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The reed die-back syndrome and its implications for floristic and vegetational traits of *Phragmitetum australis*

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Abstract
Common reed [*Phragmites australis* (Cav.) Steud.] die-back is a well known phenomenon in Central Europe, recently detected also in Italy. It has been described as a complex syndrome affecting reed populations, including multiple symptoms of retreat and decline, with significant impacts on important wetland ecosystem services. The present study takes into account, for the first time, floristic and vegetational traits in a declining reed bed and tries to search for possible relations between die-back and plant community features. 45 phytosociological relevés were carried out in the years 2006, 2007 and 2009 in 19 permanent plots at Lake Trasimeno (Central Italy), where reed die-back has been detected and monitored in former studies. Relevés have been clustered into 3 groups: dying-back, suboptimal and optimal stands, on the ground of the level of decline of the corresponding reed plots. The considered traits are: number of species, total and specific cover values, diversity indexes, Ellenberg's ecologic indicator values, number of nitrophilous species. The differential species in the three groups are also pointed out. Results show that both floristic and vegetational traits in stands affected by reed decline are significantly different from optimal and suboptimal stands. Number of species, total cover value and biodiversity indexes are significantly lower in the declining stands, while Ellenberg's indicators for nitrogen (N) and moisture (M) point out interesting correlations. It appears that reed tends to form monospecific stands in permanently flooded areas rich in autogenous litter, where the symptoms of decline are more severe. Species rich stands develop in terrestrial areas where reed shows vigorous growth and healthy condition, however this floristic richness is largely due to invasive and nitrophilous *taxa* which originate a 'pseudo-reed bed', often lacking in typical palustrine species, referred to as a variant with *Rubus ulmifolius* of *Phragmitetum australis* Savič 1926. The results draw attention to the risk of loss of an ecosystem which plays an important role in biodiversity conservation.

Key words: biodiversity, emergent macrophytes, Lake Trasimeno, *Phragmitetum australis*, *Phragmito-Magno caricetea*, phytosociology, reed decline, wet ecosystems

Introduction

Phragmites australis (Cav.) Steud. is generally considered as a strong, often invasive species, especially in NE-America (Marks *et al.*, 1994; Chambers *et al.*, 1999; Talley & Levin, 2001; Saltonstall, 2002; Windham & Meyerson, 2003; Kettenring *et al.*, 2011) and sometimes even in Europe (Brülisauer & Klötzli, 1998). It is well known that common reed can survive in hypertrophic waters (Klötzli, 1971; Tscharntke, 1983) and can even work as a heavy metals accumulator (Schierup & Larsen, 1981; Baldantoni *et al.*, 2004; Bragato *et al.*, 2006).

However, in Europe in the last decades large reed beds showed clear symptoms of retreat and decline, with significant impacts on important wetland ecosystem services such as stability of river and lake margins, water quality, local economy, biodiversity; it shouldn't be neglected that helophytic communities have often been included among the most productive vegetation types (Wetzel, 1989; Westlake *et al.*, 1998) and they represent unique ecotones between land and water, attracting many kinds of wildlife (Wetzel, 2001; Raspopov *et al.*, 2002; Schmieder, 2004).

Reed die-back has been defined as 'a visible, abnormal and non-reversible spontaneous retreat, disintegration or disappearance of a mature stand of common reed within a period not longer than a decade' (Van Der Putten, 1997). It consists of a complex syndrome of decline affecting reed populations, which appears by symptoms such as smaller size, weaker culms, dead rhizomes and buds, flowering delay, abnormal lignification and suberization, presence of *callus*, low starch levels in the rhizomes, clumped habit together with an evident retreat especially from deep waters (for a general overview see Den Hartog *et al.*, 1989; Ostendorp, 1989; Van Der Putten, 1997; Brix, 1999).

The causes of reed decline are still far from a complete explanation. The phenomenon derives from a co-occurrence of multiple driving forces, which can also act on the long term. Among them, chemical traits of the sediment, artificially stabilised water tables, low genetic diversity, increased eutrophication, parasitic attacks, grazing by alien species (e.g. coypus, *Myocastor coypus* Molina) seem to play a basic role (Sukopp & Markstein, 1989; Weisner & Graneli, 1989; Cizkova-Koncalová *et al.*, 1992; Hellings & Gallagher, 1992; Armstrong *et al.*, 1996a, 1996b; Rea, 1996; Weisner, 1996).

Evidences of reed decline have been frequently re-

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ported in Central Europe, giving rise to a large scientific production (for a review: Van Der Putten, 1997). In Italy, this phenomenon has been reported for a brackish lagoon in the Po river delta (Fogli *et al.*, 2002) and was recently detected also at the Lake Trasimeno (Gigante *et al.*, 2008, 2010, 2011; Gigante & Venanzoni, 2012; Angelini *et al.*, 2012; Reale *et al.*, 2011, 2012). According to the mentioned investigation, the die-back condition at Trasimeno appears to be related to permanently flooded stands, still totally submerged at the end of august (when, due to climatic reasons, the water level reaches its minimum), rich in organic deposits, mainly composed by autogenous reed litter. For more details, see Gigante *et al.* (2011).

In spite of the large number of scientific papers dealing with this topic, they generally limited their focus on the reed populations. Only a few studies took into account the floristic and vegetational changes of reed-dominated plant communities in relation with type of sediment and flooding (Lenssen *et al.*, 1999; Greco & Patocchi, 2003; Mäemets & Freiberg, 2004; Van Geest *et al.*, 2005; Brock *et al.*, 1987). Clear evidences of floristic and vegetational differences between declining and healthy reed stands drove us to take into account also this aspects, as possible trait caused by, or at least related to, reed die-back syndrome.

Materials and Methods

The study was carried out along the shore of the Lake Trasimeno (average altitude: 257 m a.s.l., average surface of the lake: 121.5 km^2, average water column depth: 4.2 m), a wide shallow lake hosting one of the largest freshwater ecosystems in central Italy (Landucci *et al.*, 2011). Based on climatic data recorded in Monte del Lago thermo-pluviometric station (295 m a.s.l.; data from a period of 30 years), applying the bioclimatic indexes proposed by Rivas-Martínez *et al.* (1999), processed according to Rivas-Martínez & Rivas-Saenz (2009), the study area belongs to the Mediterranean pluviseasonal-oceanic bioclimate, upper mesomediterranean low subhumid belt (Gigante & Venanzoni, 2007). The water level is irregular and depends almost completely on the rainfall; notable tributaries are lacking. The negative balance rains/evapotranspiration constantly works towards a decrease of the lake's level which is progressively dropping down, due to the long time for water replacement and the high evaporation rate (respectively: 24.4 years and 155 x 106 m^2/year, according to De Bartolomeo *et al.*, 2004). For this reason, at the end of the '50s the catching basin was artificially enlarged, causing a dramatic rise of the water level (about 2,5 m from 1959 to 1966) and the submersion of the reed beds located on the flatter shores (Gambini, 1995). This remarkable flooding has been indicated as a possible co-cause of

the reed die-back in the area (Gigante *et al.*, 2011; Gigante & Venanzoni, 2012).

The phenomenon has been formerly investigated at the Lake Trasimeno by monitoring 19 permanent plots in the reed population, in 7 locations randomly scattered along the lake shore (Gigante *et al.*, 2008, 2010, 2011). Each plot has been indicated by an ID, formed by the code of the location (OAS: Oasi La Valle di S. Savino; BRA: Poggio di Braccio; POR: Porto di Panicarola; POM: Rio Pescia; IDR: Castiglion del Lago; BOR: Borghetto; PAS: Passignano) and a number. On the ground of the analyses provided in those studies, each surveyed stand could be assigned to a different die-back status: OP (optimal condition), SU (suboptimal condition), DB (die-back condition). Following this existing experimental design, we investigated the floristic and vegetational traits in homogeneous reed stands surrounding and including the 19 mentioned permanent plots. Field surveys have been carried out at the end of the vegetative season (between the end of August and the start of September) in the years 2006, 2007 and 2009. A total amount of 45 phytosociological relevés (Braun-Blanquet, 1928, 1964), consisting of the complete list of vascular species and the relative cover values, have been carried out in square areas (size: 3x3 m^2) set around each permanent plot. Each stand is characterized by flat slope. Cover values have been recorded both as percentage and by adopting Braun-Blaunquet's cover scale, modified by Barkman *et al.* (1964).

