudacorus*, *Scutellaria galericulata*). Also in this case, like for the Groups III and V, the environmental conditions are featured by a period of emersion of the bottom sediment in summer (average values of the water depth = 0.0 cm ± 0.0) and the general status of the reeds is very good,

Tab. 6 - Group VI: *Phragmitetum australis* Savič 1926, nitrophilous variant with *Urtica dioica*.

Rel. N.	44	58	42	33	35	63	34	64	78	59	57	62	
Plot ID	14ECh12	14ETr10	14ECh10	14ECh01	14ECh03	14ETr15	14ECh02	14ETr16	14ECo14	14ETr11	14ETr09	14ETr14	
Group N.	6	6	6	6	6	6	6	6	6	6	6	6	Presences
Water depth (cm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Clumping rate (%)	0.0	5.6	0.0	0.0	0.0	10.4	0.0	8.3	2.5	5.7	3.8	7.5	
Number of species per relevé	10	9	7	13	15	18	12	12	6	9	6	8	
Dominant species													
Phragmites australis (Cav.) Steud.	4	5	5	5	5	5	5	5	5	5	5	5	12
Indicator species Group VI													
Calystegia sepium (L.) R. Br.	1	1	1	2	1	2b	3	+	.	1	+	2b	11
Urtica dioica L.	.	+	.	1	+	2a	2	2a	2a	2a	3	3	10
Limniris pseudacorus (L) Fuss	1	+	1	1	+	.	.	+	.	.	.	.	6
Galium aparine L.	.	+	.	.	.	.	.	1	+	+	.	+	5
Eupatorium cannabinum L.	.	.	.	+	1	.	1	1	.	.	.	.	4
Scutellaria galericulata L.	+	.	.	+	2	.	.	.	.	.	.	.	3
Phragmito-Magnocaricetea													
Lythrum salicaria L.	+	+	.	.	+	1	.	.	.	.	.	+	5
Mentha aquatica L.	.	.	1	2	+	r	.	.	.	.	.	.	4
Carex pseudocyperus L.	.	.	.	1	1	.	+	.	.	.	.	.	3
Galium palustre L. subsp. elongatum (C. Presl) Lange	.	.	.	+	1	.	r	.	.	.	.	.	3
Carex riparia Curtis	3	2b	.	.	.	.	.	.	.	.	.	.	2
Lycopus europaeus L.	.	.	.	+	+	.	.	.	.	.	.	.	2
Galio-Urticetea													
Stachys palustris L.	.	.	.	1	+	.	.	+	.	.	.	.	3
Cirsium creticum (Lam.) d'Urv. subsp. triumfettii (Lacaita) K. Werner	.	.	.	.	.	+	r	.	.	.	.	.	2
Agrostietea stoloniferae													
Agrostis stolonifera L.	.	2b	1	+	1	2a	.	1	.	.	2	+	8
Lycopus exaltatus Ehrh. ex L. fil.	.	.	2	.	+	.	.	.	.	.	.	.	2
Pulicaria dysenterica (L.) Bernh.	.	.	r	.	.	+	.	.	.	.	.	.	2
Other species													
Cirsium arvense (L.) Scop.	.	+	.	.	.	.	.	.	.	+	+	.	3
Rubus ulmifolius Schott	.	.	.	.	.	1	1	1	.	.	.	.	3
Salix cinerea L.	r	.	.	.	.	.	.	.	.	.	.	+	2
Elymus repens (L.) Gould	.	.	.	.	.	r	.	.	2a	.	.	.	2
Sambucus ebulus L.	.	.	.	.	.	.	1	1	.	.	.	.	2
Artemisia vulgaris L.	.	.	.	.	.	.	.	1	.	.	+	.	2
Sporadic species	3	0	0	1	1	8	3	1	2	4	0	1	

without any symptom of die-back. From the phytosociological point of view these stands are interpreted as a contact phytocoenosis with the perennial subhygro-nitrophilous vegetation of the class *Galio-Urticetea* Passarge ex Kopecký 1969, and can be considered as a variant of the association *Phragmitetum australis*. Similar plant communities dominated by common reed, developed in disturbed habitats, sometimes in contact with anthropized areas and marginal to the palustrine ecosystems, are well known from literature. They have been considered as "pseudo" reed beds (Greco & Patocchi, 2003; Gigante *et al*., 2013) and sometimes framed quite in the class *Galio-Urticetea* (Mucina *et al*., 1993; Pellizzari *et al*., 2005). In the considered areas, from a floristic point of view there is a strong affinity with the vegetation type described by Gigante *et al*. (2013) as *Phragmitetum australis* var. with *Rubus ulmifolius* Schott, although in the present study the occurrence of the latter is rather sporadic. Some relevés of this group (Tab. 6, Rels. N. 33, 34 and 35), performed at Lake Chiusi, refer to vegetation growing in contact with the association *Thelypterido palustris-Phragmitetum australis* Kuiper ex van Donselaar 1961 which represents a peculiar type of reed bed living on floating mats, as reported by Lastrucci *et al*. (2014).

