C. R. Biologies 335 (2012) 69–76

Contents lists available at SciVerse ScienceDirect

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Biodiversity/Biodiversité

Diversity and ecological characteristics of vascular flora in Mediterranean temporary pools

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ARTICLE INFO

Article history:
Received 11 January 2011
Accepted after revision 28 October 2011
Available online 8 December 2011

Keywords:
Biodiversity conservation
Ellenberg indicator values
Life forms
Ponds
Richness
Sardinia
Wetlands

ABSTRACT

Vascular flora of Mediterranean temporary pools has been studied with the aims to define its diversity and to individuate the ecological characteristics of the different plant groups associated with this relevant and endangered habitat type. Overall, 246 species were found of which 108 were terrestrial, 57 generalist of aquatic or wet habitats and 81 typical of temporary water and strongly linked to temporary pools. The results suggest that: (i) vascular flora associated with Sardinian Mediterranean temporary pools is rich and diversified; (ii) rare ferns are better represented than previously reported; (iii) plant species are generally heliophilous and acidophilous, specialized temporary pool species mainly differing from the unspecialized ones in relationship to their soil moisture requirements; (iv) these habitats are particularly important for maintaining regional freshwater biodiversity.

1. Introduction

Temporary pools are usually small (< 10 ha in area) and shallow wetlands which are characterized by an alternation of flooded and dry phases, and whose hydrology is largely autonomous. They occupy depressions, often endorheic, which are flooded for a sufficiently long period to allow the development of hydromorphic soils and wetland-dependent aquatic or amphibious vegetation and fauna communities [1]. In the Mediterranean bioclimatic region, temporary pools are recognised to be amongst the most interesting habitats from a biological and biogeographic point of view [2], and in Europe, they are considered habitats of Community Interest [3].

At the landscape scale, temporary pools can host surprisingly high levels of species diversity [4] and contribute disproportionately to biodiversity in comparison to other water-body types, such as ditches, streams and rivers [5].

Temporary pool vascular flora is characterized by considerable morphological, taxonomic, and ecological heterogeneity, which is represented by a *continuum* ranging from species capable of tolerating flooded soils, through amphibious groups adapted to live on land or in water, to submerged aquatic plants adapted to growing in deep water [6]. The high species turnover during the same growing season is mainly due to the ability of many species (e.g. tenagophytes) to germinate under water and to finish their life cycle in the terrestrial phase and to the need of other species to germinate in waterlogged or even in dry conditions [7].

Due to the short size of several species living in this habitat, Diels [8] introduced the definition "dwarf flora," to describe its flora. Two plant strategy types predominate in Mediterranean temporary pools: (i) dwarf annuals and (ii) dwarf geophytes. Dwarf annuals (e.g. *Cicendia filiformis*, *Radiola linoides* or *Exaculum pusillum*) show several structural adaptations to the ephemeroid life form [9], such as the ability to germinate in an opportunistic manner

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1631-0691/$ – see front matter
doi:10.1016/j.crvi.2011.10.005

from a permanent seed bank, to flower with a very small vegetative apparatus and to fructify within a few weeks after germination. Dwarf geophytic plants include slow-growing, stress-tolerant perennials with the Isoetid syndrome [7]. Considering these characteristics, it is possible to pick out groups of plant species particularly suitable and linked to temporary pools, which are considered characteristic of the habitat. Nevertheless, together with this very specialized flora, temporary pools host several species not specialized for this type of habitat, such as hygrophilous and aquatic or terrestrial species [10–14]. The first category is present when and where the water is deeper and the flooding period is long enough to allow their survival; the second category comprises mainly opportunistic species that occur in the peripheral areas or move toward the center during the drying period.

Temporary pools are highly vulnerable due to their shallow water and their frequently small surface area. Furthermore, the species which colonize them are often inconspicuous, exhibit a very short life cycle and are poorly studied and documented [15]. For these reasons, there is a need for data sets covering the important gaps in our knowledge, as well as for an integration of the already existing data [16,17].

The objectives of this study were: (i) to define vascular flora diversity in Sardinian Mediterranean temporary pools; and (ii) to individuate the ecological characteristics of the different plant groups associated to temporary pools with the aim to establish a useful base to better direct management strategies.