Based on floristic-vegetational data, some indexes have been calculated for each relevé: number of species, individual species cover values (%), biodiversity indexes and ecologic indicator values, number of nitrophilous and synanthropic species. The used diversity indexes are: Shannon-Wiener Diversity index (Hill, 1973), Simpson Diversity Index (Simpson, 1949) and Shannon's Equitability, which is an Evenness Index (Pielou, 1975). As ecologic indexes, we used the widely adopted system of indicator values developed by Ellenberg for central Europe (Ellenberg, 1974; Ellenberg *et al.*, 1991) and adapted by Pignatti (2005) to the Italian flora, referring to species needs of light, temperature, continentality, moisture, reaction, nutrients. One of their advantages is that they summarize complex environmental factors (Skaffers & Sykora, 2000), can be used to relate vegetation to environmental changes (Persson, 1980; Diekmann, 2003) and in general to analyse the synecology of plant communities (Jurko, 1984), especially when analysing one single vegetation type (Wamelink *et al.*, 2002; Otýpková *et al.*, 2011; Balkovič *et al.*, 2012). Ter Braak & Barendregt (1986) and Ter Braak & Gremmen (1987) supported their use with a robust theoretical basis.

The nitrophilous and synanthropic species were counted for each relevé and correlated with the total

number of species. We considered as 'nitrophilous and synanthropic' the species with a value of Ellenberg's 'N' (nutrients) equal or higher than 7 (Pignatti, 2005); in addition, we included also the other species belonging to the classes *Artemisietea vulgaris* (*Artemisia vulgaris*, *Daucus carota*, *Picris hieracioides*) and *Stellarietea mediae* (*Abutilon theophrasti*, *Bromus hordeaceus*, *Galium aparine*, *Lactuca serriola*, *L. virosa*), considering the nitrophilous and synanthropic ecology of these vegetation classes.

The phytosociologic relevés were analysed in the light of the decline status as reported in Gigante *et al*. (2008, 2010, 2011) and grouped according to the 3 mentioned cathegories (OP, SU, DB). All the selected indexes have been calculated for each single relevé by using the Juice program (Tychý, 2002) and averaged for the 3 groups (DB, SO and OP). Kolmogorov-Smirnov Test and Skewness and Kurtosis coefficients have been applied to test if the data distribution was conform to normality. The statistical significance of the differences detected among groups has been tested by non-parametric Kruskal-Wallis Test, Mann-Whitney U-Test and Median Test. For data with normal distribution, correlation analysis was based on both linear regression and Spearman's rank coefficient R. All the Statistical analyses were performed by using the software Analyst Soft Stat Plus: mac v2009.

Species names follow Conti *et al*. (2005) and the nomenclatural updatings reported in anArchive (2003-2013). Syntaxonomic nomenclature refers to Rivas-Martínez *et al*. (2001) and to Landucci *et al*. (2013). All the relevés have been archived in VegItaly data

bank (Landucci *et al*., 2012; Venanzoni *et al*., 2012; Gigante *et al*., 2012).

Results

The complete phytosociological table, including 45 relevés grouped according to the decline status, is reported in Tab. 1. The floristic list of the surveyed vegetation counts 76 species, including 2 helophytes, 4 hydrophytes, 29 hemicryptophytes, 11 geophytes, 21 therophytes, 2 nanophanerophytes and 7 phanerophytes (the last 2 categories always represented by juveniles). Reed cover is 69% on average and all the relevés can be referred to the association *Phragmitetum australis* Savič 1926, although some remarkable floristic differences can be noted, allowing the identification of 2 ecologic variants: one corresponding to the dying-back reed bed, differentiated by a very low number of species, almost monospecific (DB stands), and the second, including SO and OP stands, where *Phragmites australis* is almost always accompanied by *Rubus ulmifolius*, *Urtica dioica*, *Calystegia sepium*.

When we consider the 3 groups separately, we can observe that the floristic-vegetational traits in stands affected by reed decline (DB) are significantly different from both optimal and suboptimal stands (Fig. 1, Tab. 2). The number of species per relevé is drastically lower in the DB group (2.42 on average), while it ranges around 8.08 and 9.05 in the SO and OP groups, respectively. Analogous result is expressed by Shannon-Wiever's and Simpson's Indexes, reaching the lowest values in the declining reed stands. Also Evenness,
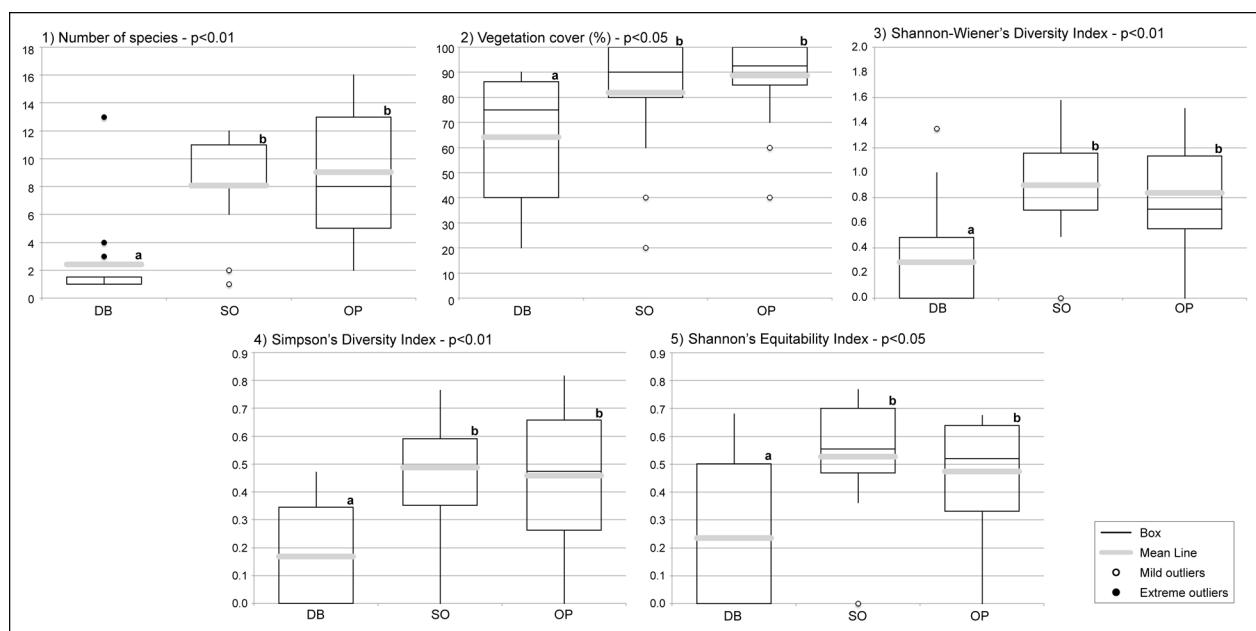
Fig. 1 - Range of values (average, median, 1st and 3rd quartile, max, min) for number of species, vegetation cover value, Shannon's Index, Simpson's Index, Evenness for the three groups of plots (DB = dying back stands; SO = stands in sub-optimal conditions; OP = stands in optimal conditions); p values refer to Kruskal-Wallis Test; different letters indicate statistically significant differences (Mann-Whitney U-Test).

Tab. 1 - Phytosociological relevés (the plot names refer to the 7 investigated locations, as follows: PAS = Passignano; BOR = Borghetto; IDR = Castiglion del Lago; POM = Rio Pescia; POR = Panicarola; BRA = Poggio di Braccio; OAS = Oasi La Valle).