Group VII: *PHRAGMITETUM AUSTRALIS* - species-poor variant with *Schoenoplectus lacustris*

The Group VII (Tab. 7) includes a heterogeneous set of relevés carried out in the reed beds of Colfiorito, some of which in permanently submerged stands and some in drier areas (average values of the water depth = 38.7 cm ± 21.8). They are extremely species-poor (3 species per relevé on average ± 0.4) and are differentiated by the presence of *Schoenoplectus lacustris*, a species widely distributed in the area in the deeper waters along the reed bed waterfront. The presence of *Nymphaea alba* is also an indication of the prolonged period of submersion. Condition of decline have been detected in the permanently submerged plots (Rels. N. 68, 71, 72). From the phytosociological point of view, they are interpreted as a transitional variant towards the association *Schoenoplectetum lacustris* Chouard 1924, observed in the site. The reed-dominated community developed on emerging sediment (Rels. N. 76, 79) shows a better health status and is differentiated also by the presence of *Phalaris arundinacea*. This species is widely represented in the surrounding areas (Pedrotti, 1982; Orsomando & Raponi, 2002) with the association *Phalaridetum arundinaceae* Libbert 1931.

Group VIII: *PHRAGMITETUM AUSTRALIS* - dry variant with *Juncus effusus*

The Group VIII (Tab. 8) refers to eight relevés mainly performed at the Lake Vico, in areas with a top soil from drenched to dry at the end of the dry season, when the surface water is completely absent (average values of the water depth = 0.0 cm ± 0.0). The reed beds in this site occupy a large muddy area in the N-W sector of the lake, extensively grazed by cattle. The general condition of the reed individuals is good, without any symptom of die-back. The relevés are rather rich in species (9 per relevé on average ± 1.4) and are differentiated by a combination of *taxa* from transition meadows (*Ranunculus repens*), grazed meadows

Tab. 7 - Group VII: *Phragmitetum australis* Savič 1926, species-poor variant with *Schoenoplectus lacustris*.

Rel. N.	76	79	68	71	72	
Plot ID	14ECo12	14ECo15	14ECo04	14ECo07	14ECo08	
Group N.	7	7	7	7	7	
Water depth (cm)	0.0	0.0	37.7	36.3	119.3	
Clumping rate (%)	3.8	0.0	34.3	100.0	75.0	
Number of species per relevé	3	4	4	3	2	Presences
Dominant species						
Phragmites australis (Cav.) Steud.	4	5	3	3	3	5
Indicator species Group VII						
Schoenoplectus lacustris (L.) Palla	.	2	+	4	3	4
Phalaris arundinacea L.	4	2	.	.	.	2
Nymphaea alba L.	.	.	2	2a	.	2
Sporadic species	1	1	1	0	0	

Tab. 8 - Group VIII: *Phragmitetum australis* Savič 1926, dry variant with *Juncus effusus*.