2. Materials and methods

2.1. Study area

The study was carried out in Sardinia, which is located in a central position of the western Mediterranean area, considered to host the more interesting temporary pool floristic assemblages of the Mediterranean biogeographical region [2].

Although the territory is mainly mountainous, the average altitude is not very high (334 m a.s.l.). Temporary pools are mainly located in the large tablelands that divide the reliefs and in the lowlands, where they occupy depressions characterized by soils with a clay texture and slow drainage along an altitudinal range of 10–1100 m a.s.l. Tableland landscape is characterized by neutroacidophilic cork oak (*Quercus suber*) woods, subjected to pastoral use and often converted to wooded pastures (*dehesa* landscape), and by deciduous oak woods, dominated by *Quercus ichnusae*, widely distributed in central-northern Sardinia on noncarbonatic substrata. Lowland landscape is characterized by edaphomesophilous holm oak (*Quercus ilex*) and cork oak (*Quercus suber*) vegetation in the alluvial plains of a mixed clay–sand matrix, on soils that are moderately hydromorphic [18]. According to the classification proposed by Rivas-Martínez et al. [19], bioclimate ranges from meso-Mediterranean (average temperature: 15 °C, annual rainfall: 946 mm) to temperate sub-Mediterranean (average temperature: 10 °C, annual rainfall: 1000 mm).

The main vernacular names in use for temporary pools in the island are *paule* or *pischina*. As testified by the widespread use of these names, temporary pools occupied large areas in the past, but during the past centuries, they were reclaimed for agricultural activities.

2.2. Data collection and analysis

Plant checklist was based on several field trips carried out in different seasons, in the years 2008–2010 in about 50 temporary pools spread in the whole island. The data were compared and integrated with published plant inventories [10,11,20–29] and herbarium surveys carried out in CAG, FI, SS, SASSA and TO.

Plants were classified following Pignatti [30] and Tutin et al. [31]. Nomenclature follows Conti et al. [32], except for the taxa marked with *, for which nomenclature follows Pignatti [30]. To define the main traits of the flora, each taxon was framed according to the phytosociological class [19]; life form according to Raunkiaer [33] and deduced from Pignatti [30]; spatial distribution corresponding to chorological types [30]; and Ellenberg indicator values [34], following the proposal for the Italian flora [35] where each indicator is described on a 9- or 12-level scale. Ellenberg indicator values [36] summarize the ecological optimum for vascular plants by assigning to each species indicator values for seven ecological factors: light regime, soil moisture, nitrogen status, soil reaction, temperature, continentality, and salinity. They have been widely used as indirect metrics of environmental conditions in aquatic and wet habitats [37,38] and to define plant traits [39]; therefore, they should be suitable in the assessment of ecological characteristics of vascular flora associated with temporary pools.

The species were split into three subsets based on their level of dependence from temporary pools: (i) terrestrial species (ter); (ii) generalist aquatic or hygrophilous species (gen), living in water or in any kind of wet habitat; and (iii) temporary water species (tw), typical of temporary water and strongly linked to temporary pools. To define the subsets, we considered the phytosociological classes to which each species was ascribed, following the ecological systematization of the vascular vegetation classes of Europe [19] as already reported in Bagella et al. [12]. This high-rank syntaxon defines the common ecological space of the included plant associations [40].

The contribution of each phytosociological class, family, life form, and chorological type to the total richness and the richness of each subset (e.g., ter, gen, and tw) was quantified. The spectra obtained for each of the attributes and subsets were compared with each other to recognize the main peculiarities of each subset in comparison with the other components of the vascular flora associated with temporary pools.

For each environmental factor, the percentage of species ascribed to each level was assessed considering the entire set of plants and the three subsets.

The comparisons were carried out using the Fisher's Exact Test, following Agresti [41] for the calculation of p-values.

3. Results

Overall, 246 species belonging to 25 phytosociological classes and 40 families were found in Sardinian temporary pools (Appendix 1).