Group (decline status)	DB	DB	DB	DB	DB	DB	DB	DB	DB	DB	DB	DB	DB	DB	DB	SU	SU	SU	SU	SU	SU	SU	SU	SU	SU	SU	SU	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	Presences
Relevé definitive number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	
Relevé field number	12	11	13	5	7	8	9	10	11	12	4	23	31	3	1	9	4	5	22	18	15	21	24	2	19	2	13	27	25	28	14	15	7	17	16	8	26	14	30	29	20	2	3	10	18	
Plot ID	OAS_6	OAS_4	OAS_3	IDR_1	OAS_1	OAS_2	OAS_3	OAS_4	OAS_5	IDR_1	IDR_1	POR_3	BRA_1	BOR_1	BOR_1	BOR_1	BRA_2	IDR_2	BRA_1	BRA_2	POR_2	IDR_1	IDR_2	IDR_2	BOR_1	BOR_2	POM_1	POM_2	PAS_1	POM_2	PAS_2	POM_1	PAS_1	POR_2	POM_2	PAS_2	POR_1	POR_1	POR_2	POR_1	BOR_2	POM_1	POM_2	BOR_2	POR_3	
Year	2006	2009	2009	2009	2006	2006	2006	2006	2009	2009	2007	2007	2006	2009	2006	2006	2009	2009	2007	2009	2009	2006	2007	2009	2007	2006	2007	2007	2007	2007	2006	2006	2009	2006	2006	2009	2006	2007	2007	2007	2007	2009	2009	2009	2006	
Cover (%)	45	40	40	20	75	80	85	90	90	75	40	100	20	40	60	85	85	100	100	80	90	90	70	100	100	40	100	100	90	85	85	95	85	60	90	80	100	100	100	100	90	100	100	100	90	
Species number	1	1	1	3	1	1	1	1	1	4	13	6	1	2	8	8	13	11	8	12	8	8	2	8	7	3	4	4	6	8	8	8	10	13	4	16	5	13	5	6	9	12	14	16	18	
Nitrophylous species number (see text for explanations)	0	0	0	1	0	0	0	0	0	1	10	4	0	0	3	3	4	4	6	9	5	4	1	4	3	0	2	1	3	6	6	7	3	8	2	8	3	8	1	3	4	6	10	6	10	
Sporadic species number	0	0	0	0	0	0	0	0	0	1	1	1	0	0	2	2	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	1	2	0	0	4	
Diagnostic species																																														
Phragmites australis (Cav.) Steud.	3	3	3	2b	5	5	5	5	5	5	4	3	5	2b	3	4	5	5	5	5	4	4	5	3	5	3	5	5	5	5	5	5	5	4	5	4	4	4	5	5	4	5	5	4	4	45
Differential species																																														
Rubus ulmifolius Schott	.	.	.	.	.	.	.	+	.	.	+	.	+	.	.	.	.	r	+	2b	2a	2a	+	2b	2a	.	.	+	.	1	+	+	.	.	2b	2a	2a	2a	.	+	1	.	.	1	+	17
Urtica dioica L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	1	1	2a	2a	.	+	1	.	.	+	r	1	1	+	r	.	2b	2a	2a	.	+	.	.	3	.	.	.	14
***Phragmito-Magno-Caricetea elatae* Klika in Klika & Novák 1941**																																															
Cirsium creticum (Lam.) d'Urv. subsp. triumfettii (Lacaita) K. Werner	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	+	1	1	+	2a	.	3	.	+	1	r	.	+	.	r	.	.	r	2a	2a	+	+	r	r	1	r	.	15
Carex riparia Curtis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2b	.	.	.	2a	.	.	1	.	.	.	.	.	3	.	1	.	.	.	.	.	3	3	2a	.	.	.	.	9
Lythrum salicaria L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	+	.	.	.	.	+	.	4	.	+	.	+	.	+	.	.	.	+	+	.	2a	.	.	.	+	.	.	.	.	8
Oenanthe aquatica (L.) Poir.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	1	.	.	+	.	+	.	.	.	.	.	.	+	.	r	.	.	.	.	+	.	.	+	.	6
Solanum dulcamara L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	r	r	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	1	.	.	.	.	3	.	.	.	6
Lycopus europaeus L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	+	1	.	.	.	.	.	.	+	+	r	.	.	+	.	+	+	r	.	.	.	r	+	.	.	r	.	6
Iris pseudacorus L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	+	.	.	.	.	.	.	.	.	+	.	.	2b	.	.	+	.	.	.	.	.	6
Sparganium erectum L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	2b	.	.	.	.	1	.	.	.	.	.	.	4
Pulicaria dysenterica (L.) Bernh.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	+	.	.	r	.	.	.	r	.	.	.	.	1	.	.	1	.	4
Schoenoplectus lacustris (L.) Palla	.	.	.	.	.	.	.	.	.	.	.	.	2a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3
Bolboschoenus maritimus (L.) Palla	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	r	.	.	.	.	.	.	2a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	3
Mentha aquatica L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	3
Stachys palustris L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	1	.	+	+	.	.	.	.	.	.	.	.	.	.	3
Alisma plantago-aquatica L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	+	.	.	.	.	.	.	.	.	+	2
Phalaroides arundinacea (L.) Rauschert	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2a	.	.	2a	.	.	.	.	.	.	.	.	2
Galium palustre L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
Veronica anagallis-aquatica L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	r	.	.	+	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	2
Scutellaria galericulata L.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	1
Cyperus longus L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Lysimachia vulgaris L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	1
Althaea officinalis L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	r	.	.	1
***Galio-Urticetea* Passarge ex Kopecký 1969**																																															
Calystegia sepium (L.) R.Br.	.	.	.	.	+	.	.	.	.	2a	1	+	.	+	2a	+	2a	.	+	+	1	+	+	1	.	1	.	+	+	+	1	+	2a	3	3	4	2a	1	.	.	1	2b	2a	3	3	28
Eupatorium cannabinum L.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	.	.	r	+	1	2b	r	.	.	.	.	.	.	.	.	.	.	+	4	.	.	2b	.	.	.	.	2a	.	3	3	9
Epilobium hirsutum L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2a	.	+	.	.	.	.	.	.	+	.	.	+	+	+	.	.	.	+	.	.	+	r	+	4
Sambucus ebulus L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	3
***Stellarietea mediae* Tüxen, Lohmeyer & Preising ex von Rochow 1951**																																															
Symphyotrichum squamatum (Spreng.) G.L. Nesom	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	r	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	6

Species		count
Amaranthus retroflexus L.		4
Echinochloa crus-galli (L.) P. Beauv.		4
Lactuca serriola L.		2
Erigeron bonariensis L.		2
Abutilon theophrasti Medik.		1
Lactuca virosa L.		1
Galium aparine L.		1
Erigeron canadensis L.		1
Bromus hordeaceus L.		1
Artemisietea vulgaris Lohmeyer, Preising & R. Tüxen ex von Rochow 1951		
Picris hieracioides L.		2
Sonchus asper (L.) Hill		1
Daucus carota L.		1
Artemisia vulgaris L.		1
Bidentetea tripartitae Tüxen, Lohmeyer & Preising ex von Rochow 1951		
Bidens tripartitus L.		7
Bidens frondosus L.		5
Persicaria maculosa (L.) Gray		4
Cirsium arvense (L.) Scop.		3
Xanthium orientale L. subsp. italicum (Moretti) Greuter		3
Ranunculus sceleratus L.		3
Molinio-Arrhenatheretea Tüxen 1937		
Holcus lanatus L.		5
Agrostis stolonifera L.		5
Galega officinalis L.		2
Potentilla reptans L.		1
Other species		
Sambucus nigra L. (juv.)		5
Samolus valerandi L.		4
Oxybasis rubra (L.) S. Fuentes, Uotila et Borsch		3
Lemna minor L.		3
Cornus sanguinea L. (juv.)		3
Azolla filiculoides Lam.		3
Atriplex patula L.		2
Acer negundo L. (juv.)		2

Sporadic species

R12: Ballota nigra L. subsp. meridionalis (Bég.) Bég. 1; R13: Petasites hybridus (L.) G. Gaertn., B. Mey. et Scherb. 1; R16: Chenopodium album L. r, Amaranthus sp. r;
R21: Equisetum ramosissimum Desf. r; R22: Carex cuprina (I. Sándor ex Heuff.) Nendtv. ex A. Kern. +; R25: Populus nigra L. (juv.) 2a; R30: Salix cinerea L. (juv.) +;
R39: Populus x canescens (Aiton) Sm. (juv.) +; R42: Cyperus fuscus L. 2a; R43: Rumex conglomeratus Murray 1, Salix alba L. (juv.) 3;
R45: Carex hirta L. 3, Rumex maritimus L. +, Scrophularia nodosa L. +, Epilobium obscurum Schreb. +

Legend: DB = die-back condition, SU = suboptimal condition, OP = optimal condition
The plot names refer to the 7 investigated locations, as follows: PAS = Passignano; BOR = Borghetto; IDR = Castiglion del Lago; POM = Rio Pescia; POR = Panicarola; BRA = Poggio di Braccio; OAS = Oasi La Valle

Tab. 2 - Values of the number of species, vegetation cover value, Shannon's Index, Simpson's Index, Evenness (average ± SE) for the three groups of plots (DB = dying back stands; SO = stands in sub-optimal conditions; OP = stands in optimal conditions); p values refer to Kruskal-Wallis Test; different letters indicate statistically significant differences (Mann-Whitney U-Test).

	DB (n=12)	SO (n=13)	OP (n=20)	p value
Number of species	2.42±1.00[a]	8.08±0.98[b]	9.05±1.06[b]	<0.001
Cover value (%)	64.17±7.28[a]	81.92±7.24[b]	88.75±3.57[b]	<0.05
Biodiversity indexes				
Shannon-Wiener's Diversity	0.36±0.17[a]	1.13±0.15[b]	1.05±0.13[b]	<0.01
Simpson's Diversity	0.17±0.07[a]	0.49±0.06[b]	0.46±0.05[b]	<0.01
Shannon's Equitability	0.23±0.10[a]	0.53±0.06[b]	0.47±0.04[b]	<0.05

expressed by the Shannon's Equitability Index, which quantifies how equal the community is numerically, shows remarkably lower levels in the DB group of relevés. All the values recorded in the declining plots are significantly different from those recorded in the SO and OP groups of relevés.

