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

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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 Saviè 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 (Fogli 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...
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-Blanquet’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...
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 affects 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-

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 association **Phragmitetum australis**. AnArchive (Lucarini et al., 2015). For the syntaxonomic framing, we followed the standards proposed by Biondi & Blasi (2013) and Biondi et al. (2014).
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 reversed 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...
Phytocoenotic survey on reed die-back

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).

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 FucecchioMarsh, rather poor and including only 5 species per relevé on average ± 0.8 (SE). Besides P. australis, the only taxon in 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.

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, Lyopus europaeus, Carex riparia. The only constant presence, although not suitable as an indicator species being also present in other groups, is Calystegia sepium.

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).
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 submergence, 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 minor submergence period. 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).
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 coefficient, 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 the 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.

**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 coefficient points out a statistically significant presence of five species: two perennial nitrophilous (Urtica dioica, Galium aparine), one hygro-subnitrophilous (Eupatorium cannabinum) and two hygro-nitrophilous taxa typical of palustrine vegetation (Linum inigoirius, Scutellaria galericulata). Also in this case, like for the Groups III and V, the environmental conditions are featured by a period of erosion 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.

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

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<td>9</td>
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<td>1</td>
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<td>+</td>
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**Tab. 6 - Group VI: Phragmitetum australis Savić 1926, nitrophilous variant with Urtica dioica.**

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<tr>
<td>Dominant species</td>
<td>Phragmites australis (Cav.) Steud.</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

---

**Phytocoenotic survey on reed die-back**

21
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-Urticetalia Passarge ex Köpecký 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-Urticetalia (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, Rel. 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 (Rel. N. 68, 71, 72). From the phytosociological point of view, they are interpreted as a transitional variant towards the association Schoenoplectetum lacustris Choudar 1924, observed in the site. The reed-dominated community developed on emerging sediment (Rel. 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

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

<table>
<thead>
<tr>
<th>Rel. N.</th>
<th>76</th>
<th>79</th>
<th>68</th>
<th>71</th>
<th>72</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot ID</td>
<td>HEG012</td>
<td>HEG015</td>
<td>HEG004</td>
<td>HEG007</td>
<td>HEG008</td>
</tr>
<tr>
<td>Group N.</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Water depth (cm)</td>
<td>0.0</td>
<td>0.0</td>
<td>37.7</td>
<td>36.3</td>
<td>119.3</td>
</tr>
<tr>
<td>Clamping rate (%)</td>
<td>3.8</td>
<td>3.0</td>
<td>34.3</td>
<td>100.0</td>
<td>75.0</td>
</tr>
<tr>
<td>Number of species per relevé</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

---

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

<table>
<thead>
<tr>
<th>Rel. N.</th>
<th>60</th>
<th>29</th>
<th>30</th>
<th>27</th>
<th>32</th>
<th>25</th>
<th>28</th>
<th>31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot ID</td>
<td>HEG012</td>
<td>HEG013</td>
<td>HEG014</td>
<td>HEG015</td>
<td>HEG016</td>
<td>HEG009</td>
<td>HEG002</td>
<td>HEG015</td>
</tr>
<tr>
<td>Group N.</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Water depth (cm)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Clamping rate (%)</td>
<td>7.7</td>
<td>0.0</td>
<td>0.0</td>
<td>6.9</td>
<td>0.0</td>
<td>0.0</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td>Number of species per relevé</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>16</td>
<td>11</td>
<td>9</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

---

**Dominant species**

- Phragmites australis (Cav.) Steud. 5 5 5 5 5 5 4 5 8
- Phragmites communis var. australis 4 5 3 3 3 5
- Schoenoplectus lacustris (L.) Palla 2 2 2 2 2 2 2 2 2
- Phalaris arundinacea L. 2 2a 2a 2a 2a
- Nymphaea alba L. 2 2a 2a 2a 2a