The largest group of species belonged to the *Isoëto-Nanojuncetea* class (33%), followed by *Molinio-Arrhenatheretea* (12%), *Stellarietea mediae* (11%), *Helianthemetea guttati* (10%), *Artemisietea vulgaris* (7%), *Poetea bulbosae* (5%), and *Phragmito-Magnocaricetea* (4%), all the other classes included less than 10 species each. The best-represented family was that of *Poaceae* (17%), followed by *Fabaceae* (8%); *Juncaceae*, *Asteraceae*, and *Ranunculaceae* (6%); and *Cyperaceae* (5%) (Fig. 1). Among life forms, therophytes were the dominant, representing more than 50% of the total (Fig. 2), whereas the dominant chorological type was euri-Mediterranean (Fig. 3).

The three subsets—ter, gen, tw—comprised, respectively, 108 (44%), 57 (23%), and 81 (33%) species. Terrestrial plants constituted a heterogeneous group, which included mainly species belonging to ubiquitous or synanthropic plant communities, such as, according to Rivas-Martínez et al. [19], annual ephemeral weeds, ruderal, nitrophilous, and semi-nitrophilous species (*S. mediae*); perennial and tall biennal forbs, grasses, thistles, pioneer ruderal, and nitrophilous sunny communities (*A. vulgaris*); dwarf perennial grasses favored by sheep pastures, grazed and manured (*P. bulbosae*); annual pioneer ephemeral nitrophilous species of heavy-trodden urban and rural paths (*Polygono-Poetea annuae*). Nevertheless, non-nitrophilous annual short herbs and grasses (*Helianthemmetea guttati*) and pioneer ephemeral plants typical of bare salt marshes (*Saginetea maritimae*) were also present. The ter contingent, originating from the surrounding area, is thus due to both the long dry period that characterizes these habitats and the anthropic activities.

On the contrary, 24% of the species were indicated as belonging to gen. They included a contingent of species typical of wet, often-manured meadows and pasture communities on deep and moist soils (*Molinio-Arrhenateretea*) and a contingent of typical aquatic species: perennial graminoids, sedges, forbs, and herbs of fresh waters (*Phragmito-Magnocaricetea*); aquatic freshwater macrophytes (*Potametea*); and dwarf amphibious helophytes (*Isoëto-Littorelletea*).

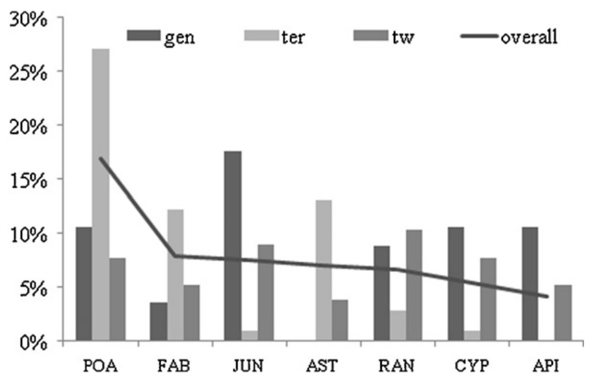

Fig. 1. Contribution of the most abundant families to the temporary pool vascular flora (overall) and to the three subsets (ter, gen, and tw). Families representing at least 10% of the flora in each of the three subsets are represented. API: Apiaceae; AST: Asteraceae; CYP: Cyperaceae; FAB: Fabaceae; JUN: Juncaceae; POA: Poaceae; RAN: Ranunculaceae.

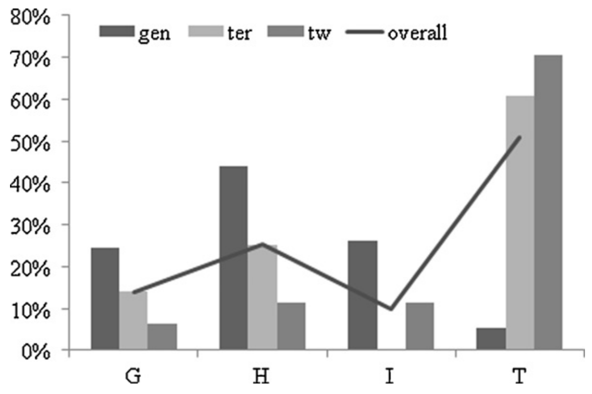

Fig. 2. Biological spectra relative to the temporary pool vascular flora (overall) and the three subsets (gen, ter and tw). G: Geophytes; H: Hemicriptophytes; I: Hydrophytes; T: Therophytes.