As concerns the total vegetation cover, it ranges around 64.17% in the declining stands, reaching far higher values in the sub-optimal plots (81.92) and the highest rates on average in the optimal stands (88.75). When we consider which species are more significant to differentiate the 3 groups (Tab. 3), it appears that *Phragmites australis*, although always present and dominant, shows significantly different cover values in the 3 groups of relevés (p<0.001), just like *Calystegia sepium* and *Eupatorium cannabinum* (p<0.01 and p<0.001 respectively). Among the species with average cover value per group >1% and average frequency value per group >10%, it appears that *Cirsium creticum* subsp. *triumfetti*, *Carex riparia*, *Solanum dulcamara*, *Iris pseudacorus*, *Sparganium erectum*, *Mentha aquatica* subsp. *aquatica*, *Sambucus nigra*, *Bidens tripartita*, *Agrostis stolonifera*, *Urtica dioica*, *Rubus ulmifolius* are good differential species, totally missing in the declining reed stands. It should be stressed that many of these species are typically representatives of palustrine ecosystems, while the last 2 are generally ascribable to disturbed environments.

Ellenberg's indicators point out interesting differences among the 3 groups of relevés (Fig. 2, Tab. 4). The strongest statistical significance regards the parameter M (moisture, p<0.001); the highest values are reached in the declining reed stands (DB). The parameters T (temperature) and N (nitrogen) are both significantly lower in the dying-back plots (p<0.01 for both), while R (reaction) is higher (p<0.01). Continentality (C), although still significantly different (p<0.05), widely ranges inside the DB group of relevés, while light (L) doesn't appear to be a relevant ecological character when comparing the 3 groups.

We searched for any correlation existing between the total number of species and the number of nitrophilous and synanthropic species for each relevé. According to

Kolmogorov-Smirnov Test and Skewness and Kurtosis coefficients, the data had a normal distribution; by applying both linear regression and Spearman's correlation, it appeared that a very high correlation exists between these 2 parameters (linear regression $R^2 = 0.851$, p<0.001; Spearman's correlation rank = 0.94; p<0.001; Fig. 3).

Discussion

Although reed die-back is a largely investigated phenomenon, this is the first time that floristic traits are analysed in a declining reed bed and that dying-back symptoms are put in relation with the plant community features. *Phragmitetum australis* has generally been considered as a paucispecific vegetation type (Balátová-Tuláckova *et al.*, 1993; Gerdol, 1987; Philippi, 1977). However, on the ground of several published phytosociological tables referring to this association in Peninsular and Northern Italy (Biondi & Baldoni, 1993; Baldoni & Biondi, 1993; Iberite *et al.*, 1995; Venanzoni & Gigante, 2000; Landi *et al.*, 2002; Maiorca *et al.*, 2002; Pirone *et al.*, 2003; Venanzoni *et al.*, 2003; Presti *et al.*, 2004; Biondi & Bagella, 2005; Brusa *et al.*, 2006; Ceschin & Salerno, 2008; Tomaselli *et al.*, 2008; De Martis & Serri, 2009; Lastrucci *et al.*, 2010; Allegrezza *et al.*, 2010), it appears that the number of species in reed beds is 7.84 ± 4.45 (average ± st. dev.), ranging from a minimum of 1 species to a maximum of 19 (number of considered relevés: 134).

In the present case-study, the reed stands affected by die-back syndrome appear significantly correlated to species-poor or even monospecific plant communities (Tab. 1, group DB); their floristic diversity and evenness are far lower when compared to healthy and sub-optimal stands, indicating a reduced number of species and an unequal distribution of the species dominance. Also the total vegetation cover is lower in the declining reed stands: it is well known that the dying-back reeds, although sometimes showing higher stem density (Gigante *et al.*, 2011; Reale *et al.*, 2011, 2012), are typically characterized by significantly lower stem's diameter and height, thus producing reduced biomass

(Van Der Putten, 1997). At the same time, the total vegetation cover value is further reduced by the low number of species.

On the ground of the analysed data, and in accordance with the results reported in Gigante *et al*. (2011, 2012), the species-poor, declining reed stands appear to be located only in the permanently flooded areas, on the water-front; this matches with the high values of the moisture (M) index. Reed beds tend to become monospecific in permanently flooded areas, where the sediment gets rich in autogenous not-decomposed litter, and where the symptoms of decline are more severe (Cízková *et al*., 1996; Rea, 1996; Schmieder *et al*., 2002; Gigante *et al*., 2011). It is evident that the deep waters alone should not be considered as an exhaustive explanation of reed decline; the remarkable floristic poverty in permanently flooded reed beds can be related to the fact that litter originated from emergent macrophytes (especially reed itself) is rich in lignin and cellulose, slowly decomposable under permanent flooding and originating adverse conditions for growth (Clevering & Van Der Putten, 1995; Van Der Putten *et al*., 1997; Pieczyńska, 1993; Boschker *et al*., 1995). Reed creates shade and organic litter to detriment of several macrophyte *taxa* whose frequency progressively decrease (Mäemets & Freiberg, 2004). Also Lenssen *et al*. (1999) pointed out that waterlogged reed-originated litter can decrease the growth of several wetland species. Long-term submersion and inundations often result in low species richness, in both hydrophytes and helophytes (Van Geest *et al*., 2005; Brock *et al*., 1987); on the long term, the sediment deposition can strongly interfere with the growth of aquatic plants (Bornette & Puijalon, 2011). Reed-derived litter can inhibit the growth of wetland species, including *Phragmites australis* itself (Van Der Putten, 1993; Van Der Putten *et al*., 1997; Clevering, 1998), in spite of its strong capacity for rhizosphere oxidation (Conlin & Crowder, 1989; Armstrong *et al*., 1992).

Mäemets & Freiberg (2004) noticed that the occurrence of periods of low-water can be correlated to large reed expansion, while permanent flooding affects reed's growth on the medium-long term (Schmieder *et al*., 2002; Clevering, 1998). Indeed, it is well known that reed die-back generally affects aquatic stands (Güsewell & Klötzli, 2000) and that reed tends to retreat from deep waters (Boar *et al*., 1989; Cízková *et al*., 1996; Ostendorp, 1999). The accumulation of litter, especially when deriving from reed itself, seems to be harmful to reed stands (Van Der Putten, 1993; Van Der Putten *et al*., 1997; Granéli, 1989; Weisner, 1996; Cízková *et al*. 1996; Clevering, 1998). Even suggestions about the auto-toxicity of the genus *Phragmites* have been reported in literature (Gopal & Goel 1993): autotoxic effects have been noticed in *Phragmites karka* (Retz) Trin. ex Steud., the South-Asian reed, in India (Sharma *et al*., 1990). Szczepanska (1971) observed that the growth of reed's seedlings is inhibited by the presence of litter from several macrophytic species. Furthermore, algae such as *Cladophora* sp. pl. can play an allelopathic effect on the sprouting of rhizomes and growth of roots of reed (Schroeder, 1987); species of this algal genus have been observed at the Lake Trasimeno (Lazzerini *et al*., 2011). The perma-
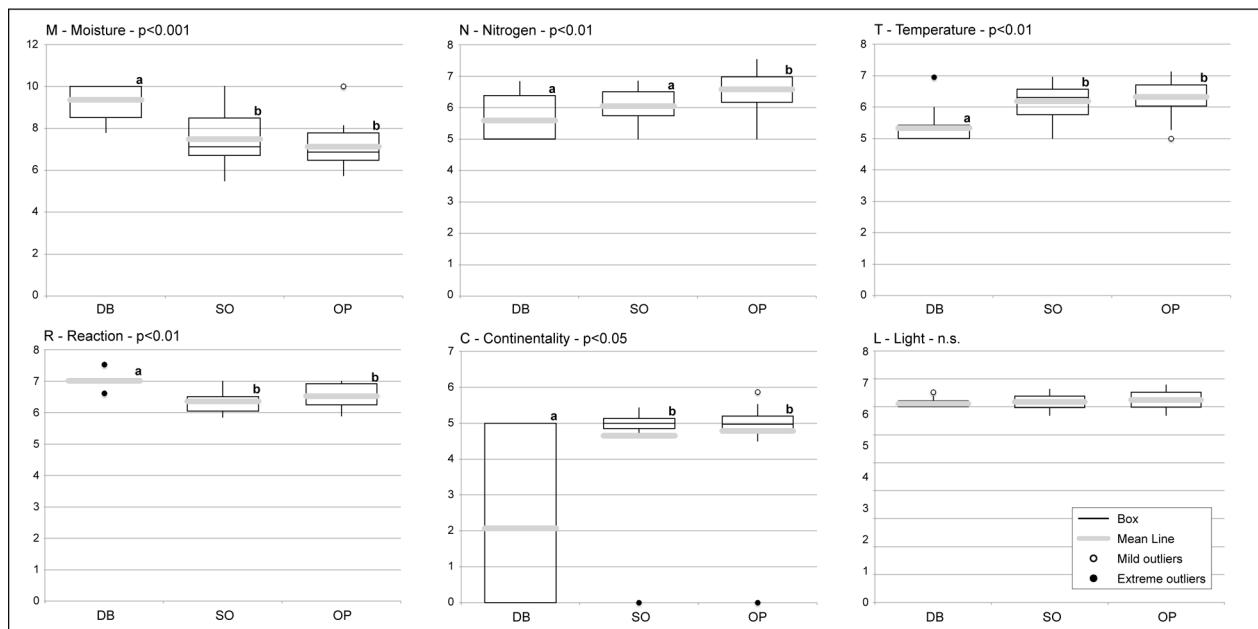
Fig. 2 - Range of values (average, median, 1st and 3rd quartile, max, min) for Ellenberg parameters for the three groups of plots (DB = dying back stands; SO = stands in sub-optimal conditions; OP = stands in optimal conditions); p values refer to Kruskal-Wallis Test; different letters indicate statistically significant differences (Mann-Whitney U-Test).