Rel. N.	60	29	30	27	32	25	28	31	
Plot ID	14ETr12	14EVi13	14EVi14	14EVi11	14EVi16	14EVi09	14EVi12	14EVi15	
Group N.	8	8	8	8	8	8	8	8	
Water depth (cm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Clumping rate (%)	7.7	0.0	0.0	0.0	6.9	0.0	0.0	5.6	
Number of species per relevé	9	10	11	16	11	9	4	4	Presences
Dominant species									
Phragmites australis (Cav.) Steud.	5	5	5	5	5	5	4	5	8
Indicator and differential (d) species Group VIII									
Juncus effusus L.	.	+	1	+	2b	2	3	3	7
Agrostis stolonifera L. (d)	+	+	+	1	1	+	.	.	6
Lycopus europaeus L.	.	.	+	1	+	1	.	1	5
Galium palustre L.	.	.	+	1	1	r	.	.	4
Ranunculus repens L.	1	+	+	.	.	.	.	.	3
Persicaria hydropiper (L.) Delarbre	.	+	+	1	.	.	.	.	3
Phragmito-Magnocaricetea									
Calystegia sepium (L.) R. Br.	+	.	+	1	.	+	.	.	4
Carex riparia Curtis	.	+	1	1	.	.	.	.	3
Oenanthe aquatica (L.) Poir.	.	.	.	+	+	+	.	.	3
Bidentetea tripartitae									
Bidens frondosus L.	.	.	.	+	+	+	+	.	4
Potametea pectinati , Lemnetea minoris									
Persicaria amphibia (L.) Delarbre	.	.	.	.	+	+	+	.	3
Other species									
Solanum dulcamara L.	.	+	.	2	2a	.	.	+	4
Rubus ulmifolius Schott	3	2b	1	.	.	.	.	.	3
Equisetum arvense L.	.	+	+	.	.	.	.	.	2
Sporadic species	4	1	0	5	2	0	0	0	

Tab. 9 - Synoptic Table; the indicator species of the clusters of relevés produced by the dendrogram, and some additional differential (d) species, are indicated. The sporadic species of each single group have been removed (this group, although indicated as "dry" on average, includes the floating mats).