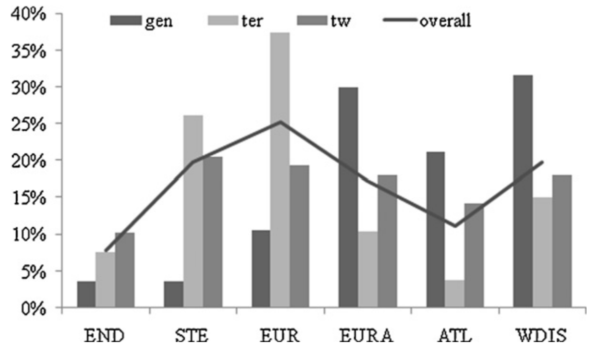

Fig. 3. Chorological spectra relative to the temporary pool vascular flora (overall) and the three subsets (gen, ter and tw). ATL: Atlantic; END: endemic; EUR: euri-Mediterranean; EURA: Eurasiatic; STE: steno-Mediterranean; WDIS: wide distribution.

The third group included the species characteristic of the temporary pools and strongly dependent on them. They all belonged to the best-represented class, the *Isoëto-Nanojuncetea*, which includes pioneer annual and dwarf perennial. Ephemeral, isoetid communities growing on periodically flooded bare soils [19].

Family composition showed strong differences between the ter and the other two subsets (e.g., tw and gen), the latter being richer in terms of plants belonging to *Juncaceae*, *Cyperaceae,* and *Apiaceae* (Fig. 1, Table 1). Nevertheless, the relevance of the families *Lythraceae*, *Isoëtaceae*, *Marsiliaceae,* and *Ophioglossaceae,* which are deeply linked to temporary pools, has to be underlined, although no statistical differences have been found between the three subsets because of the few number of species in each family.

In the comparisons between biological spectra, gen and tw were similar in the percentage of hydrophytes included while tw and ter spectra showed the same arrangement in terms of therophytes and geophytes (Fig. 2, Table 1).

Table 1
Significance of the Fisher's Exact Test carried out between each subset (gen, ter, and tw) for all the tested variables. Only the levels with significant differences are reported.

	gen vs ter	ter vs tw	tw vs gen
Families			
POA	*	***	
JUN	***	**	
AST	**	*	
CYP	**	*	
API	**	*	
Life forms			
G			**
H	*	*	***
I	***	***	
T	***		***
Chorological types			
STE	***		**
EUR	***	**	
EURA	**		
ATL	**	**	
WDIS	*		
Light regime			
7	**	***	
8		*	
11	***	**	
Temperature			
5			*
6	*	*	
7	*		
8	*		
9	***	**	*
Soil moisture			
2	***		
3	***	***	
4		*	
7		***	***
8	***	***	
9	***	***	
10	***	**	
Soil reaction			
2			*
6	*		
X		*	*
Nitrogen status			
1			*
2	***	*	
4		**	
5	***		**
7		*	
8	*		*

X: large-spectrum species; API: Apiaceae; AST: Asteraceae; CYP: Cyperaceae; FAB: Fabaceae; JUN: Juncaceae; POA: Poaceae; RAN: Ranunculaceae; G: Geophytes; H: Hemicriptophytes; I: Hydrophytes; T: Therophytes; ATL: Atlantic; END: endemic; EUR: euri-Mediterranean; EURA: Eurasiatic; STE: steno-Mediterranean; WDIS: wide distribution; ns: not significant.

* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$

In the chorological spectrum, strong affinities were found between tw and gen, which differed only in the percentage of the steno-Mediterranean species (Fig. 3, Table 1).

Overall, approximately 60% of the species indicated a light regime corresponding to 7 and 8 on a 12-level scale, meaning full-light conditions, sometimes with reduction in intensity. Gen and ter showed the same model of distribution (Fig. 4; Table 1), whereas tw had less values in the more represented levels (7 and 8) and an upswing corresponding to 11.