Tab. 3 - Statistical significance of the differences in individual species cover values for the 3 groups of relevés (DB = dying back stands; SO = stands in sub-optimal conditions; OP = stands in optimal conditions), calculated by the Median Test; each species cover (average ± SE) per group (%) is indicated (only the species with average cover value per group > 1% and average frequency value per group > 10% have been considered).

	DB (n=12)	SO (n=13)	OP (n=20)	p value
Phragmites australis (Cav.) Trin.	63,0±7,86	68,8±6,71	72,8±4,38	<0.001
Calystegia sepium (L.) R.Br.	1,0±0,75	1,3±0,69	10,6±3,72	<0.01
Eupatorium cannabinum L.	0,0±0,04	1,8±0,90	2,8±2,05	<0.001
Oxybasis urbica (L.) S. Fuentes, Uotila et Borsch	0,7±0,73	-	2,0±1,87	<0.001
Rubus ulmifolius Schott	-	4,4±1,97	1,3±0,61	<0.01
Cirsium creticum (Lam.) D'Urv. subsp. *triumfetti* (Lacaita) Werner	-	5,5±3,05	0,7±0,45	<0.01
Carex riparia Curtis	-	8,6±5,33	4,2±2,58	<0.001
Solanum dulcamara L.	-	0,3±0,23	2,0±1,87	<0.001
Iris pseudacorus L.	-	0,3±0,23	1,1±0,94	<0.001
Sparganium erectum L.	-	0,5±0,31	1,1±0,94	<0.001
Urtica dioica L.	-	3,3±1,56	7,9±4,66	<0.01
Bidens tripartita L.	-	0,0±0,04	1,0±0,93	<0.001
Mentha aquatica L. ssp. *aquatica*	-	0,2±0,23	1,9±1,87	<0.001
Sambucus nigra L.	-	-	1,1±0,94	<0.001
Agrostis stolonifera L.	-	-	7,1±3,88	<0.001

nence of water might enhance the allelopathic effect, especially in anaerobic conditions (Gopal & Goel, 1993; Patrick *et al*., 1964).

With regard to the species rich aspects, the highest number of *taxa* is recorded in the stands where dieback was not (or only slightly) detected: the plots in optimal and suboptimal conditions show a changeable floristic composition but none of them is monospecific (Tab. 1, groups SO and OP). These stands are always located in dry or temporarily flooded areas (Gigante *et al*., 2008, 2010, 2011), generally on the land-facing margin of the reed bed, often in contact with agricultural areas. In fact, reed shows the most vigorous growth and healthy condition in the species richest stands, which develop in terrestrial areas. In wetlands, recurring lowering of water level are usually considered to increase plant biodiversity, compared to stable water-levels (Riis & Hawes, 2002). However, in the study area this high number of species is to be referred, at least in part, to *taxa* which are not typical elements of *Phragmitetum australis*. The observed floristic richness is mostly due to invasive, nitrophilous and alien *taxa*, which originate a reed bed often co-dominated by disturbance-indicating species, above all *Rubus ulmifolius* and *Urtica dioica* (Tab. 1). This interpretation is supported by the high values of the nitrogen indicator value (N) and in general by the high rate of nitrophilous species (Fig. 2, Fig. 3). According to studies which took into account both Ellenberg's indicator values and measured parameters in the field (Hill

& Carey, 1997; Schaffers & Sýkora, 2000), N can be interpreted as an indicator of productivity.

From the phytosociological point of view, the healthy reed stands are differentiated by a large number of transgressive elements from the nitrophilous classes *Stellarietea* and *Artemisietea*. This pattern shows that *Phragmites australis* can vigorously grow in disturbed environments. Indeed, in the study area reed tends to invade landward sites, often successfully competing with other species. Similar vegetation types had already been observed at the Lake Trasimeno by Venanzoni & Gigante (2000) and referred to *Phragmitetum vulgaris* Soó 1927 (syn.: *Phragmitetum australis* Savič
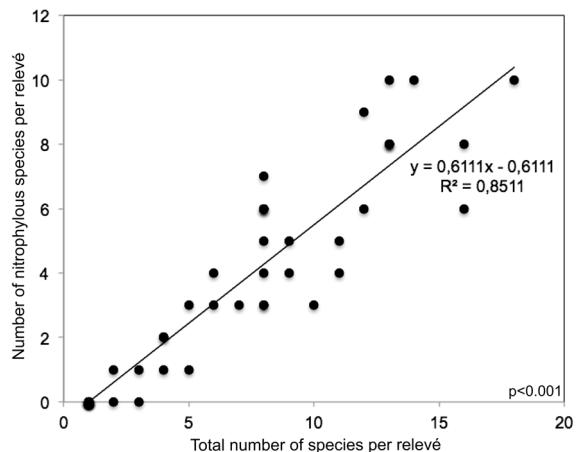
Fig. 3 - Number of nitrophilous species vs. total number of species per relevé; the regression line is reported.

Tab. 4 - Values of the Ellenberg parameters (average ± SE) for the three groups of plots (DB = dying back stands; SO = stands in sub-optimal conditions; OP = stands in optimal conditions); p values refer to Kruskal-Wallis Test; different letters indicate statistically significant differences (Mann-Whitney U-Test).

	DB (n=12)	SO (n=13)	OP (n=20)	p value
Ellenberg parameters				
Moisture (M)	9.37±0.27[a]	7.49±0.42[b]	7.13±0.21[b]	<0.001
Nitrogen (N)	5.59±0.26[a]	6.04±0.17[a]	6.59±0.15[b]	<0.01
Temperature (T)	5.32±0.17[a]	6.18±0.20[b]	6.33±0.13[b]	<0.01
Reaction (R)	7.01±0.06[a]	6.35±0.11[b]	6.52±0.08[b]	<0.01
Continentality (C)	2.07±0.74[a]	4.65±0.39[b]	4.78±0.26[b]	<0.05
Light (L)	7.12±0.05	7.18±0.09	7.25±0.07	n.s.

1926), in spite of the high cover values of species like *Urtica dioica*, which might address towards the description of a reed-dominated community to be referred to, e.g., *Convolvuletalia sepium* Tüxen ex Mucina 1993 Riv.-Mart., T.E. Díaz, Fernández-González, Izco, Loidi, Lousã & Penas 2002 nom. mut. propos. On the ground of the here reported data, *Rubus ulmifolius* and *Urtica dioica* can be used to point out a variant of the typical association, since the presence of elements from the class *Phragmito-Magno-Caricetea* is still remarkable (Tab. 1, Tab. 3). Similar vegetation patterns were observed in S-Switzerland and inspired the word 'pseudo-reed bed' (Greco & Patocchi, 2003) to indicate a vegetation type where *Phragmites australis* colonizes terrestrial stands, often on nutrient-rich soils (Brülisauer & Klötzli, 1998).

Conclusive remarks

On the ground of the anlysed data, a clear picture of the floristic-vegetational traits characterizing the dying-back reed stands can be outlined. Results support the idea that in permanently flooded stands, rich in organic deposits and autogenous reed litter, the phenomenon of reed die-back matches with an extreme floristic poorness, often stretched to monospecific phytocoenoses. On the other side, species-rich reed beds are often related to terrestrial disturbed sites, which seem to be the healthiest condition for the species *Phragmites australis*. However, their floristic richness is main-ly due to the presence of invasive species.