Group N.	1	2	3	4	5	6	7	8
Number of relevés	21	5	7	16	6	12	5	8
Average water depth (cm)	59.9	6.93	0.0	33.3	0.0	0.0	38.7	0.0
Average clumping rate (%)	45.3	6.4	10.4	44.5	0.6	3.7	42.6	2.5
Average number of species per relevé	1	5	5	3	11	10	3	9
Indicator species Group 4								
Myriophyllum spicatum L.	.	.	.	II	.	.	.	.
Najas marina L.	.	.	.	II	.	.	.	.
Indicator species Group 5								
Echinochloa crus-galli (L.) P. Beauv.	.	.	.	.	IV	.	.	.
Eclipta prostrata (L.) L.	.	.	.	.	III	.	.	.
Persicaria lapathifolia (L.) Delarbre	.	.	.	.	III	.	.	.
Amorpha fruticosa L.	.	I	.	.	III	.	.	.
Xanthium orientale L. subsp. italicum (Moretti) Greuter	.	I	.	.	III	.	.	.
Bidens connatus Muhl. ex Willd.	.	.	.	.	II	.	.	.
Indicator species Group 6								
Urtica dioica L.	.	.	.	.	I	V	.	.
Galium aparine L.	.	.	.	.	.	III	.	.
Limniris pseudacorus (L) Fuss	.	I	I	.	I	III	.	.
Eupatorium cannabinum L.	.	.	.	.	.	II	.	.
Scutellaria galericulata L.	.	.	.	.	.	II	.	.
Indicator species Group 7								
Schoenoplectus lacustris (L.) Palla	.	.	.	I	.	.	IV	.
Nymphaea alba L.	.	.	.	.	.	.	II	.
Phalaris arundinacea L.	.	.	.	.	.	.	II	.
Indicator species Group 8								
Juncus effusus L.	.	.	.	.	.	.	.	V
Lycopus europaeus L.	.	.	I	.	.	I	.	IV
Galium palustre L.	.	.	.	.	.	.	.	III
Ranunculus repens L.	.	.	.	.	.	.	.	II
Persicaria hydropiper (L.) Delarbre	.	.	.	.	.	.	.	II
Phragmito-Magnocaricetea								
Phragmites australis (Cav.) Steud.	V	V	V	V	V	V	V	V
Mentha aquatica L.	.	I	I	I	I	II	I	.
Lythrum salicaria L.	.	V	II	.	V	III	.	.
Calystegia sepium (L.) R. Br.	.	.	V	.	V	V	I	III
Oenanthe aquatica (L.) Poir.	.	I	.	.	II	.	.	II
Carex riparia Curtis	.	.	I	.	.	I	.	II
Lysimachia vulgaris L.	.	I	.	.	I	.	.	.
Galium palustre L. subsp. elongatum (C. Presl) Lange	.	.	.	.	I	II	.	.
Glyceria sp.	.	.	I	.	.	.	.	.
Bolboschoenus sp.	.	.	.	.	I	.	.	.
Bolboschoenus glaucus (Lam.) S.G. Sm.	.	.	.	.	I	.	.	.
Veronica anagallis-aquatica L.	.	.	.	.	I	.	.	.
Carex pseudocyperus L.	.	.	.	.	.	II	.	.
Galio-Urticetea								
Barbarea vulgaris W.T. Aiton	.	I	I	.	.	.	.	.
Stachys palustris L.	.	.	I	.	.	II	.	.
Galega officinalis L.	.	.	I	.	.	.	.	.
Thalictrum lucidum L.	.	.	I	.	.	.	.	.
Epilobium hirsutum L.	.	.	.	.	I	.	.	.
Cirsium creticum (Lam.) d'Urv. subsp. triumfettii (Lacaita) K. Werner	.	.	.	.	.	I	.	.
Bidentetea tripartitae								
Cyperus odoratus L.	.	III	.	.	II	.	.	.
Bidens frondosus L.	.	.	.	.	III	.	.	III
Atriplex prostrata Boucher ex DC.	.	.	I	.	.	.	.	.
Bidens tripartitus L.	.	.	.	.	I	.	.	.
Lipandra polysperma (L.) S. Fuentes, Uotila et Borsch	.	.	.	.	I	.	.	.
Oxybasis urbica (L.) S. Fuentes, Uotila et Borsch	.	.	.	.	I	.	.	.
Agrostietea stoloniferae								
Agrostis stolonifera L.	.	.	.	.	.	IV	.	IV
Rumex obtusifolius L.	.	I	.	.	.	.	.	.
Pulicaria dysenterica (L.) Bernh.	.	.	.	.	.	I	.	.
Lycopus exaltatus Ehrh. ex L. fil.	.	.	.	.	.	I	.	.
Potametea pectinati , Lemnetea minoris								
Persicaria amphibia (L.) Delarbre	.	II	.	I	II	.	.	II
Ceratophyllum demersum L.	.	.	.	I	.	.	.	.
Potamogeton lucens L.	.	.	.	I	.	.	.	.
Potamogeton nodosus Poir.	.	.	.	I	.	.	.	.
Ricciocarpos natans (L.) Corda	.	.	.	I	.	.	.	.
Other species								
Solanum dulcamara L.	.	.	III	.	I	I	.	IIII
Rubus ulmifolius Schott	.	.	.	.	I	II	.	II
Plantago major L.	.	.	I	.	I	.	.	.
Cirsium arvense (L.) Scop.	.	.	.	.	I	II	.	.
Salix cinerea L.	.	.	.	.	I	I	.	.
Cornus sanguinea L.	.	.	I	.	.	.	.	.
Juncus conglomeratus L.	.	.	I	.	.	.	.	.
Stellaria media (L.) Vill.	.	.	.	.	I	.	.	.
Erigeron bonariensis L.	.	.	.	.	I	.	.	.
Samolus valerandi L.	.	.	.	.	I	.	.	.
Symphyotrichum squamatum (Spreng.) G.L. Nesom	.	.	.	.	I	.	.	.
Artemisia vulgaris L.	.	.	.	.	.	I	.	.
Elymus repens (L.) Gould	.	.	.	.	.	I	.	.
Salix purpurea L.	.	.	.	.	.	I	.	.
Sambucus ebulus L.	.	.	.	.	.	I	.	.
Solanum nigrum L.	.	.	.	.	.	I	.	.
Equisetum palustre L.	.	.	.	.	.	.	I	.
Equisetum arvense L.	.	.	.	.	.	.	.	II

(*Juncus effusus*), hygro-subnitrophilous (*Persicaria hydropiper* and palustrine phytocoenoses (*Lycopus europaeus*, *Galium palustre*). *Agrostis stolonifera* also plays a differential role. From the phytosociological point of view, these mixed reed beds can be considered as a transitional variant towards the meadows of the class *Molinio-Arrhenatheretea* Tüxen 1937.

Discussion and conclusive remarks

The present study provides an overview of the floristic-vegetational features of a variety of reed beds from different wetlands in central Italy, part of which have been formerly diagnosed as affected by die-back (Lastrucci *et al*., 2017). The results show that the floristic and vegetational features, neglected by the large majority of the scientific production, play a clear role in the die-back phenomenology.