In terms of temperature (12-level scale), the most abundant class was that corresponding to level 8 (30%), meaning mesophilous conditions suitable both for euri-Mediterranean and steno-Mediterranean species. The main differences emerged between the gen and the ter subsets, the most abundant being in the levels 6–7 and the second-largest occurrence in the levels 8–9 (Fig. 4; Table 1).

Soil moisture curve showed two upswings on a 12-level scale: the first corresponding to very low values (2–3), meaning aridity conditions and the second corresponding to medium–high value, meaning wet to flooded soil. Comparing the three curves corresponding to the three subsets, the main differences, as expected, actually fell in these intervals (Fig. 4; Table 1). The curve of soil reaction (scale comprising 1–9 levels) did not show evident upswings, even if the highest percent value was at level 5, meaning mesophilous conditions suitable for species not present in strongly acidic or basic soils and very small differences were found between the three subsets (Fig. 4; Table 1).

The curve relative to nitrogen status (9 levels) showed a decreasing trend from the lowest to the highest levels. The maximum for ter was at level 2 (30%), meaning oligotrophic to low-nutrient soils; for tw at level 1 (32%), meaning oligotrophic soils; and for gen at level 5 (33%), meaning soils that are rich in nutrients (Fig. 4; Table 1).

4. Discussion

In a comparison between river, stream, ditch, and pools (including temporary and permanent) biodiversity within an anthropogenically impacted area of a lowland British countryside [5], the disproportionate contribution of small water bodies to the γ-biodiversity of freshwater plants was observed. Based on the findings of the current article, a preliminary observation can be made regarding the contribution of vascular flora associated with temporary pools in semi-natural habitats at a regional level. Our checklist included 118 of the 311 taxa listed for the entire vascular flora of Sardinian freshwater habitats and wetlands [29] confirming the relevance of temporary pools for freshwater plant biodiversity conservation. The presence of different contingents of species belonging to different phytosociological classes with various water requirements was a consequence of the variability of water availability and the small-scale zonation, which depends on water depth and flooding period, a typical trait of temporary pools [7,42,43]. In Mediterranean temporary pools, an arrangement in three concentric belts was observed: a central belt, an intermediate belt, and an outer or peripheral belt, characterized by different plant assemblages [10,11,13,26].