From the point of view of nature conservation, reed die-back is a dramatic phenomenon affecting wide portions of European reed beds and should be considered with attention. The presence of large stands of 'pseudo-reed bed', although species-rich, cannot be considered as a compensation since their floristic composition is often jeopardized by conditions of strong disturbance, as indicated by the present study. The overall result is a trivialization of the plant communities, both in the flooded and the drier locations, drawing attention to the risk of loss of an ecosystem which plays an important role in biodiversity conservation.

Although not included in any of the specific Habitats listed in Annex I of 92/43/EEC Directive (Biondi *et al*., 2009, 2012), reed beds and in general the plant communities belonging to the alliance *Phragmition* represent valuable ecosystems for biodiversity conservation. Wetlands are also highly vulnerable to alien species invasions, especially neophytes (Chytrý *et al*. 2005, 2009). Their increasing decline and contraction call for a deeper knowledge of the dynamics lying behind the observed phenomena. It seems therefore more and more necessary to find out suitable models and traits in order to detect and monitor the declining condition of these delicate ecosystems. With this aim, floristic and phytosociological aspects combined with population analysis can be taken into account as important and visible indicators of the die-back phenomenon.

Syntaxonomic scheme

PHRAGMITO-MAGNO-CARICETEA Klika in Klika et Novák 1941
PHRAGMITETALIA AUSTRALIS Koch 1926
Phragmition australis Koch 1926
Phragmitetum australis Savič 1926
var. with *Rubus ulmifolius*

Bibliographic references

Allegrezza M., Mentoni M. & Tesei G., 2010. Geomorfologia e paesaggio vegetale: l'esempio della grande frana di Pescacci (Comune di Serra San Quirico - Appennino centrale). Fitosociologia, 47(2): 57-97.

anArchive, 2003-2013. anArchive 5 - Database System for Botanical Data. Published on the internet: http://www.anarchive.it/ [accessed on 2013, April 20].

Angelini P., Rubini A., Gigante D., Reale L., Pagiotti R. & Venanzoni R., 2012. The endophytic fungal communities associated with the leaves and roots of the common reed (*Phragmites australis*) in Lake Trasimeno (Perugia, Italy) in declining and healthy stands. Fungal Ecology, 5: 683-693. Elsevier.

Armstrong J., Armstrong W., Armstrong I.B. & Pittaway G.R., 1996a. Senescence and phytotoxin insect, fungal and mechanical damage: factors reducing convective gas-flows in *Phragmites australis*. Aquat. Bot., 54: 211-226.

Armstrong J., Armstrong W. & Van Der Putten W.H., 1996b. *Phragmites* die-back: bud and root death, blockages within the aeration and vascular systems and the possible role of phytotoxins. New Phytologist, 133: 399-414.

Balátová-Tuláckova, Mucina L., Ellmauer T. & Wallnöfer S., 1993. *Phragmiti-Magnocaricetea*. In Mucina L., Grabherr G. & Wallnöfer S. (Eds.), Die Pflanzengesellschaften Österreichs, Teil II: 79-130. Gustav Fischer Verlag, Jena.

Baldantoni D., Alfani A., Di Tommasi P., Bartoli G. & Virzo De Santo A., 2004. Assessment of macro and microelement accumulation capability of two aquatic plants. Environmental Pollution, 130: 149-156.

Baldoni M. & Biondi E., 1993. La vegetazione del medio e basso corso del Fiume Esino (Marche - Italia centrale). Stud. Bot., 11: 209-257.

Balkovič J., Kollár J. & Šimonovič V., 2012. Experience with using Ellenberg's R indicator values in Slovakia: oligotrophic and mesotrophic submontane broad-leaved forests. Biologia, 67(3): 474-482.

Barkman J.J., Doing H. & Segal S., 1964. Kritische Bemerkungen und Vorschläge zur quantitativen Vegetationsanalyse. Acta Bot. Neerl., 13: 394-419.

Biondi E. & Bagella S., 2005. Vegetazione e paesaggio vegetale dell'arcipelago di La Maddalena (Sardegna nord-orientale). Fitosociologia, 42(2), Suppl. 1: 3-99.

Biondi E. & Baldoni M., 1993. La vegetazione del fiume Marecchia (Italia Centrale). Biogeographia n.s., 17: 51-87.

Biondi E., Blasi C., Burrascano S., Casavecchia S., Copiz R., Del Vico E., Galdenzi D., Gigante D., Lasen C., Spampinato G., Venanzoni R. & Zivkovic L., 2009. Manuale Italiano di interpretazione degli habitat della Direttiva 92/43/CEE. Società Botanica Italiana. Ministero dell'Ambiente e della Tutela del Territorio e del Mare, D.P.N. [available online at: http://vnr.unipg.it/habitat/]

Biondi E., Burrascano S., Casavecchia S., Copiz R., Del Vico E., Galdenzi D., Gigante D., Lasen C., Spampinato G., Venanzoni R., Zivkovic L. & Blasi C., 2012. Diagnosis and syntaxonomic interpretation of Annex I Habitats (Dir. 92/43/ EEC) in Italy at the alliance level. Plant Sociology, 49(1): 5-37.

Bornette G. & Puijalon S., 2011. Response of aquatic plants to abiotic factors: a review. Aquat. Sci., 73: 1-14.

Boschker H.T.S., Dekkers E.M.J., Pel R. & Cappenberg T.E., 1995. Sources of organic carbon in the littoral of Lake Gooimeer as indicated by stable carbon isotope and carbohydrate compositions. Biogeochemistry, 29: 89-105.

Bragato C., Brix H. & Malagoli M., 2006. Accumulation of nutrients and heavy metals in *Phragmites australis* (Cav.) Trin. ex Steudel and Bolboschoenus maritimus (L.) Palla in a constructed wetland of the Venice lagoon watershed. Environmental Pollution, 144: 967-975.

Braun-Blanquet J., 1928. Pflanzensoziologie. Grundzüge der Vegetationskunde. 1 ed. Berlin.

Braun-Blanquet J., 1964. Pflanzensoziologie. Grundzüge der Vegetationskunde. 3 ed. Wien-New York.

Brix H., 1999. The European research programme on reed die–back and progression (EUREED). Limnologica, 29: 5-10.

Brock T.C.M., Van Der Velde G. & Van De Steeg H.M., 1987. The effects of extreme water level fluctuations on the wetland vegetation of a Nymphaeid-dominated oxbow lake in the Netherlands. Arch. Hydrobiol., 27: 57-73.

Brülisauer A. & Klötzli F., 1998. Habitat factors related to the invasion of reeds (*Phragmites australis*) into wet meadows of the Swiss Midlands. Z. Ökol. u. Naturschutz, 7(3): 125-136.

Brusa G., Raimondi B. & Cerabolini B., 2006. La vegetazione della Riserva Naturale "Lago di Biandronno" (Lombardia, Italia Settentrionale). Fitosociologia, 43(2): 111-128.

Ceschin S. & Salerno G., 2008. La vegetazione del basso corso del Fiume Tevere e dei suoi affluenti (Lazio, Italia). Fitosociologia, 45(1): 39-74.

Chambers R.M., Meyerson L.A. & Saltonstall K., 1999. Expansion of *Phragmites australis* into tidal wetlands of North America. Aquat. Bot., 64: 261-273.

Chytrý M., Pyšek P., Tichý L., Knollová I. & Danihelka J., 2005. Invasions by alien plants in the Czech Republic: a quantitative assessment across habitats. Preslia, 77: 339-354.

Chytrý M., Wild J., Pyšek P., Tichý L., Danihelka J. & Knollová I., 2009. Maps of the level of invasion of the Czech Republic by alien plants. Preslia, 81: 187-207.

Cízková H., Strand J. & Lukavská J., 1996. Factors associated with reed decline in a eutrophic fishpond, Rozmberk (South Bohemia, Czech Republic). Folia Geobot. Phytotax, 31: 73-84.

Cízková-Koncalová H., Kvet J. & Thompson K., 1992. Carbon starvation: a key to reed decline in eutrophic lakes. Aquat. Bot., 43: 105-113.

Clevering O.A., 1998. Effects of litter accumulation and water table on morphology and productivity of *Phragmites australis*. Wetlands Ecology and Management, 5(4): 275-287.

Clevering O.A. & Van Der Putten W.H., 1995. Effects of detritus accumulation on the growth of *Scirpus maritimus* under greenhouse conditions. Can. J. Bot., 73: 852-861.

Conti F., Abbate G., Alessandrini A. & Blasi C. (Eds.), 2005. An annotated check-list of the italian vascular flora. Palombi Ed., Roma.