Although the common reed-dominated vegetation is a typically species-poor phytocoenosis (see, *e.g.*, Philippi, 1977; Gerdol, 1987; Balátová-Tuláckova *et al*., 1993), our results show a certain differentiation among types and, on average, between healthy and declining stands. The phytosociological analysis allowed to point out eight major types, which differ between each other for species number, floristic composition and levels of nitrophily and hydrophily, as supported by the indicator species. In particular, when we compare the healthy and the declining stands, it is evident that, as already suggested by Gigante *et al*. (2013), there is a clear correlation between number of species per relevé and intensity of the reed decline expressed as clumping rate (Fig. 4), which has been proved to be a robust quantitative diagnostic symptom of die-back

(Lastrucci *et al*., 2017).

It is acknowledged that reed decline most heavily affects the reed stands growing in permanent submersion with deep water levels (Hellings & Gallagher, 1992; Weisner *et al*., 1993; Rea, 1996; Mauchamp *et al*., 2001), and that prolonged submergence is strongly related to incidence and severity of die-back (Lastrucci *et al*., 2017). Results of our study show that the permanently submerged stands are also the ones with the lowest floristic variety, with the extreme situation represented by the monospecific vegetation referred to *Phragmitetum vulgaris* "*nudum*" (Tab. 3).

It has been reported that the reed-dominated vegetation tends to be monospecific when growing in permanently flooded areas (Sieghardt, 1990; Cízková *et al*., 1996; Schmieder *et al*., 2002) and that, in general, prolonged submersion or lack of drying up can often cooccur with low values of species richness, especially with reference to macrophytes (see, *e.g.*, Van Geest *et al*., 2005). Indeed, periods of drying up are needed for seed germination and survival of several macrophytic species (Keddy & Constabel, 1986; Coops & Van Der Velde, 1995; Bonis & Grillas, 2002). Additionally, the litter generated by *Phragmites australis*, slowly decomposing especially in submerged conditions, can inhibit the growth of wetland species (Van Der Putten, 1993; Van Der Putten *et al*., 1997).

On the other side, studies on the reed productivity reported that the highest aboveground dry matter production of *Phragmites australis* could be found in the landward zone (Sieghardt, 1990). These results match with the observed preferential occurrence of non-declining stands in drier locations, only temporarily submerged, generally on the land-facing border of the reed beds, often in contact with agricultural areas, as reported both in the present study and in former investigations (*e.g.* Gigante *et al*., 2014; Lastrucci *et al*., 2016).

The stands where reed does not show symptoms of decline, developing in terrestrial areas, are also the richest in species. It has been indicated in literature that recurring periods of low water level tend to increase plant biodiversity (Riis & Hawes, 2002). However, as already noticed by Gigante *et al*. (2013), this floristic richness is often due to the increase of nitrophilous species, favoured by the terrestrial environment and by the nutrient income from the agricultural areas in the surroundings.

Overall it can be stated that, in the study sites, only the pauci-specific stands including hygrophilous *taxa* (Groups II and III) seem to better correspond to typical, wet reed beds where reeds grow healthily and the floristic spectrum includes typical wetland species. It should be emphasized that the aquatic stands of reed often represent a refugium for little floating or rooted aquatic *taxa* (see *e.g.* Group IV) and their disruption and retreat implies the disappearance of suitable micro-habitats for these vulnerable species.

Studies on patterns and processes of common reed die-back appear extremely important for conservation purposes. This phenomenon affects not only the reed populations themselves, but also general aspects of wetland ecosystems, due to the key role played by *Phragmites australis* in providing habitat for other flora and fauna elements, filtering a wide range of pollutants, maintaining shore stability, only to mention some of the most prominent ecosystem services provided by this very common species (Ostendorp, 1993; Kiviat, 2013). Additionally, reed decline might also have social and economic impacts, given the importance of reed beds for eco-tourism and for several traditional human activities (Kiviat, 2013). For these reasons a deeper understanding of the phenomenon of reed decline is more and more urgent.

Syntaxonomic scheme

PHRAGMITO-MAGNOCARICETEA Klika in Klika & Novák 1941
PHRAGMITETALIA Koch 1926
Phragmition communis Koch 1926
Phragmitetum australis Savič 1926
"*nudum*"
var. with *Lythrum salicaria*
var. with *Calystegia sepium*
var. with *Myriophyllum spicatum*
var. with *Echinochloa crus-galli*
var. with *Urtica dioica*
var. with *Schoenoplectus lacustris*
var. with *Juncus effusus*

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Appendix I: Localities, dates and sporadic species of the relevés.

[the sequence is as follows: Relevé Number, Plot ID, locality, date (gg/mm/aaaa), Lat/Long (degrees, minutes), sporadic species with cover values].