**Sporadic species**

- Juncus effusus L. 2 2a 2a 2a 2a
- Galium palustre L. 2 2a 2a 2a 2a
- Persicaria amphibia (L.) Delarbre 2 2a 2a 2a 2a
- Solanum dulcamara L. 2 2a 2a 2a 2a
- Bidens frondosa L. 2 2a 2a 2a 2a
- Oenanthe aquatica (L.) Poir. 2 2a 2a 2a 2a
- Persicaria hydropiper (L.) Delarbre 2 2a 2a 2a 2a
- Persicaria bistorta (L.) Delarbre 2 2a 2a 2a 2a
- Persicaria amphibia (L.) Delarbre 2 2a 2a 2a 2a
- Equisetum arvense L. 2 2a 2a 2a 2a
- Calamagrostis epigejos (L.) Trin. 2 2a 2a 2a 2a
- Sporadic species 2 2a 2a 2a 2a
### 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).

<table>
<thead>
<tr>
<th>Group N.</th>
<th>Number of relevés</th>
<th>Average water depth (cm)</th>
<th>Average clumping rate (%)</th>
<th>Average number of species per relevé</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 3 4 5 6 7 8</td>
<td>59.9 6.93 0.0 33.0 0.0 38.7 0.0</td>
<td>45.3 6.4 10.4 44.5 0.6 37.4 2.6 2.5</td>
<td>1 5 5 3 11 10 3 9</td>
</tr>
</tbody>
</table>

- **Indicator species Group 4**
  - Myriophyllum spicatum L.
  - Najas marina L.

- **Indicator species Group 5**
  - Echinocystis crus-galli (L.) P. Beauv.
  - Eclipta prostrata (L.) L.
  - Amorpha fruticosa L.

- **Xanthium orientale L. subsp. italicum (Moretti)**

- **Indicator species Group 6**
  - Lythrum salicaria L.
  - Potamogeton lucens L.

- **Indicator species Group 7**
  - Elymus repens (L.) Gould
  - Salix purpurea L.
  - Eupatorium cannabinum L.

- **Indicator species Group 8**
  - Lycopus europaeus L.
  - Thalictrum lucidum L.

#### Other species
- Solanum dulcamara L.
- Rubus ulmifolius Schott
- Plantago major L.
- Cirsiurn arvense (L.) Scop.
- Salix cinerea L.
- Cornus sanguinea L.
- Juncus conglomeratus L.
- Stellaria media (L.) Vill.
- Eriogonum bonariense L.
- Samolus valerandi L.
- Symphytum officinale (Spreng.) G.L.
- Nasonia trifurcata (L.) Vill.
- Artemisia vulgaris L.
- Elymus repens (L.) Gould
- Salix purpurea L.
- Sambucus ebulus L.
- Solanum nigrum L.
- Equisetum arvense L.
- Equisetum palustre L.
- Equisetum arvense L.

- **Phragmone-Magnocaricateae**
  - Phragmites australis (Cav.) Steud.
  - Mentha aquatica L.
  - Lythrum salicaria L.
  - Calystegia sepium (L.) R. Br.
  - Oenanthe aquatica (L.) Poir.
  - Carex riparia Curtis
  - Galium palustre L.

- **Phragmone-Composito-Urticetea**
  - Barbaris vulgaris W.T. Aiton
  - Stachys palustris L.
  - Galega officinalis L.
  - Thalictrum lucidum L.
  - Epilobium hirsutum L.
  - Cirsium arvense (L.) d’Urv. subsp. triumfettii (Lacaita) K. Werner

### Discussion and conclusion 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 phenomenon.

Although the common reed-dominated vegetation is a typically species-poor phytocoenosis (see, e.g., Philippi, 1977; Gerold, 1987; Balátová-Tuláčkova 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 nitrophyll and hydrophyll, 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 clamping 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; Cizková et al., 1996; Schmieder et al., 2002) and that, in general, prolonged submergence or lack of drying up can often co-occur 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 hygrophyllous *taxis* (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 *taxis* (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*

**Acknowledgements**

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**References**


Phytocoenotic survey on reed die-back


Gigante D., Venanzoni R. & Zuccarello V., 2011. Reed die-back in southern Europe? A case study from Cen-
Lucarini D., Gigante D., Landucci F., Panfili E. & Venanzoni R. 2015. The anArchive taxonomic Chec-

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].