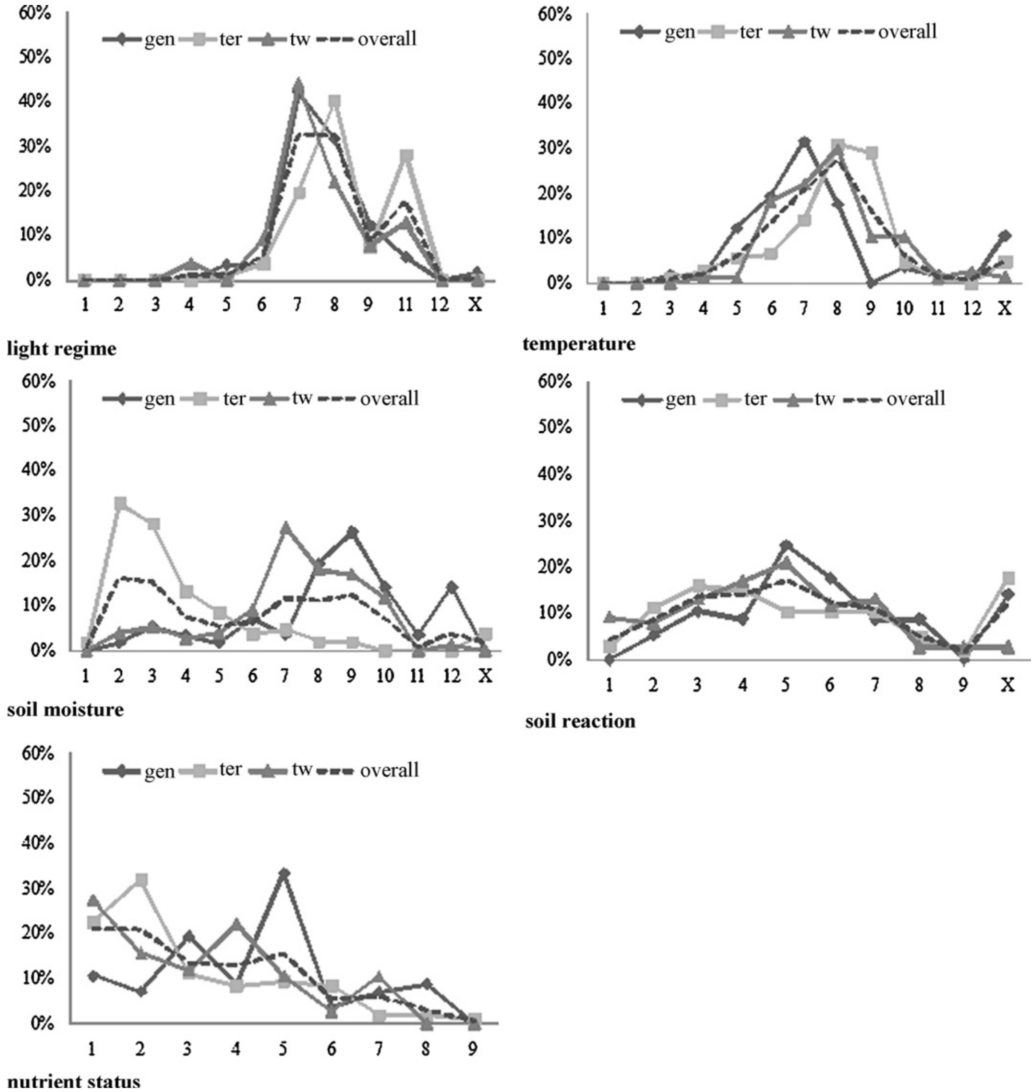

Fig. 4. Percentage of taxa for each level of Ellenberg indicator values relative to the temporary pool vascular flora (overall) and the three subsets (gen, ter and tw). X: large-spectrum species.

Therophytes were the dominant life form, comprising 51% of the overall flora and 61 and 71% of the ter and tw subsets, respectively. This data confirms what has been already observed in several regions, such as central Italy [44], France [45], Minorca [46], Morocco [13] and California [47]. The predominance of annuals should be considered a consequence of adaptation to harsh environmental conditions [45], mainly due to the strong variability of intra- and interannual water regimes. Nevertheless, temporary pools were very rich in hydrophytes, hosting 24 of the 66 species recorded for the flora of Sardinian freshwater habitats and wetlands [29].

In contrast with those in California, the temporary pools of the Mediterranean Basin are characterized by a rather low degree of plant endemism [2], some of which belonging to the genus *Isoetes* [48–50]. Nevertheless, our chorological spectrum indicated 7.8% of endemic taxa, approximately one percent higher than that reported by Pignatti [51] for the Sardinian flora (7%). No significant differences were found in the contribution of endemic taxa from each plant subset (gen, ter, and tw). However, the uniqueness of the flora of Mediterranean temporary pools is derived mainly from the presence of the aquatic ferns *Isoetes, Marsilea,* and *Pilularia* normally endangered [1] and well represented in Sardinian temporary pools. According to Conti et al. [32], we have recognized the presence of four quillworts in Sardinian temporary pools: *I. durieui*, *I. histrix*, *I. velata* subsp. *tegulensis,* and *I. velata* subsp. *velata.* Nevertheless, these species show a conspicuous morphological variability [52] that has prompted the description of many segregates, mainly at the intraspecific level, with different interpretations [29,53,54]. *Marsilea strigosa* was considered to have disappeared from Sardinia since '800 [30,51], but it has recently been discovered in two different sites [55,56]. *M. quadrifolia*, found along the Tirso River (CAG 1867) is considered to have disappeared [57]. The third genus, *Pilularia*, is represented in Sardinia by the species *P. minuta*. Furthermore, the rare small pillwort appeared to have disappeared until a few years ago [54], but it was recently found again initially in three sites [58] and in three more sites during the present study.