Tab. 3 - Group I: *Phragmitetum australis* Savič 1926 "*nudum*": Rel. 66, 14ECo02, Colfiorito Marsh, 29/09/2014, N43°1.51' E12°52.532; Rel. 65, 14ECo01, Colfiorito Marsh, 29/09/2014, N43°1.598' E12°52.575; Rel. 38, 14ECh06, Lake Chiusi, 15/09/2014, N43°3.401' E11°58.67; Rel. 37, 14ECh05, Lake Chiusi, 15/09/2014, N43°3.341' E11°58.659; Rel. 21, 14EVi05, Lake Vico, 09/09/2014, N42°19.923' E12°9.275; Rel. 16, 14EFu16, Fucecchio Marsh, 03/09/2014, N43°48.74' E10°48.49; Rel. 6, 14EFu06, Fucecchio Marsh, 03/09/2014, N43°48.308' E10°48.254; Rel. 4, 14EFu04, Fucecchio Marsh, 03/09/2014, N43°48.247' E10°48.072; Rel. 2, 14EFu02, Fucecchio Marsh, 03/09/2014, N43°48.346' E10°48.372; Rel. 3, 14EFu03, Fucecchio Marsh, 03/09/2014, N43°48.279' E10°48.175; Rel. 56, 14ETr08, Lake Trasimeno, 26/09/2014, N43°6.223' E12°11.066; Rel. 55, 14ETr07, Lake Trasimeno, 26/09/2014, N43°6.019' E12°11.178; Rel. 52, 14ETr04, Lake Trasimeno, 26/09/2014, N43°6.04' E12°11.196; Rel. 51, 14ETr03, Lake Trasimeno, 26/09/2014, N43°6.169' E12°11.171; Rel. 48, 14ECh16, Lake Chiusi, 19/09/2014, N43°2.645' E11°58.477; Rel. 47, 14ECh15, Lake Chiusi, 19/09/2014, N43°2.613' E11°58.341; Rel. 36, 14ECh04, Lake Chiusi, 15/09/2014, N43°3.207' E11°58.634; Rel. 40, 14ECh07, Lake Chiusi, 19/09/2014, N43°2.717' E11°58.472; Rel. 54, 14ETr06, Lake Trasimeno, 26/09/2014, N43°5.842' E12°11.169; Rel. 50, 14ETr02, Lake Trasimeno, 25/09/2014, N43°5.691' E12°11.087; Rel. 53, 14ETr05, Lake Trasimeno, 26/09/2014, N43°5.791' E12°11.049.

Tab. 4 - Group II: *Phragmitetum australis* Savič 1926, species-poor variant with *Lythrum salicaria*: Rel. 46, 14ECh14, Lake Chiusi, 15/09/2014, N43°3.159' E11°57.012, Lysimachia vulgaris L. 1; Rel. 14, 14EFu14, Fucecchio Marsh, 03/09/2014, N43°48.751' E10°48.522, Oenanthe aquatica (L.) Poir. +, Xanthium orientale L. subsp. italicum (Moretti) Greuter 1, Rumex obtusifolius L. +; Rel. 13, 14EFu13, Fucecchio Marsh, 03/09/2014, N43°48.764' E10°48.565; Rel. 1, 14EFu01, Fucecchio Marsh, 03/09/2014, N43°48.39' E10°48.501; Rel. 7, 14EFu07, Fucecchio Marsh, 03/09/2014, N43°48.374' E10°48.435; Group III: *Phragmitetum australis* Savič 1926, species-poor variant with Calystegia sepium: Rel. 26, 14EVi10, Lake Vico, 09/09/2014, N42°19.981' E12°9.225, Juncus conglomeratus L. 1; Rel. 45, 14ECh13, Lake Chiusi, 15/09/2014, N43°3.545' E11°57.104, Stachys palustris L. +, Galega officinalis L. +, Thalictrum lucidum L. r, Plantago major L. r; Rel. 39, 14ECh08, Lake Chiusi, 15/09/2014, N43°4.012' E11°57.717, Carex riparia Curtis 1; Rel. 41, 14ECh09, Lake Chiusi, 15/09/2014, N43°4.049' E11°57.392, Atriplex prostrata Boucher ex