De Bartolomeo A., Poletti L., Sanchini G., Sebastiani B. & Morozzi G., 2004. Relationship among parameters of lake polluted sediments evaluated by multivariate statistical analysis. Chemosphere, 55: 1323-1329.

De Martis G. & Serri G., 2009. L'analisi fitosociologica della vegetazione per il monitoraggio degli habitat nel Parco Naturale Regionale Molentargius-Saline (Sardegna meridionale). Primi risultati. Inf. Bot. Ital., 41(2): 293-301.

Den Hartog C., Kvet J. & Sukopp H., 1989. Reed. A common species in decline. Aquat. Bot., 35(1): 1-4.

Diekmann M., 2003. Species indicator values as an important tool in applied plant ecology - a review. Basic Appl. Ecol., 4: 493-506.

Ellenberg H., 1974. Zeigerwerte der Gefässpflanzen Mitteleuropas. Scripta Geobot., 9. Göttingen. 97 pp.

Ellenberg H., Weber H.E., Düll R., Wirth V., Werner W. & Paulissen D., 1991. Zeigerwerte von Pflanzen in Mitteleuropa. Scripta Geobot., 18: 1-248.

Fogli S., Marchesini R. & Gerdol R., 2002. Reed (*Phragmites australis*) decline in a brackish wetland in Italy. Marine Env. Research, 53: 465-479.

Gambini E., 1995. Le oscillazioni di livello del lago Trasimeno. Quaderni del Museo della Pesca del Lago Trasimeno, 2. Grafiche Piemme, Perugia. 139 pp.

Gerdol R., 1987. Geobotanical investigations in the small lakes of Lombardy. Atti Ist. bot. Lab. crittogam. Univ. Pavia, s. 7, 6: 5-49.

Gigante D., Acosta A.T.R., Agrillo E., Attorre F., Cambria V.M., Casavecchia S., Chiarucci A., Del Vico E., De Sanctis M., Facioni L., Geri F., Guarino R., Landi S., Landucci F., Lucarini D., Panfili E., Pesa-resi S., Prisco I., Rosati L., Spada F. & Venanzoni R., 2012. VegItaly: Technical features, crucial issues and some solutions. Plant Sociology, 49(2): 71-79.

Gigante D., Ferranti F., Reale L., Venanzoni R. & Zuccarello V., 2010. Nuovi dati sul declino della popolazione di *Phragmites australis* al Lago Trasimeno. In: Bottarin R., Schirpke U., Tappeiner U., Oggioni A., Bolpagni R. (Eds.), Macrofite & Ambiente, Atti XIX S.It.E. Congress, Vol. 3: 23–41. ISBN: 9788888906577

Gigante D. & Venanzoni R., 2007. Some remarks about the annual subnitrophilous vegetation of the *Thero-Brometalia* order in Umbria (central Italy). Lazaroa, 28: 15-34.

Gigante D. & Venanzoni R., 2012. Il declino della popolazione di *Phragmites australis* al Lago Trasimeno. In: Martinelli A. (Ed.), Tutela Ambientale del lago Trasimeno: 109-120. Libri/A.R.P.A. Umbria. ISSN: 978-88-905920-03

Gigante D., Venanzoni R. & Zuccarello V., 2008. Detection of reed–bed decline and die–back at the Lake Trasimeno (central Italy). In: Mucina L., Kalwij J.M., Smith V.R., Chytrý M., White P.S., Cillier S.S., Pillar V.D., Zobel M., Sun I.-F. (Eds.), Frontiers of Vegetation Science - An Evolutionary Angle: 62–63.

Gigante D., Venanzoni R. & Zuccarello V., 2011. Reed die-back in southern Europe? A case study from Central Italy. Comptes Rendus Biologies, 334(4): 327-336. Elsevier.

Gopal, B. & Goel U., 1993. Competition and allelopathy in aquatic plant communities. Botanical Review, 59: 155-210.

Granéli W., 1989. Influence of standing litter on shoot production in reed, *Phragmites australis* (Cav.) Trin. ex Steudel. Aquat. Bot., 35(1): 99-109.

Greco G. & Patocchi N., 2003. Parametri topologici, pedologici e floristici caratterizzanti la formazione di pseudocanneti in ambienti palustri aperti alle Bolle di Magadino (Svizzera meridionale). Studi Trent. Sci. Nat., Acta Biol., 80: 253-255.

Hellings S.E. & Gallagher J.L., 1992. The effects of salinity and flooding on *Phragmites australis*. J. of Applied Ecology, 29: 41-49.

Hill M.O. 1973. Diversity and evenness: a unifying notation and its consequences. Ecology, 54: 427-432.

Hill M.O. & Carey P.D., 1997. Prediction of yield in the Rothamsted Park grass experiment by Ellenberg indicator values. J. Veg. Sci., 8: 579-586.

Iberite M., Palozzi A.M. & Resini A.M., 1995. La vegetazione del lago di Bolsena (Viterbo, Italia centrale). Fitosociologia, 29: 151-164.

Jurko A., 1984. Ökologische Indikationswerte der Pflanzengesellschaften der Ostslowakischen Tiefebene. Ekológia (CSSR), 3: 413-425.

Kettenring K.M., McCormick M.K., Baron H.M. & Whigam D.F., 2011. Mechanisms of *Phragmites au-*

stralis invasion: feedbacks among genetic diversity, nutrients, and sexual reproduction. J. Applied Ecology, 48: 1305-1313.

Klötzli F., 1971, Biogenous influence on aquatic macrophytes especially *Phragmites communis*. Hidrobiologia, 12: 107-111.

Landi M., Angiolini C. & De Dominicis V., 2002. Analisi fitosociologica dei fiumi della Toscana meridionale: il tratto medio-basso del Merse (Italia centrale). Stud. Bot., 21: 37-88.

Landucci F., Gigante D. & Venanzoni R., 2011. An application of the Cocktail Method for the characterization of the hydrophytic vegetation at Lake Trasimeno (Central Italy). Fitosociologia, 48(2): 3-22.

Landucci F., Gigante D., Venanzoni R. & Chytrý M., 2013 (in press). Wetland vegetation of the class *Phragmito-Magno-Caricetea* in central Italy. Phytocoenologia, 43(1). doi: 10.1127/0340-269X/2013/0043-0545

Landucci F., Acosta A.T.R., Agrillo E., Attorre F., Biondi E., Cambria V.M., Chiarucci A., Del Vico E., De Sanctis M., Facioni L., Geri F., Gigante D., Guarino R., S. Landi, Lucarini D., Panfili E., Pesaresi S., Prisco I., Rosati L., Spada F. & Venanzoni R., 2012. VegItaly: The Italian collaborative project for a national vegetation database. Plant Biosystems, 146(4): 756-763.

Lastrucci L., Paci F. & Raffaelli M., 2010. The wetland vegetation of the Natural Reserves and neighbouring stretches of the Arno river in the Arezzo province (Tuscany, Central Italy). Fitosociologia, 47(1): 31-61.

Lazzerini G., Todini B. & Ciccarelli D., 2011. Prime valutazioni ecologiche sulle macrofite del Trasimeno. In: Martinelli A. (Ed.), Tutela Ambientale del lago Trasimeno: 100-108. Libri/A.R.P.A. Umbria. ISSN: 978-88-905920-03

Lenssen J.P.M., Menting F.B.J., Van Der Putten W.H. & Blom C.W.P.M., 1999. Effects of sediment type and water level on biomass production of wetland plant species. Aquat. Bot., 64: 151-165.

Mäemets H. & Freiberg L, 2004. Characteristics of reeds on Lake Peipsi and the floristic consequences of their expansion. Limnologica, 34: 83-89.

Maiorca G., Spampinato G. & Caprio A., 2002. Flora e vegetazione dei laghi costieri La Vota (Calabria centro-occidentale). Fitosociologia, 39(1): 81-108.

Marks M., Lapin B. & Randall J., 1994. *Phragmites australis* (*P. communis*): threats, management and monitoring. Natural Areas Journal, 14: 285-294.

Ostendorp W., 1989, 'Die-back' of reeds in Europe - a critical review of literature. Aquat. Bot., 35(1): 5-26.

Otýpková Z., Chytrý M., Tichý L., Pechanec V., Jongepier J.W. & Hájek O., 2011. Floristic diversity patterns in the White Carpathians Biosphere Reserve, Czech Republic. Biologia, 66(2): 266-274.

Patrick Z., Toussoun T. & Koch L., 1964. Effect of crop residue decomposition products on plant roots. Ann. Rev. Phytopath., 2: 267-292.

Persson S., 1980. Succession in a south Swedish deciduous wood: a numerical approach. Vegetatio, 43: 103-122.

Philippi G, 1977. Klasse: *Phragmitetea* Tx. et Prsg. 42. In: Oberdorfer E. (Ed.), Süddeutsche Pflanzengesellschaften, Teil I: 119-165. Gustav Fischer Verlag, Stuttgart-New York.