The chorological elements of the Mediterranean temporary pool flora are mainly represented by three lineages: a typically Mediterranean lineage, a mid-European lineage, and a tropical lineage [2]. The Mediterranean lineage is represented by steno- and euri-Mediterranean taxa. This lineage was more abundant among the ter but also well represented among tw species: *Damasonium alisma* subsp. *alisma*, *Elatine macropoda, Eryngium corniculatum*, *E. barrelieri*, *E. pusillum*, *Kickxia cirrhosa*, *Lotus parviflorus*, *Lythrum tribracteatum*, *L. thymifolia*, *Middendorfia borysthenica*, and *Trifolium michelianum* are just a few examples. The mid-European lineage, including Eurasiatic, Atlantic, and Mediterranean–Atlantic taxa, was more abundant among tw and gen, in comparison with the ter subset. Moreover, it was represented by a percentage occurrence approximately double in number, in comparison to those of the entire Sardinian flora (11% versus 6%) [51]. In addition to three of the quillworts, *I. velata* subsp. *tegulensis* being subendemic, it included several tw species, such as *C. filiformis, Illecebrum verticillatum*, *Juncus pygmaeus, J. capitatus, Ophioglossum lusitanicum,* and *R. linoides*. Finally, the tropical lineage, which was included in the wide distribution species, was represented just by 11 species.

Vascular flora associated with temporary pools was generally heliophilous. In southern Europe, the abandonment of extensive agricultural practices led to the recovery of woody vegetation, which determined the degradation of Mediterranean temporary pools [45]. In France, during the past decades, a progressive decline in grazing, notably by sheep, favored the encroachment of shrubs (*Ulmus minor* and *Fraxinus angustifolia*) into the temporary pools. A major consequence of this colonization was the regression of the aquatic and amphibious annual plant species, resulting from shading by dominant vegetation and from litter accumulation [59]. The effects of the light reduction were also tested on the rare quillwort *I. setacea*: all the reproductive and vegetative parameters examined were negatively affected and already significant at 15% light reduction [60].

In terms of thermic requirements, the range was wider. Water temperature has been recognized to be a relevant factor affecting plant assemblages in Mediterranean temporary pools [27], and its value changes very quickly with variations in air temperature because of the short depth of this type of water bodies. The wide altitudinal range of temporary pools in Sardinia (0–1000 m a.s.l.) should explain the presence of species with different thermic requirements.

As expected, the largest variability was found in the soil moisture. Three different curves representing ter, tw, and gen were obtained. These trends indicate that changes in water regimes affect the percentage distribution of the three subsets.

The species distribution along a gradient of soil reaction suggests that they are mainly acidophilous to mesic species according to fact that temporary pools are mainly localized on acid substrata: acid volcanites and granites.

Finally, the nutrient status curves indicate low requirements of phosphorus and nitrates and a general preference for oligotrophic soils, with the exception of gen. According to the definition of the habitat types in Annex-I of the Habitats Directive [3], temporary pools are referred to as belonging to three habitat types: (a) 3120–Oligotrophic waters containing very few minerals, generally on sandy soils of the West Mediterranean, with *Isoetes* spp.; (b) 3130–Oligotrophic to mesotrophic standing waters with vegetation of *Littorelletea uniflorae* and/or of *Isoeto-Nanojuncetea*; and (c) 3170*–Mediterranean temporary ponds; this is a subtype of 3120 [61].

In summary, our results suggest that: (i) vascular flora associated with Sardinian Mediterranean temporary pools is rich and diversified, including groups of species with different life forms and chorological patterns with a consistent contribution of endemic taxa; (ii) rare ferns are better represented than previously reported; (iii) plant species are generally heliophilous and acidophilous, tw species mainly differing from the unspecialized ones in relationship to their soil moisture requirements; (iii) these habitats may contribute to the biodiversity at a regional scale, supporting taxon types (e.g., species and families) not found in other habitats and they are particularly important for maintaining regional freshwater biodiversity.

This study has significant practical implications that stress the importance of conservation of these types of water bodies.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

Acknowledgments

This research was funded by a grant assigned to Dott.ssa Maria Carmela Caria from the Sardinian Region (Programma Operativo FSE Sardegna 2007-2013 - Legge Regionale 7 Agosto 2007, n. 7: "Promozione della ricerca scientifica e dell'innovazione tecnologica in Sardegna").

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.crvi.2011.10.005.

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