DC. +, Cornus sanguinea L. +; Rel. 73, 14ECo09, Colfiorito Marsh, 29/09/2014, N43°1.563' E12°52.749, Glyceria sp. r; Rel. 10, 14EFu10, Fucecchio Marsh, 03/09/2014, N43°48.689' E10°48.703; Rel. 74, 14ECo10, Colfiorito Marsh, 29/09/2014, N43°1.221' E12°52.732; Group IV: *Phragmitetum australis* Savič 1926, aquatic variant with Myriophyllum spicatum: Rel. 24, 14EVi08, Lake Vico, 09/09/2014, N42°18.11' E12°10.663, Potamogeton perfoliatus L. r; Rel. 18, 14EVi02, Lake Vico, 09/09/2014, N42°19.218' E12°11.643; Rel. 19, 14EVi03, Lake Vico, 09/09/2014, N42°19.295' E12°11.688; Rel. 23, 14EVi07, Lake Vico, 09/09/2014, N42°20.194' E12°10.084; Rel. 20, 14EVi04, Lake Vico, 09/09/2014, N42°19.473' E12°11.815; Rel. 22, 14EVi06, Lake Vico, 09/09/2014, N42°20.37' E12°9.498; Rel. 69, 14ECo05, Colfiorito Marsh, 30/09/2014, N43°1.364' E12°52.155; Rel. 67, 14ECo03, Colfiorito Marsh, 29/09/2014, N43°1.696' E12°52.58; Rel. 17, 14EVi01, Lake Vico, 09/09/2014, N42°19.149' E12°11.737, Najas minor All. +; Rel. 49, 14ETr01, Lake Trasimeno, 25/09/2014, N43°5.502' E12°10.676; Rel. 80, 14ECo16, Colfiorito Marsh, 29/09/2014, N43°1.674' E12°52.416, Phalaris arundinacea L. r, Sorghum sp. +; Rel. 70, 14ECo06, Colfiorito Marsh, 30/09/2014, N43°1.398' E12°52.165; Rel. 75, 14ECo11, Colfiorito Marsh, 29/0/92014, N43°1.417' E12°52.162; Rel. 77, 14ECo13, Colfiorito Marsh, 29/09/2014, N43°1.152' E12°52.437, Agrostis stolonifera L. r, Equisetum palustre L. r, Poa trivialis L. 1; Rel. 5, 14EFu05, Fucecchio Marsh, 03/09/2014, N43°48.234' E10°48.041; Rel. 8, 14EFu08, Fucecchio Marsh, 03/09/2014, N43°48.439' E10°48.629.

Tab. 5 - Group V: *Phragmitetum australis* Savič 1926, hygro-subnitrophilous variant with *Echinochloa crus-galli*: Rel. 11, 14EFu11, Fucecchio Marsh, 03/09/2014, N43°48.758' E10°48.658, Lipandra polysperma (L.) S. Fuentes, Uotila et Borsch +; Rel. 15, 14EFu15, Fucecchio Marsh, 03/09/2014, N43°48.721' E10°48.483; Rel. 61, 14ETr13, Lake Trasimeno, 25/09/2014, N43°11.425' E12°6.68, Bolboschoenus sp. +, Mentha aquatica L. +, Veronica anagallis-aquatica L. r, Bidens tripartitus L. 1, Oxybasis urbica (L.) S. Fuentes, Uotila et Borsch +, *Urtica dioica* L. 1, Epilobium hirsutum L. +, Erigeron bonariensis L. +, Plantago major L. r, Rubus ulmifolius Schott 1, Samolus valerandi L. +, Symphyotrichum squamatum (Spreng.) G.L. Nesom 1; Rel. 43, 14ECh11, Lake Chiusi, 15/09/2014, N43°3.402' E11°58.738, Bolboschoenus glaucus (Lam.) S.G. Sm. 2, Galium palustre L. subsp. elongatum (C. Presl) Lange 1, Lysimachia vulgaris L. +, Limniris pseudacorus (L) Fuss +, Cirsium arvense (L.) Scop. +, Salix cinerea L. +, Solanum dulcamara L. +, Stellaria media (L.) Vill. r; Rel. 9, 14EFu09, Fucecchio Marsh, 03/09/2014, N43°48.701' E10°48.718; Rel. 12, 14EFu12, Fucecchio Marsh, 03/09/2014, N43°48.778' E10°48.627.