Pieczyńska E., 1993. Detritus and nutrient dynamics in the shore zone of lakes: a review. Hydrobiologia, 251: 49-58.

Pielou E.C. 1975. Ecological diversity. John Wiley and Sons, Inc. New York, NY.

Pignatti S., 2005. Valori di Bioindicazione delle piante vascolari della flora d'Italia. Braun-Blanquetia, 39. Camerino.

Pirone G., Ciaschetti G., Frattaroli A.R. & Corbetta F., 2003. La vegetazione della Riserva Naturale Regionale "Lago di Serranella" (Abruzzo - Italia). Fitosociologia, 40(2): 55-71.

Presti G., Di Filippo C. & Blasi C., 2004. La vegetazione igrofila del Monumento Naturale Pantane e Lagusiello (Lazio centrale). Inf. Bot. Ital., 36(2): 401-408.

Raspopov I.M., Adamec L. & Husák S., 2002. Influence of aquatic macrophytes on the littoral zone habitats of the Lake Ladoga, NW Russia. Preslia, 74: 315-321.

Rea N., 1996. Water levels and Phragmites: decline from lack of regeneration or dieback from shoot death. Folia Geobot. Phytotax., 31: 85-90.

Reale L., Gigante D., Landucci F., Ferranti F. & Venanzoni R., 2012. Morphological and histo-anatomical traits reflect die-back in *Phragmites australis* (Cav.) Steud. Aquat. Bot., 103: 122-128. Elsevier.

Reale L., Gigante D., Landucci F., Venanzoni R. & Ferranti F., 2011. Correlation between sexual reproduction in *Phragmites australis* and die-back syndrome. The International Journal of Plant Reproductive Biology, 3(2): 133-140. ISSN: 0975-4296

Riis T. & Hawes I., 2002. Relationships between water level fluctuations and vegetation diversity in shallow water of New Zealand lakes. Aquat. Bot., 74:133-148.

Rivas-Martínez S., Fernández-Gonzalez F., Loidi J., Lousã M. & Penas A., 2001. Syntaxonomical checklist of vascular plant communities of Spain and Portugal to association level. Itin. Geobot., 14: 5-341.

Rivas-Martínez S. & Rivas-Saenz S., 2009. Worldwide Bioclimatic Classification System, 1996-2009. Phytosociological Research Center, Spain. [available online at: http://www.globalbioclimatics.org]

Rivas-Martínez S., Sánchez Mata D. & Costa M., 1999. North American boreal and western temperate

forest vegetation. It. Geobot., 12: 5-316.

Saltonstall K., 2002. Cryptic invasion by a non-native genotype of the common reed, *Phragmites australis,* into North America. PNAS, 99(4): 2445-2449.

Schaffers A.P. & Sýkora K.V., 2000. Reliability of Ellenberg indicator values for moisture, nitrogen and soil reaction: a comparison with field measurements. J. Veg. Sci., 11: 225-244.

Schierup H.H. & Larsen V.J., 1981. Macrophyte cycling of zinc, copper, lead and cadmium in the littoral zone of a polluted and a non-polluted lake. I. Availability, uptake and translocation of heavy metals in *Phragmites australis* (Cav.) Trin. Aquat. Bot., 11: 197-210.

Schmieder K., 2004. European lake shores in danger - concepts for a sustainable development. Limnologica, 34: 3-14.

Schmieder K., Dienst M. & Ostendorp W., 2002. Auswirkungen des Extremhochwassers 1999 anf die Flächendynamik und Bestandsstruktur der Uferröhrichte des Bodensees. Limnologica, 32: 131-146.

Schröder R., 1987. Das Schilfsterben am Bodensee-Untersee: Beobachtungen, Untersuchungen und Gegenmassnahmen. Arch. Hydrobiol., Suppl. 76: 53-99.

Sharma K.P., Khushwaha S.P.S. & Gopal. B., 1990. Autotoxic effect on *Phragmites karka* (Retz) Trin. ex Steud. plant on its seed germination. Geobios, 17: 287-288.

Simpson E. H., 1949. Measurement of diversity. Nature, 163: 688.

Skaffers A.P. & Sykora K.V., 2000. Reliability of Ellenberg indicator values for moisture, nitrogen and soil reaction: a comparison with field measurements. J. Veg. Sci., 11: 225-244.

Sukopp H. & Markstein B., 1989. Changes of the reed beds along the Berlin Havel. Aquat. Bot., 35: 27-40.

Szczepanska W., 1971, Allelopathy among the aquatic plants. Pol. Arch. Hydrobiol., 18: 17-30.

Talley T.S. & Levin L.A., 2001. Modification of sediments and macrofauna by an invasive marsh plant. Biological invasions, 3: 51-68.

Ter Braak C.J.F. & Barendregt L.G., 1986. Weighted averaging of species indicator values: its efficiency in environmental calibration. Math. Biosci., 78: 57-72.

Ter Braak C.J.F. & Gremmen N.J.M., 1987. Ecological amplitudes of plant species and the internal consistency of Ellenberg's indicator values for moisture. Vegetatio, 69: 79-87.

Tichý L., 2002. JUICE, software for vegetation classification. J. Veg. Sci. 13: 451-453.

Tomaselli V., Perrino E.V. & Cimmarusti G., 2008. Paludi Sfinale e Gusmay, due aree umide di rilevante interesse naturalistico nel Parco Nazionale del Gargano. Inf. Bot. Ital., 40(2): 183-192.

Tscharntke T., 1983. Klärteiche - Feuchtgebiete in einer ausgeräumten Kulturlandschaft. Natur Landschaft, 58: 333–337.

Van Der Putten W.H., 1993, The effects of litter on the growth of *Phragmites australis*. In: Ostendorp W., Krumscheid–Plankert R. (Eds.), Seeuferzerstörung und Seeuferrenaturierung in Mitteleuropa. Limnologie Aktuell, 5: 19-22.

Van Der Putten W.H., 1997, Die-back of *Phragmites australis* in European wetlands: an overview of the European Research Programme on reed die-back and progression (1993-1994). Aquat. Bot., 59: 263-275.

Van Der Putten W.H., Peters B.A.M. & Van Den Berg M.S., 1997. Effects of litter on substrate conditions and growth of emergent macrophytes. New Phytol., 135: 527-537.

Van Geest G.J., Wolters H., Roozen F.C.J.M., Coops H., Roijackers R.M.M., Buijse A.D. & Scheffer M., 2005. Water-level fluctuations affect macrophyte richness in floodplain lakes. Hydrobiologia, 539: 239-248.

Venanzoni R., Apruzzese A., Gigante D., Suanno G. & Vale F., 2003. Contributo alla conoscenza della vegetazione acquatica e igrofitica dei Laghi di Monticchio. Inf. Bot. Ital., 35(1): 69-80.

Venanzoni R. & Gigante D., 2000. Contributo alla conoscenza della vegetazione degli ambienti umidi dell'Umbria (Italia). Fitosociologia, 37(2): 13-63.

Venanzoni R., Landucci F., Panfili E. & Gigante D., 2012. Toward an Italian national vegetation database: VegItaly. In: Dengler J., Oldeland J., Jansen F., Chytrý M., Ewald J., Finckh M., Glöckler F., Lopez-Gonzalez G., Peet R.K. & Schaminée J.H.J. (2012) [Eds.], Vegetation databases for the 21st century. Biodiversity & Ecology, 4: 185-190. ISSN: 1613-9801

Wamelink G.W.W., Joosten V., van Dobben H.F. & Berendse F., 2002. Validity of Ellenberg indicator values judged from physico-chemical field measurements. J. Veg. Sci., 13: 269-278.

Weisner S.E.B., 1996. Effects of an organic sediment on performance of young *Phragmites australis* clones at different water depth treatments. Hydrobiology, 330: 189-194.

Weisner S.E.B. & Graneli W., 1989. Influence of substrate conditions on the growth of *Phragmites australis* after a reduction in oxygen transport to below-ground parts. Aquat. Bot., 35: 71-80.

Westlake D.F., Kvĕt J. & Szczepanski A. (Eds.), 1998. Production ecology of wetlands. Cambridge Univ. Press, Cambridge.

Wetzel R.G., 1989. Land-water interfaces metabolic and limnological regulators. Ver. Int. Ges. Limnol., 24: 6-24.

Wetzel R.G., 2001. Limnology. 3rd ed. Academic

Press. London, 1006 pp.

Windham L. & Meyerson L., 2003. Effects of Common Reed (*Phragmites australis*) expansions on nitrogen dynamics of tidal marshes of the Northeastern U.S. Estuaries, 26: 452-464.