Tab. 6 - Group VI: *Phragmitetum australis* Savič 1926, nitrophilous variant with *Urtica dioica*: Rel. 44, 14ECh12, Lake Chiusi, 15/09/2014, N43°3.289' E11°56.803, Lysimachia vulgaris L. 1, Populus nigra L. 2, Salix purpurea L. +; Rel. 58, 14ETr10, Lake Trasimeno, 25/09/2014, N43°5.377' E12°4.909; Rel. 42, 14ECh10, Lake Chiusi, 15/09/2014, N43°3.891' E11°57.968; Rel. 33, 14ECh01, Lake Chiusi, 15/09/2014, N43°3.241' E11°57.031, Teucrium scordium L. 1; Rel. 35, 14ECh03, Lake Chiusi, 15/09/2014, N43°3.401' E11°57.022, Bidens frondosus L. r; Rel. 63, 14ETr15, Lake Trasimeno, 25/09/2014, N43°5.453' E12°4.729, Phalaris arundinacea L. +, Galega officinalis L. 2b, Xanthium orientale L. subsp. italicum (Moretti) Greuter 1, Atriplex cfr. patula L. +, Bidens tripartitus L. +, Ranunculus repens L. 2a, *Echinochloa crus-galli* (L.) P. Beauv. +, Solanum nigrum L. r; Rel. 34, 14ECh02, Lake Chiusi, 15/09/2014, N43°3.33' E11°56.97, Thelypteris palustris Schott 2, Scrophularia auriculata L. +, Persicaria lapathifolia (L.) Delarbre +; Rel. 64, 14ETr16, Lake Trasimeno, 25/09/2014, N43°5.898' E12°3.931, Cyperus longus L. +; Rel. 78, 14ECo14, Colfiorito Marsh, 29/09/2014, N43°1.086' E12°52.61, Daucus carota L. r, Equisetum arvense L. +; Rel. 59, 14ETr11, Lake Trasimeno, 25/09/2014, N43°4.934' E12°6.147, Brachypodium rupestre (Host) Roem. et Schult. 1, Brachypodium sylvaticum (Huds.) P. Beauv. +, Convolvulus arvensis L. +, Solanum dulcamara L. +; Rel. 57, 14ETr09, Lake Trasimeno, 25/09/2014, N43°5.865' E12°4.038; Rel. 62, 14ETr14, Lake Trasimeno, 25/09/2014, N43°4.906' E12°6.192, Artemisia verlotiorum Lamotte 1.

Tab. 7 - Group VII: *Phragmitetum australis* Savič 1926, species-poor variant with *Schoenoplectus lacustris*: Rel. 76, 14ECo12, Colfiorito Marsh, 29/09/2014, N43°1.127' E12°52.365, Equisetum palustre L. 1; Rel. 79, 14ECo15, Colfiorito Marsh, 29/09/2014, N43°1.72' E12°52.625, Calystegia sepium (L.) R. Br. 1; Rel. 68, 14ECo04, Colfiorito Marsh, 29/09/2014, N43°1.654' E12°52.637, Mentha aquatica L. +; Rel. 71, 14ECo07, Colfiorito Marsh, 30/09/2014, N43°1.658' E12°52.635; Rel. 72, 14ECo08, Colfiorito Marsh, 30/09/2014, N43°1.632' E12°52.398;

Tab. 8 - Group VIII: *Phragmitetum australis* Savič 1926, dry variant with *Juncus effusus*: Rel. 60, 14ETr12, Lake Trasimeno, 25/09/2014, N43°11.466' E12°6.498, Cyperus longus L. +, Lemna minuta Kunth 1, Pulicaria dysenterica (L.) Bernh. +, Epilobium hirsutum L. +; Rel. 29, 14EVi13, Lake Vico, 09/09/2014, N42°20.395' E12°8.965, Stachys palustris L. 1; Rel. 30, 14EVi14, Lake Vico, 09/09/2014, N42°20.375' E12°8.993; Rel. 27, 14EVi11, Lake Vico, 09/09/2014, N42°20.022' E12°9.136, Mentha aquatica L. 1, Bidens tripartitus L. r, Juncus bufonius L. +, Ranunculus cfr. sardous Crantz +, Stellaria media (L.) Vill. +; Rel. 32, 14EVi16, Lake Vico, 09/09/2014, N42°20.389' E12°9.728, Alisma plantago-aquatica L. +, Carex pseudocyperus L. +; Rel. 25, 14EVi09, Lake Vico, 09/09/2014, N42°20.398' E12°9.772; Rel. 28, 14EVi12, Lake Vico, 09/09/2014, N42°19.968' E12°9.149; Rel. 31, 14EVi15, Lake Vico, 09/09/2014, N42°20.397' E12°9.693.